Table of contents

1. Research problem identification.. 3
1.1 Background.. 3
1.2 Problem discussion 4
1.3 Presentation of the problem 4
1.4 Problem formulation 5
1.5 Purpose... 5
1.6 Relevance.. 5
1.7 Limitations and delimitation 6
2. Research Design &Methodology 7
2.1 General concept 8
2.1.1 Research process activities 8
2.1.2 General concepts review 8
2.2 Systems theory- a way to design your methodology 10
2.3 Designed research 10
2.3.1 Research design and methodology.. 10
3. Literature Review 18
3.1 Integration theories summary 18
3.2 Maintenance management literatures 20
3.3 Manufacturing management literatures 24
3.3.1 Computer integrated manufacturing 24
3.3.2 Toyota production systems 24
3.3.3 Kaizen systems.. 24
3.4 Maintenance/manufacturing integration literature review.......................... 25
3.5 systems engineering and six sigma methodologies 26
3.5.1 Methods and Techniques 27
4. Developed Model.. 32
4.1 Model literature survey.. 32
4.2 Modelling basic concepts and approaches... 38
4.3 Overall modelling processes... 39
4.3.1 Finding out (model) 39
4.3.2 Selection (methodology and theory).. 40
4.3.3 Building the Model 42
5. Empirical findings... 45
5.1 Case company 45
5.2 Case study; selecting and description. 46
5.2.1 Production operations 46
5.2.2 Maintenance operations 48
5.2.3 Quality operations.. 51
5.2.4 Employee competence 52
5.3 Integrated working areas situation... 52
5.4 Data types, sources and collection processes... 54
5.4.1 General data types;... 54
5.4.2 detailed data types and resources.. 55

6. Analysis of the case study **56**
6.1 Phase 1: Define the problem; situation and conditions 56
6.1.1 Analysis of manufacturing systems descriptions. 57
6.1.2 Analysis of Maintenance management auditing. 62
6.1.3 Analysis of Manufacturing Process modelling 65
6.1.4 Analysis of measuring phase. 67
6.1.5 Analysis of Process FMECA. 68
6.2 Phase 2: extracting requirements 69
6.3 Phase 3: Define the system & its boundary 71
6.3.1 Conceptual solutions generation process 71
6.3.2 Evaluation of the conceptual solutions 75
6.3.3 The selected conceptual solution description 76
6.3.4 Vision and key acceptance criteria of the integrated system 76
6.3.5 Context diagram 77
6.3.6 Integration levels: systems, and sub-systems, assemblies and components 77
6.3.7 The capabilities & characteristics of the new integrated system: Use-case scenarios method 80
6.4 Phase 4: Design the architecture 82
6.5 phase 5: Control – verification and integration 82

7. Results & Contribution **84**
7.1 Research contributions 84
7.2 Results 84

8. Conclusions & Recommendations **86**
8.1 Acceptability test and Conclusions 86
8.2 Research criticism points 87
8.3 Recommendation and Future research works 88

9. References **90**
Appendix 1: Systems theory- a way to design your methodology **95**
Types of research 96
Appendix 4: defining, measuring and analysis techniques: step by step **105**
Appendix 5.1 – maintenance management audit **106**
Appendix 5.2, manufacturing process flowchart **111**
Appendix 5.3, measurements collection sheets **114**
Appendix 5.4, Process FMECA **121**
Appendix 6.1, Modelling checklist sheet **124**
Appendix 6.2: stakeholder's requirements **125**
Appendix 6.3-A Maintenance management systems **127**
Appendix 6.3-B Manufacturing management systems **131**

1. Research problem identification

The specific objectives of this chapter are:

- Describe the background of different perspectives and define the research position.
- Discuss and represent the research problem into detailed levels in order to Formulate the research problem and define the purpose and relevance of the developed model
- Finally, represent the managerial issues of the research, mainly, the limitations and delimitations.

Chapter One

1.1 Background

Because of the globalization and technology which drive the company moves toward increased competitiveness. Therefore, it's crucial for the company to build its strategic concerns surrounding those aspects, and this can be the verdict whether the organization will survive the struggle in the long-term. ***"Integration between what?"*** In the move towards world-class manufacturing many firms are realizing a critical needs for the use of a proper, i.e. efficient and effective, maintenance of production facilities and systems, Sherwin.D(200), Al-Najjar et al. (2001) and Kalpakijian.S and Schim.S (2001), Raouf.A and Ben-Daya.M, (1995), Ip and Fung.R, (2000) . Thus, the coordination of manufacturing and maintenance work play a significant role in formulating strategy (Jonsson.P,1999,Tsang.A 2002, Nikolopoulos.K et al, 2003,), planning (Bamber.C et al,2004,), scheduling and in daily operations, as a result, maintenance should also be integrated into manufacturing (Tu.P and et al, 2001) for better long-term benefits.

"Integration and technological changes?" Increased competition and customer demand for timely delivery of high–quality products have forced manufacturers to adopt technological changes. This has resulted in very high investment in equipment. To achieve the target rates of return on investment, the equipment has to be reliable and capable of being kept reliable without costly work stoppages and repairs. More attention has been focused recently on broadening the perspective of maintenance through integrating it with the production program and into a complete market-oriented system, and on the importance of utilizing a feedback system in improving, e.g. productivity, quality, reliability, designs. Al-Najjar, (1996). Advanced manufacturing systems employing extensive integrated machining and robotics systems, with automated material and tool changing devices, use information technology-systems to form the link between each item of production machinery, and ensure that the system performs as a single entity. Specifically, the technological changes (Duffuaa.S et al.1999) are changing also the relation between the production process resources, because -in the past – the most important relation was between the production and human resources, while now due to the automated machines and high technological systems the relation of human being has decreased where maintaining side has increased.

Jonsson.P, (1999) introduce that the fully production-integrated maintenance approach is not simple to apply; it must be carefully planned and implemented. Al-Najjar (2000) introduces and uses the idea of the production process which includes several sub-processes, i.e. working areas or disciplines, responsible of performing different tasks that are required to accomplish the mission of that process. Therefore, Prof. Basim al najjar was developing model which express how should maintenance be integrated with other plant activities, such as operation and quality to avoid overlapping and friction between these working areas and consequently financial losses. Al-Najjar (2005). Also Prof. bassim express the importance and the value of having a process with clear responsibilities and authorities for quality work at the company. Also he suggested that a system for documentation, analysis and actions for tracing defective boards is significant for identifying where and how faults have been done and preventing recurrence of the same faults. Thus, the problem addressed in this thesis is; how to identify the interfaces looses (overlapping and frictions) in the integration process of maintenance into production, quality and employee competence, and how to integrate them together.

1.2 Problem discussion

When we returned to the definitions of operations management, we will find that the total operations function is made up of individual processes, in manufacturing systems there are production process which concerns about resources of whole operations and not only to insure that the operation are working also if its effective, efficient and productive, maintenance process which tries to insure that plant, systems, machines and equipment are working, human management process (Campbell.J, 1995) which deals with employment aspects. All of those processes are working as a chain within the whole operations, we can find the whole operation as a summation of individual processes and the relational processes between those processes, this relational process called integration process. Manufacturing systems is far more complex today than few years ago and we believe that it will be even more complex in the future. Due to the technological changes and its complexity, companies should have a clear and systematic approach to understand the integration process between the internal and external processes in proper way. In order to integer the individual processes inside the working area, the company needs a strong investigation technique to identify the probable faults which could be appeared within the integration process ,mainly, when the operational process will be running.

1.3 Presentation of the problem

Integration of the processes within one chain it is a process of arrangement (planning, scheduling) all the operational resources that transforms inputs to outputs that satisfy customer needs (Chase.R et al 2006). Most of the operational management researches till us the there are many difficulties and problems when the industries try to run one process. Therefore they have definitely more difficulties in integrate multi processes or other plant activities in one efficient operation. The difficulties it takes different types according to the affects factors; volume of those processes, variety between the processes, variation in demand and visibility of each process. While the most practical problems which happen always it could be due to human failures, or organizational failures when they designing procedures and running the processes, moreover, the technology failures in machines, equipments and IT systems. All of the practical problems are the core of the research.

All of those difficulties, problems and failures are results of integration process failures, but the hidden causes are due to some missing parts inside the integration process or one process overlaps other processes, furthermore, the frictional problems between the processes.

Practically, integrating the individual processes it is not easy in real situation, for example, the Swedish survey work done by (Jonsson .P, 1997) where he was showed that effects of fully production integrated maintenance, and the status of maintenance management in Swedish manufacturing firms summarise as follows: Presents a model of five linked maintenance management components (strategy, human aspects, support mechanisms, tools/techniques and organization). Analyses the present status of these components in Swedish manufacturing firms through a survey of 284 respondents was showed that fewer than half have written maintenance strategies or computerized maintenance information systems and several give maintenance low status. Jonsson .P, (1997)as mentioned before, the reasons behind these results in terms of process integration that the fully production-integrated maintenance approach is not simple to apply. That means there is need to user friendly model which identify and integrate the operations within the working situation.

1.4 Problem formulation

The problem will theoretically and empirically investigate the case study, using both quantitative and qualitative research methodologies and using systems methodological approach to describe the process integrity. And can be formulated as:

How to identify systematically the integration losses; missing, overlapping and frictions within working area between sub-processes such as operation, personnel competence, maintenance, and quality, and to eliminate those losses ?

The authors argue that using the most suitable integration practises which eliminate or reduce the overlapping and frictions within specific process will result in increasing the utilization of the production systems, due to integrity effects on the elements of overall process effectiveness. The integration between the sub-systems on the basis of: How it is established? How it works? Internal frictions and if there are overlapping between sub-processes and its impact on the operations effectiveness.

1.5 Purpose

The purpose of this research work is to develop a model that deals with the integration losses of production process through two phases: identification and treatment. The objective of identification part will be achieved through the activities and tasks modelling within the process, then by investigating the causes that reduce the performance of those processes or even though which produce stoppages in those processes or delays within processing time. Consequently, the treatment part treats the process situation by build cost-effective solution which will be generated from the industrial or company needs and will translate these needs into requirements, activities, and factors to initiate the company implementation ability in order to achieve the industrial satisfaction.

1.6 Relevance

The essential question here is ‘To what extent is this problem worth researching?’ The relevance of the research problem and problem formulation is to showing why it is important to do research in this area.

According to a survey done by Jonsson.P(1997) of 747 companies in Sweden reported firms' own opinions whether they had an integrated IT system that included the maintenance function. Less than 13% claimed any integration, and only 4% included maintenance. As a result, authors shall describe the difference between existing system's capabilities with the lacks, overlaps and frictions and those of fully integrated system, and give examples of how their proposal could enhance company performance. Also Jonsson.P(1997)had concluded that Production-integrated maintenance may affect the competitive capabilities and long-term benefits of organizations. It is important as a value adding activity in increasingly integrated business and manufacturing strategies. There is a lack of empirical studies explaining of how should the maintenance integrating with company systems and it not simple to apply (Jonsson 1999), Al- Najjar (2005) discussed in detailed levels the difficulties of maintenance integrated implementation process and he has founded and defined some of the overlapping and frictions between company systems. The most interesting feature of Ip and Fung.R (2000) paper the method of design the integrated system where they had been used the systematic approach for the design. The authors try to ask two questions; the first one is, if the company wants to build a maintenance integrated system how it could be able to build it without overlapping and frictions, they means how to define theses losses in the design stage which is less costly than in operations – when the system running- stage. The second question focus on the existing maintenance integrated system, how companies will define the overlapping and frictions in their system, then how they will generate, evaluate and select the most cost effective solution and how to design this selected solution. Thus, the model should support the developing a capable structure to solve the problem and feasible to apply, in summary, it characterise by the following characteristics;

- Theoretically crystallite, the model has developed as a scientific result of the crystallization and structuring of theories in this area, its transformation into methods and techniques, fitted and mediated for the user, and to implement, utilize and follow up in the industrial enterprise.
- Working Ability for deep investigation, identify integration losses needs deep investigation process, so it needs model which supporting the suitable methods and techniques within the complicated conditions.
- Systematic, adequate and user-friendly model for identifying the integration losses is one of the motivating reasons. Add to that the needs to investigate how the industry treats the integration losses, and adaptive to IT systems.
- The feasibility to apply is one of powerful feature of the model to show that increasing the recognition of integration role will keep and improve process availability, performance, quality products, on-time deliveries, safety requirements and overall plant productivity at high levels.

1.7 Limitations and delimitation

Every research model is a limited part of reality, real or imagined. Research delimitation can be questioned. There are no absolute systems delimitations, only more or less useful ones in relation to a certain research purpose. Nevertheless, no matter how the research of this complexity is created, every research becomes relatively limited. The authors was faced the two types of delimitations; external delimitations (which delimit the research object in relation to its environment), and internal delimitations (which limit to how much details can be considered in our research), based on that, they will always be necessary to stop at same level of magnification.

Chapter Two

2. Research Design &Methodology

The specific objectives of this chapter are:

- To discuss the available literature in the field of research methodologies
- Based on above, to suggest directions for my research, and build a real methodological approach for the studied problem.

The organization of this chapter is as follows:

- After a brief introduction, in the next section existing literature on methodological approaches has been classified in to a number of areas and sub-areas.
- Develop our methodology with detailed discussion on these areas and sub-areas along with critical observations.
- In the final section, we draw up the overall developed methodology, and discuss the characteristics (reality, capability, quality, etc) of this methodology.

Importance's of Different methodological approaches make different assumptions about their subject areas. This means that when people apply the different approaches in practice, they have to proceed differently when trying to understand, explain, and improve business, depending on the approach being used. History shows that observations are based on beliefs. If we believe that mother earth is flat, our observations and statements will be based on this belief, and our models of navigation will be concerned with avoiding sailing over the edge. Another example of how theoretical backgrounds or methodological approaches develop their own explanations is the invention of railroad steam engines, which for the first time allowed people to travel at 20 miles an hour for sustained periods. Some physicists claimed that the pressure of the passing air would push people off the railroad carriages. Some psychologist asserted that people would not be psychologically able to perceive passing objects at such a speed.

Our point is that when we make a statement based on a particular methodological approach, it is only speculatively and reflectively (but not logically or empirically) possible to overcome historical verification. From this it follows that there will be problems comprehending the data we collect or try to explain/understand unless we have already considered how the particular approach will shape our observations, our understanding, and our explanation.

We can't just collect data and make statements, the various methodological approaches differ, above all, in the sense that they make different assumptions about the reality they try to explain and understand. This, in turn, means that observations, collections of data, and results are determined to a large extent by the approach chosen. Also, you can never empirically or logically determine the best approach. This can only be done reflectively by considering a situation to be studied and your own opinion of life. So the problem itself determines the best technique for its solution.

2.1 General concept

2.1.1 Research process activities

Research is a process, and in order to enhance conducting research, it would seem reasonable to make is as systematic as possible. Indeed, many writers describe research as a systematic. McMillan and Schumacher define research as “a systematic process of collecting and analyzing information (data) for some purpose”, and Kerlinger and Lee define scientific research as “systematic, controlled, empirical, amoral, public, and critical investigation of natural phenomena guided by theory and hypotheses about the presumed relations among such phenomena”. (Wiersma.W, and Jurs.S, 2005)
The research can use the approach of scientific inquiry, the search for knowledge through recognized methods of data collection, analysis, and interpretation, which is consist of a series of sequential steps. These begin with identifying the problem through interpreting results and drawing conclusions. Five steps are compatible with the scientific method and provide the elements of a general, systematic approach to research: (1) identification of the research problem, (2) reviewing information, (3) data collection, (4) analyzing the data, and (5) drawing conclusions.

2.1.2 General concepts review

A. Arbnor and bjerke (1997) see the methods as “guiding principles for the creation of knowledge. For such principles to be effective they must fit both the problem under consideration and the ultimate presumptions held by the creator of knowledge. Another way to express this: methods must be both consistent (fit the problem and the ultimate presumptions of the creator of knowledge) and constructive (fit each other)”. Also they ask about “how is it possible to choose good methods when everything appears to depend on everything else?” because when we looking for methodology process it seems like a circular –iterative discussion to claim that methods depend on problems, which depend on ultimate presumptions, which depend on methods or vice versa. The answer according to them of this complicated situation is the Paradox, which is that the contents of ultimate presumptions, problems, available and developed techniques, and methods change at different rates and different degrees. The paradox of *Arbnor and bjerke* is consists of five parts; ultimate presumptions, paradigm, methodological approach, operative paradigm, and study area. Actually, *Arbnor and bjerke* was focusing deeply on the third part – methodological approach- where they clearly illustrated that knowledge can be developed using one of the following three methodological approaches: analytical approach, systems approach, actors approach, and how to apply the selected approach.

.

B. Ghauri and Grönhuag (2005) said that “a particular research orientation prescribes the relationship between methods, data, theories, and values of the researcher” and it one of the most important issues in the research management which called research orientation. That is mean the researchers do not preach or ask whether the activity observed is good or bad; they just analyse, present and explain it. In fact, that is the

starting point of research: that we have a number of assumptions, but we should not accept or reject them unless we study these assumptions critically and unless we find logical and reliable explanations to accept or reject them. Actually, that lead to two ways of establishing what is true or false and to draw conclusions: induction and deduction. Induction is based on empirical evidence, while deduction is based on logic. As we can see, *Ghauri and Grönhuag* present us with two alternative ways or stages of building theories. Most of researchers and scientists believe that they have been using both of these in their research. The importance of discuss this issue it based on practical fact which tells us that "the processes of induction and deduction are not totally exclusive of each other" which will effect on your research starting point decision; what comes first: theory or data?
Ghauri and Grönhuag developed the answer about this complicated research situation based on the process perspective, where they mentioned "while solving problems we need to look at what is already known about this type of situation/problem" so when we want to decide the starting point, we should have a clear understanding of problems, assumptions, and concepts, then we can start thinking how to go about finding answers to our questions. The process perspective idea generated from the nature of any research process which is a set of activities unfolding over time. *Ghauri and Grönhuag* give reasoning for their idea as "A main reason for considering it so is that research takes time and consideration. Insights may be gain gradually, and may also be modified and/or changed over time. It is also useful to look at it as a process with distinct stages, as different stages entail different tasks. This can help researchers to perform these tasks systematically and to understand what is to be done at a particular stage". The *Ghauri and Grönhuag* research process include a number of steps as follows:

1. Topic and research problem
2. Research design and plan
3. Data collection and measurements
4. Data analysis and interpretation

Ghauri and Grönhuag describe in details the qualitative and quantitative; methods and techniques for data collection and data analysis.

The question now, which approach is best? Previously, we explained that you can never empirically or logically determine the best approach, but you can get the benefits of the all approaches what you have. In the next section we will discuss how.

I. The core of our review

The two previous research theories have a strong evidences or reasoning to follow them, but when we try to answer the above question "how to follow them in the proper way?" we should take in our considerations the following aspects:

- Research processual perspective; which focus on dynamic structure and non-regular processes.
- Research path; evidences and reasoning
- Treatment of the research complexity; starting point, circularity, dependency between research parts and the partial exclusive character within orientations.
- The process of operationalization; what is required to translating a very general research aim into specific, concrete questions to which specific, concrete answers can be given.

Correspondingly, educational research, too, is complex and demanding. So knowing what to do in specific situations is important. Most of researchers define the main research characteristics as follows: empirical, systematic, valid, and reliable.

2.2 Systems theory- a way to design your methodology

Systems scientists tried instead to find an optimal level of generality, as the most fundamental objective of general systems theory, we can formulate that it tried to find similarities in theoretical constructions among various disciplines as its highest purpose we can formulate that it wanted to develop a 'spectrum' of theories-a system of systems. The idea with general systems theory was that certain methods for studying behaviour were applicable to all organized living and nonliving real systems, namely, studies concerning; structures, functions and evolutions of various types of real systems. Appendix 1 represents all the required theories which the authors have been followed when they designed their research methodology.

2.3 Designed research

The characteristics of our designed research methodology are as follows:
According to questions of the research (in chapter one), we decide that our research design should follow a systematic process in order to enhance and be able to answered the research questions. The problem was defined through the research questions which can be show the orienting decisions and establish the key parameters of our research.
So chapter one in this thesis is like the strategic; authors set the general nature of the research, and the questions that they need to considered.

2.3.1 Research design and methodology

If the preceding chapter is strategic then decisions in this chapter are tactical: authors establish the practicalities of the research. The decisions here were addressed by some basic questions:

- What is the need to be the focus of the research in order to answer the research questions?

The authors tried to have an operationalizational process which is critical for effective research, where they specified the main methodology of the research and transferred it from the general level into specific, in other words, the research process moves from the general to the particular. Thus the authors broke down the general research questions into more specific elements. For example, they specified the research types, orientation, stakeholders and their requirements, and based on that, they define the detailed elements in the research like the data collection and analysis techniques.

Phase 1: identification of the research problem and research orienting decisions

Nearly, all subject areas have their own distinctive intellectual traditions, key authors, works and styles. For example, most of key theorists wrote about maintenance field based on the system approach due to the elements, levels and the features of the maintenance operations. Thus, the authors work within the common view or perspective, to do a valid research they show the selection of the research features based on fact or evidence. The authors working with the applied research type, where they want to produce recommendations and solutions to the integration problem which are faced the production departments in companies in general, and in the case company in particular. Thus, the research question is of a how form. One part of the research the authors used the formative evaluation type, where they tried to make improvement to specific elements in the studied area such as to specific programme, policy, or activities. So, there no mutual exclusive research type or research orientation, and specially, if it is applied research type definitely, researchers will use both qualitative and quantitative data.

Phase 2: extracting the research design & methodology requirements
Logically, the authors want to define the requirements of their research design, firstly, they define the research life cycle processes, and then they define the research stakeholders within those processes. Finally, they extract the requirements from each stakeholder group. The table (2-1) explain in details the three steps.

Table (2-1), Research design & methodology; life cycle processes, stakeholders and requirements

Research design & methodology life cycle processes	Stakeholder	Requirements
Development	Supervisor , Subject key authors & researchers	should be consistent correct should be fit to purpose should be fit to the situation should be logical should be understandable should be confirmable should be useful
Data collection and analysis	Supervisor and researcher	Should be express effective collection method
Conclusion drawing	Supervisor and researcher	Should be able to draws Valid conclusions
Presentation	Examiner	should be addressed validity and reliability
Modification / updating	Developer & updater	should has logical sequence should be capable to develop our experiences

Phase 3: Define the research design and methodology
Maintenance operations are a part of the company operations like a production, quality design operations, etc. those operations groups are a company entities as individual working areas, while - theoretically and empirically - approved that also their relations are essential to complete the functionality of company operations. Our research problem was formulated to understanding and explaining more the relationships side. Because of that, the authors defined the integration as “it is a systematic relationship within internal and external entities”. That is the most important reason (as were described in table (2.2)) for selection the system approach. In other words,

- The maintenance operations are more than the sum of the maintenance subsystems (corrective system, preventive system, etc.),
- the whole maintenance system determines the nature of the subsystems,
- The maintenance subsystems cannot be understood of considered in isolation from the whole maintenance system.
- Finally, the maintenance subsystems are dynamically interrelated or interdependent.

Table (2.2), selection criteria

Criteria	Our research design and methodology
Concerns	Structure & process, Method, Purpose & function
Paradigm	Design of the whole system
thinking processes	Induction and synthesis
Output	Optimization of the whole system
Method	Determination of differences between actual and optimum design (opportunity costs)
Emphasis	Predictions of future results
Outlook	Extrospective: from system outward

1) Define the research design & methodology objectives;

The main research objectives are to explain the causes of the integration interfaces problem within the company working operations and to show the systematic connections and relationships between those operations. Finally, to suggest reasons for "as-is" events and make recommendations for the industrial changes ("to-be" events).

2) Identify research design & methodology content and context

Ultimate presumptions; Defining the problem may be one of most critical steps in the whole process, because it affected by the researcher's background. The most obvious presumptions of the authors in this research are that; the science should be objective oriented, as we simplify our solutions, we lose realism, and we can never reach the optimum.

*Paradigm (design theoretical material)***;** According to the definition of paradigm "a process, a procedure that can be used repeatedly to tackle a specific type of problem", for instance, the science paradigm which drives the scientific method. Based on previous, the authors use the systems paradigm to derive and embody the system approach. The Model which the authors will explain it in the chapter four is based on the systems paradigm.

Methodological approaches (design the research die)

In order to explain or to understand a system (components, relations, environment, states, behaviour, analysis and construction) it is sometimes necessary to place it in its own context or environment; this makes it possible to distinguish between open and closed systems. Open systems are studied in the context of their environment; closed systems are not. Maintenance theories are usually interested in open systems which related to the productions and quality systems. In this thesis, the authors work to develop a self-organizing systems model which has ability to feedback in a negative as well as a positive sense, in other word, ability to amplify deviations between the current situations of the maintenance systems and its goal, and to change its own structure in order to master new demands made by the external systems like production and quality systems. In addition, the maintenance sciences become less technique oriented and more problem oriented (Arbnor and bjerke (1997). What was necessary, according to the system approach, was a language and a way of thinking that could be used to analyze the industrial problems and construct new industrial solutions in more basic terms. In this spirit, the thesis authors derived the following characteristics that they used to characterize their knowledge creation model; all of the applying methodological approach aspects and elements are clearly explained in the model chapter (chapter four).

Operative paradigm (design empirical material)
In this part of the methodology design process, authors show how they understand and constructed the methods of data collection and analysis. Based on the characteristics of maintenance integrated system as a case studied the authors will study the incidence, relationships and the distributions of the variables are studied, and the main question were asked is; what are the characteristics of the variables (working areas variables) and what are the relationships and possible effects among the variables? According to this question the authors select the observational case study to conduct the answers to this question. Designing of the case study follows the steps were undertaken.

- Setting the policy, goal and objectives
- Setting the integration structure
- Locating the factors- controllable and uncontrollable
- Locating the missing parts in the model of operation integration
- Linking the controllable elements and their dimensions
- Linking the missing part and those controllable elements dimensions
- Settling the concepts/approaches on each element
- Execution of those concepts/approaches
- Assessment the effects of implementation of operational integration
- Suggestion of the future improvement

Data collection; in this case study, the researchers engage in the following data collection activities:

- Interview managers, operators and staffs of different industrial working departments like; maintenance, production, and quality.
- Observe the interaction taking place between operators and its working area and between operators and departments.
- Review industrial records which are relative to working area like; machine historical records, production planning and schedules sheets, maintenance work orders, and quality controls sheets.

Data analysis; the research of this thesis use the coding techniques like a process for organizing the industrial data and obtaining the non-added value data reduction, by asking one question to see what they have in the data. They used a number of codes which are specific to the research study. They used the following codes to make the data analysis effectively;

- Setting or context codes; as the name implies these codes reflect the context or setting in which the industrial integration situation under study is observed. In the thesis example, the integration situation would fit a setting code and categories might include a production operations setting, a quality operations setting and so on. Categorizes might also include information about factors such as the size of the working area (production line).

- Subjects' perception codes; it is categorise based on the operators may have different views of their managers, and these views may differ from those of other operators.
- Process codes; here the authors focus on the sequence of events and how changes occur.

Understanding the Study area; (empirical resources of data) given that the designers' case study (authors) views play such a preponderant role in shaping their version of reality, it is essential that their premises, assumptions, styles, and inquiring systems be mapped and understood. This part of methodology design process is related to the empirical findings chapter; how the authors describe the studied area. Characterises of the maintenance systems -in context of the industrial working areas- are described in form of systems uptime and downtime situations, usually taken to be a measurable attributes such as mean time between failures (MTBF), maintainability, efficiency, and the like.

3) Research interfaces: There are two types of interfaces were appeared within the methodology design process, firstly, the interface between the theory and the practice as shown in the following diagram.

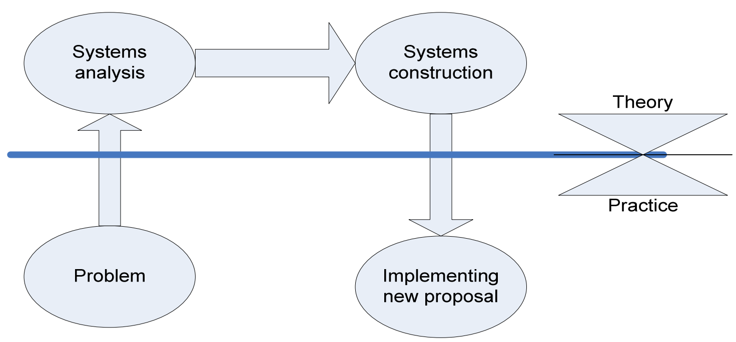


Figure 2.1, research interfaces (Wiersma.W, and Jurs.S, 2005)

Secondly, the interfaces between generality, power, specificity, complexity, and the problem structure it was a very important aspect when the authors decompose the industrial situation into subsystems. Technically, how to design a well-structured problem where the authors can be solved it with algorithms, whereas ill-structured problems are amenable only to solutions by heuristics.

Phase 4: define the research architecture design

Research cycle; the research methodology; design and processes is an integrated of three basic modules; conceptual, approach and empiric methodology. Theoretical background of the studied field and the empirical background of the actual situations are the main inputs of the research cycle; the methodological approach is like the die or the structure of the developed model while the theoretical and empirical findings are the material of it. The processing also have three ways; collect and reviewing the theories, collect and evaluate the approaches, and collect and analysis the empirical findings. Development of the knowledge is the final purpose of the whole research, where the research cycle will continue to open new doors and views for the next researches.

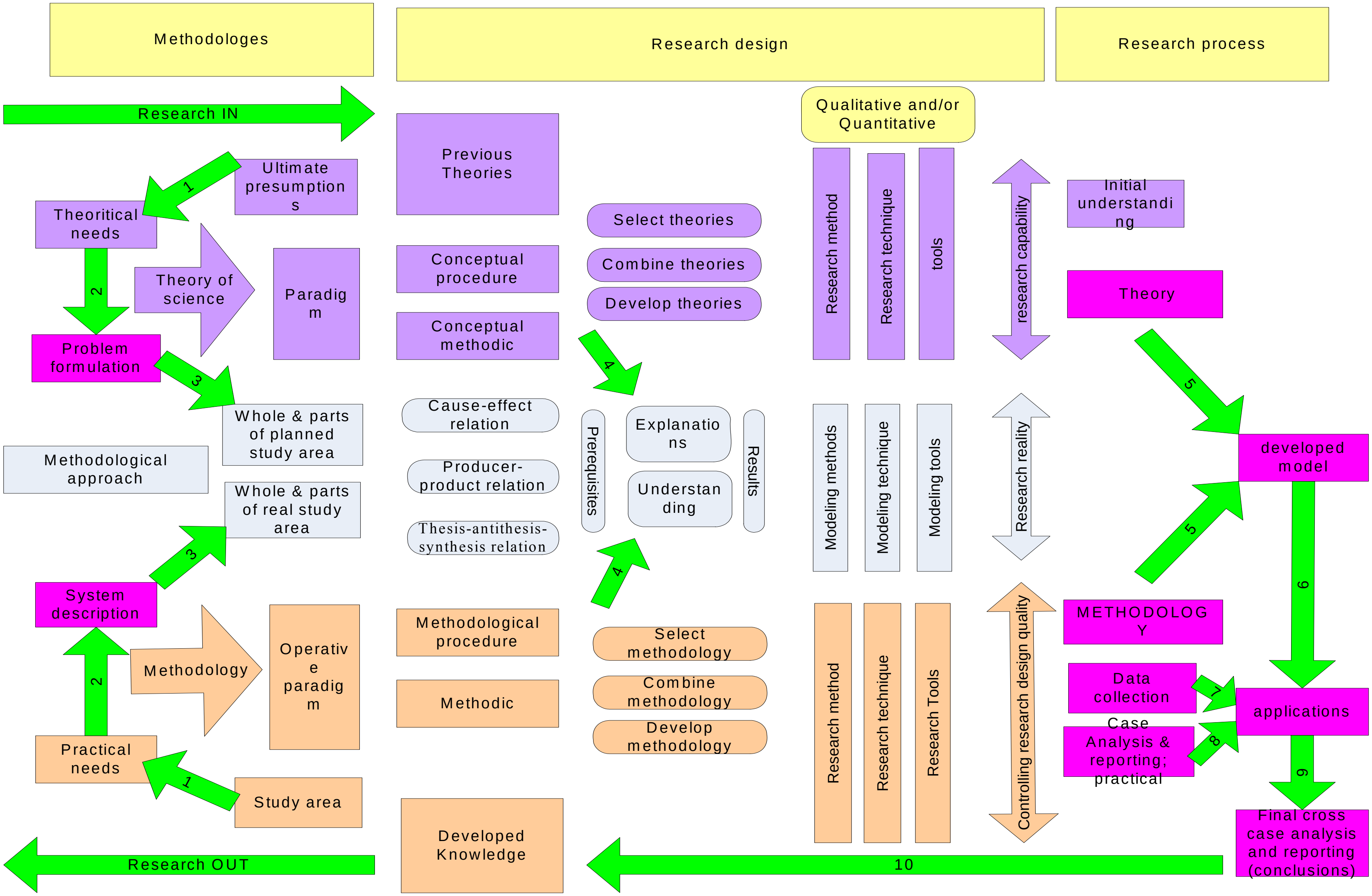


Figure 2.2, Overall research design and methodology process

research flow and Report writing processes; the diagram showed the numbered arrows; that explain the direction or the author's path which they were followed to manage this research, and here the explanation table for those arrows;

Table (2.3), overall research design and methodology process

Arrow number	Description	Process writing output
1(up &down)	General Theoretical and empirical background about the research field	Chapter 1/ problem description
2(up & down)	Theoretical Formulate the research problem based on the empirical description of the studied situation	Chapter1/ problem description Chapter 5/ empirical findings- the 1st part/ system description
3(up & down)	Define the applied approach (based on relation type) of the studied situation in terms of whole and its parts	Chapter 2/ research methodology and design
4(up & down)	Define the research purpose based on more detailed theoretical and empirical structures of the problem	Chapter 2/ research methodology and design
5(up & down)	Develop the reviewed theories and applied methodology	Chapter 3/ literature review Chapter 2/ research methodology and design
6	Develop the research model	Chapter 4/ developed model
7,8	Apply the developed model through two part; data collection and data analysis	Chapter 5/ empirical findings- the 2nd part/ data collection Chapter 6/ model application
9	Final model analysis of the applied model	Chapter 7/ model analysis
10	Drawing the conclusions and recommendations	Chapter 8/ conclusions & recommendations

Phase 5: research integration and qualification: validate and verify

Finally, the authors discuss how they will deal with the concepts of research verification, validation and acceptance.

- Validation; here the authors determine the systems approach processes that produced the right model. Conceptual validity, requirements validity, and design validity are the main validation types of this thesis. Conceptual validity is the correspondence between the research needs and the concept of problem formulation. Requirements validity is the correspondence between the problem formulation and studied case requirements, thus the authors causing the research methodology and design of the studied problem. Design validity is the correspondence between of problem requirements and the derived requirements through the analysis part of the model applying step; evolve to sub-system and component specifications. Thus the improvement solutions of the case problem are functionally related to the requirements parameters and case variables.

- Verification; it is a measure of the matching between the model's analysis part and model's design part, to ensure that each has been built right.
- Acceptance; it is for agreeing that the developed methodology, as applied or otherwise evaluated by the research stakeholders, is acceptable.

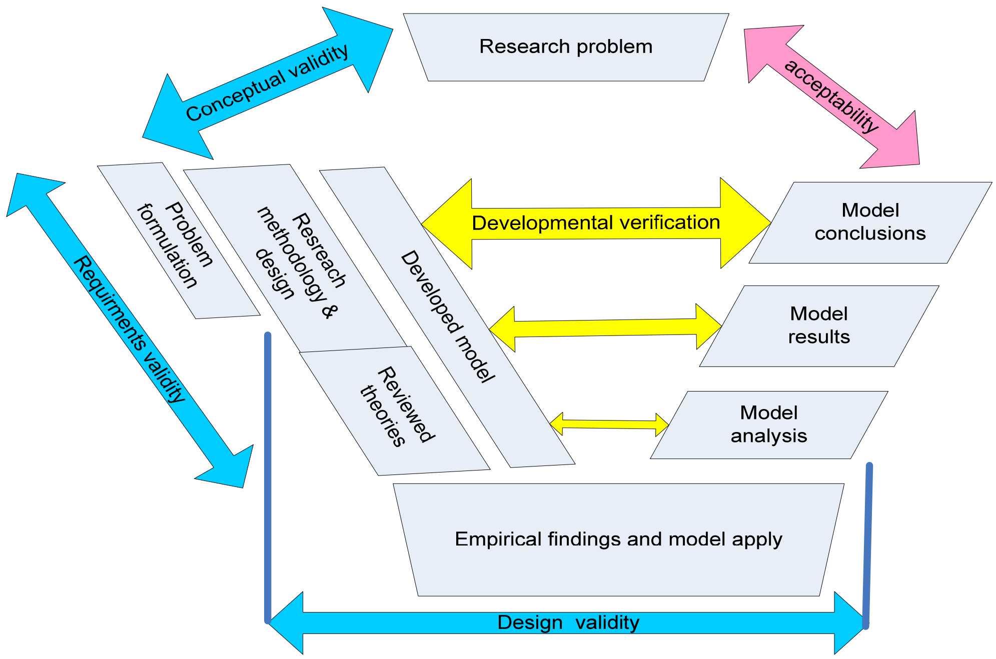


Figure 2.3, Research integration and qualification

Chapter Three

3. Literature Review

The specific objectives of this chapter are:

- Review the available literatures in the field of maintenance integration.
- In addition to the above, review all of the used theoretical and practical methods.

The organization of this chapter is as follows:

- Integration management theories: review
- Maintenance management: review basic systems and approaches
- Maintenance management: review basic systems and approaches
- Maintenance/manufacturing integration losses; causes and effects
- Systems engineering & six sigma: Phases,Methods and techniques

3.1 Integration theories summary

Integration definition means to join things so that they become one thing or fit together. So before do any integration we should identify the segregated group. Also defined by " the making up or composition of a whole by adding together or combining the separate parts or elements, combination into an integral whole: a making whole or entire. Integrity is the measurable adj: The condition (original perfect state) of having no part or element taken a way or wanting; undivided or unbroken state; materials wholeness completeness, entirety. (Oxford English Dictionary) Reference Dictionary. oed. com / cgi / entry

Richard Stevens et al (1998) define the integration process as “Balancing the rigor of testing against the resources and calendar time needed to perform it”, after that came Mike Danilovic (1999) to put his as follows “Is the process of combining components, tasks, or activities in to subsystems, chunks”, and Dennis M.Buede(2000) define the integration like “Is the process of assembling the systems from its components, which must be assembled from their configuration items(CIs)”. The common feature in these definitions is the integration path or approach which looks like a combination of top down method and bottom up method in order to integrate the systems form their configurations items into integrated system. The authors of the previous three literatures try to define the relations between the integrated system components, where Richard Stevens et al (1998) have been discussed the purpose of integration process in way of how to Check the interactions, overlaps, or inconsistencies between the groups, and according to this purpose statement they developed their integration model which consists of three levels; Component level verification, integration level verification, and system level verification, in order to perform the integration process in more controllable and effective way. Thus, the developed model of Stevens et al (1998) is a model to define the configuration items structure, organization breakdown structure, and schedule, work break down structure, testing model, and information model of any integration process. They suggest two methods in order to this defining process; configuration management for the technical aspects of the integrated system, and traceability management for the functional aspects of the integration process. While, Mike Danilovic

(1999) define the purpose of any integration process as “To take into account relations and dependencies between components in the product architecture” where his model is interesting for defining the relations types and dependencies by establishing the architecture of integration, Task specification, and work break down structure. Also, he defines clearly the difference between the coordination and integration terms “The relation between the people and the tasks is called coordination and the relation between the tasks and the components is called integration”. Dennis M.Buede (2000) has been discussed the integration process form another perspective where he is looking to the integration process as a interface design process, where he defined the interface as “interfaces are common failure points on systems”.

Literatures review observations

Our observations are aimed to define the basic requirements to integrate any industrial system in order to integrate our case study. The previous literatures represent for the readers the basic elements of any integration process in addition to the used methods which have been applied in purpose to perform an effective integrated system. Our observations are as follows;

- There are two phase for any integration process; define the basic components and their configuration items using the top down approach and define the interfaces between these components using bottom up approach.
- in order to determining the components and interfaces of the integrated system, authors suggest the following steps as shown in figure (3.1);
    1. Define components and their configurations items using configuration management to do the configuration items structure.
    2. Define interfaces and their inputs and outputs using the interface design management to do the interface structure.

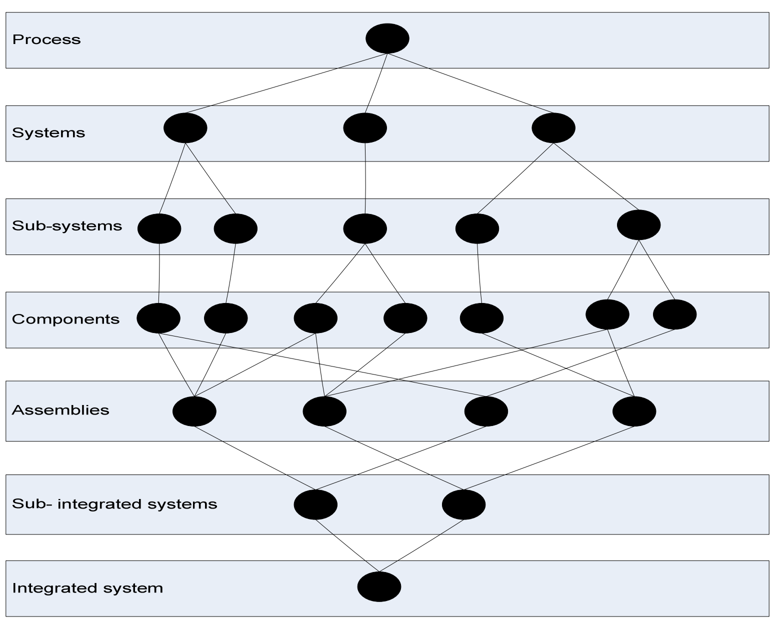


Figure (3.1), decomposition and integration processes (Danilovic(1999),modified by authors)

3.2 Maintenance management literatures

The main objective of this literature review is to present a framework for describing maintenance management systems.

Maintenance management; purposes, importances and impacts

Many of the key authors of the maintenance management filed have been discussed the important of the maintenance role inside the companies, Jonsson(1997) he said “maintenance has become more important since firms have downsized their organizations, minimized inventory levels and changed to flexible and time based manufacturing systems, and the aim of maintenance is to support the maintain efficient production”. The benefits of the maintenance management systems are: to improve the equipment availability (Sherwin and Jonsson, 1995) due to better planning, improve equipment reliability (Sherwin, 1993) through the identification of repetitive faults, improved stock control (Iravani.S and Duenyas.I, 2001), improve maintenance staff productivity (Duffuaa .S and et al, 1998) by better organizing and knowledge learning, improve quality (Duffuaa .S and Ben-Daya.M, 1995) of the produced products through better manufacturing conditions, improve safety by providing detailed standard job procedures (Abdul Raouf S.I, 2004), and improve long-term reduction in maintenance cost and the maintenance related costs (Al- Najjar.B and Alsyouf.I, 2003) which are divided into direct and indirect costs.

Maintenance management; life cycle, systems and models

Maintenance management system -as shown in the figure (3.2)- consists of five basic components (Harvey H.Kaiser, 1991); maintenance organization systems includes the essential management activities that guide policies and procedures, workload identification systems addresses the way(s) in which needed work is brought to the attention of the maintenance organization and documented, work planning systems to perform work (prioritizing, planning, estimating, and budgeting all tasks) are evaluated , work accomplishment systems describe various support activities and requirements (personnel, materials, equipment, and transportation, training, supervision and contracting procedures) that enable the maintenance management organization to perform effectively, and maintenance appraisal systems summarizes the information system features needed to monitor the comparison of actual to planned results . Each of these components has individual key elements.

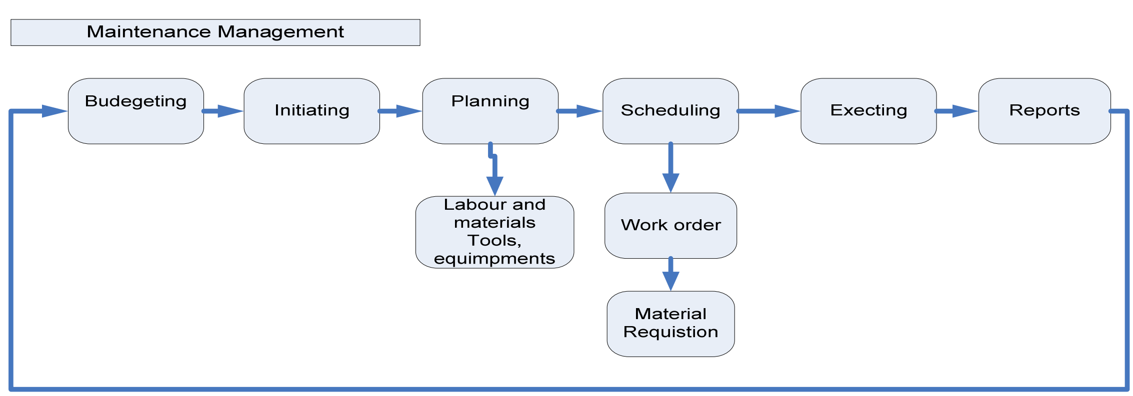


Figure 3.2, maintenance management functional areas (Harvey H.Kaiser, 1991)

Harvey H.Kaiser, (1991) has defined the basic components of any maintenance management system. While, the technological changes in the Manufacturing systems affect the maintenance management systems because of the supporting relation of the maintenance activities. In fact, these changes have been generated new maintenance strategies with new maintenance workloads, e.g. Total productive maintenance (TPM) establishes a system of autonomous maintenance to be performed by the equipment operators. Kelly.A (1984 and 1997) and Duffuaa .S and et al (1998) collected and defined the components of modern maintenance management system where they have been focused on the following aspects:

- A maintenance system can be viewed as a simple input-output model. The inputs to such a model are labour, management, tools, spares, equipment, and so forth, and the output is equipment that is up, reliable, and well configured to achieve the planned operation of the plant. This enables us to optimize the resources for maximizing the output of maintenance system. A typical maintenance system is shown in figure (3.3). The activities needed to make this system functional, namely, planning, organizing, and control, are shown in this figure, which also presents the components of a maintenance system that need to be planned, organized, and optimized in order to maximize the output of a maintenance system and achieve the best utilization of resources.

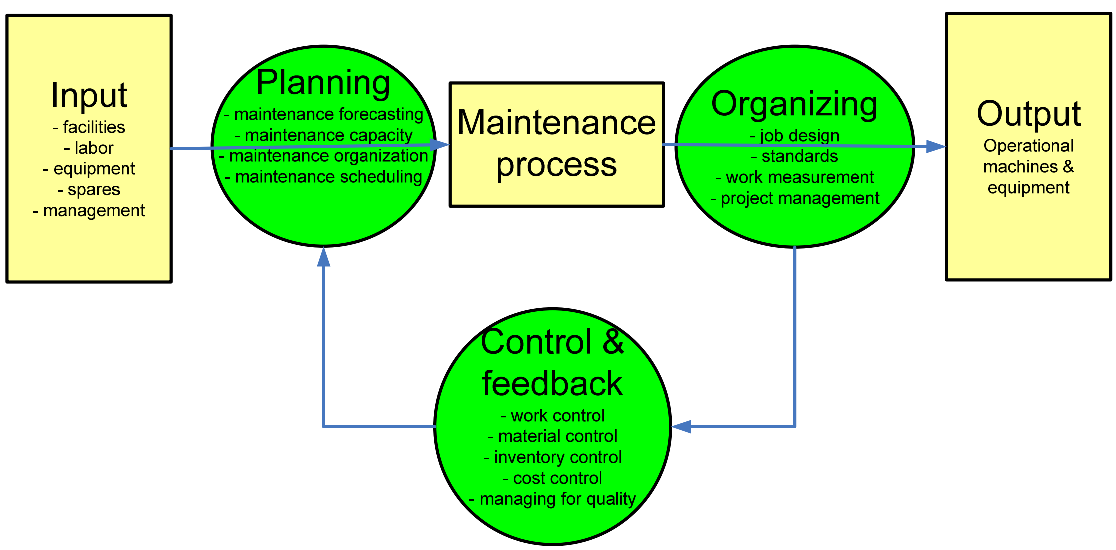


Figure 3.3, typical maintenance management system (Duffuaa .S et al 1998)

- Maintenance work types; unplanned maintenance (corrective maintenance, opportunity maintenance), planned maintenance (time- or use- based preventive maintenance, condition based preventive maintenance, reliability based maintenance), fault finding, and design modification.
- Maintenance management purposes; the typical maintenance management system has a purpose to enhance an operational machines and equipment (availability), modern maintenance management purposes to enhance an efficient operational machines and equipment, while in more advanced maintenance techniques like TPM focuses on improving equipment quality and overall equipment

effectiveness and ensure reliability by operator (Imai.M,1997), reliability centered maintenance (RCM) focuses on improving equipment reliability specially by design (John.D. Campbell, 1995), Total maintenance management (TMM) to improve the maintenance productivity and maintainability of the productive systems (Duffuaa .S and Ben-Daya.M, 1995), computerized maintenance management system (CMMS) supporting the maintenance management system in order to improve the utilization of the productive maintenance systems (Zhihong.H et al, 2005). Total quality maintenance (TQMain) integrates maintenance techniques in order to optimize the most cost effective maintenance system (Al- Najjar.B, 1996).

Different maintenance tactical systems

Corrective maintenance; this type of maintenance is only performed when the equipment is incapable of further operation. This type of tactical work is sometimes referred to as a run-to-failure strategy. (Duffuaa .S et al, 1998)

Time- or use based Preventive maintenance; this is based typically on either time or use factors, such as cycles, throughput, and running hours. It is carried out by conducting inspections, cleaning, lubrications, minor adjustments and other failure prevention actions. Often, records of observed condition are kept for trend analysis. (Campbell.J, 1995)

Reliability based replacement; involves replacing the equipment instead of performing maintenance. It is a planned replacement upon failure. (Duffuaa .S et al, 1998)

Fault finding; is an act or inspection performance to assess the level of failure onset. (Duffuaa .S and et al, 1998)

Condition based preventive maintenance; maintaining equipment is based on its measured condition. Examples include vibration, temperature, stress, contamination, flow, electrical measure and visual inspection. (John.D. Campbell, 1995)

Autonomous maintenance; is an especially important pillar of Total Productive Maintenance (TPM) because it enlists the intelligence and skills of the people who are most familiar with factory machines, equipment operators. Operators learn the maintenance skills they need to know through a seven-step autonomous maintenance program. (Sekine.K and Aril.K, 1998)

Instant maintenance; is a technology for restoring equipment to its dormer state within three minutes of a breakdown, it is the most important one at the job site.

Out-sourcing maintenance; major shutdown and overhaul maintenance requires the contracting out of a large segment of the shutdown work backlog; because there is usually a short, finite time period to accomplish all the work and not enough capacity within the organization to accomplish it. (Duffuaa .S et al, 1998)

Design out maintenance; is carried out to bring a piece of equipment to a currently acceptable condition. It involves improvement and, occasionally, manufacturing and capacity expansion. Design modification usually requires coordination with engineering and other departments within the organization. (Duffuaa .S et al, 1998)

Total productive maintenance; TPM focuses on improving equipment quality; TPM seeks to maximize equipment efficiency through a total system of preventive maintenance spanning the life time of the equipment. (Imai.M, 1997), (HO.S, 1999) figure(3.4) represents the basement and the pillars of total productive maintenance.

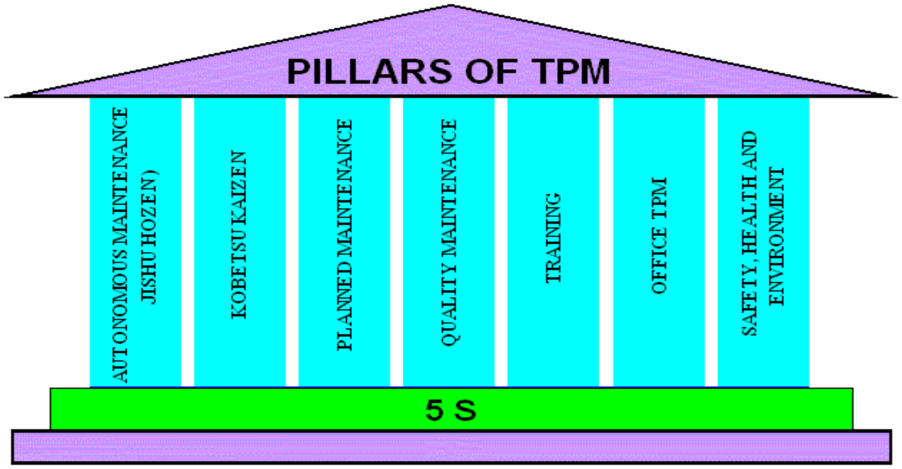


Figure (3.4) Pillars of TPM (Plant Maintenance Resource Center)

Reliability centred maintenance; (RCM) is based on the philosophy that maintenance is a key function of the company. It is crucial for the expected functional performance and productivity goals to be achieved. Further, maintenance requirements are best developed by multidisciplinary teams from production, materials, maintenance, and technical departments, and should be founded on a logical, structural, and engineered approach. (Campbell.J, 1995) RCM is the optimum mix of reactive, time- or interval-based, condition-based, and proactive maintenance practices. The basic application of each strategy is shown in figure (3.5).

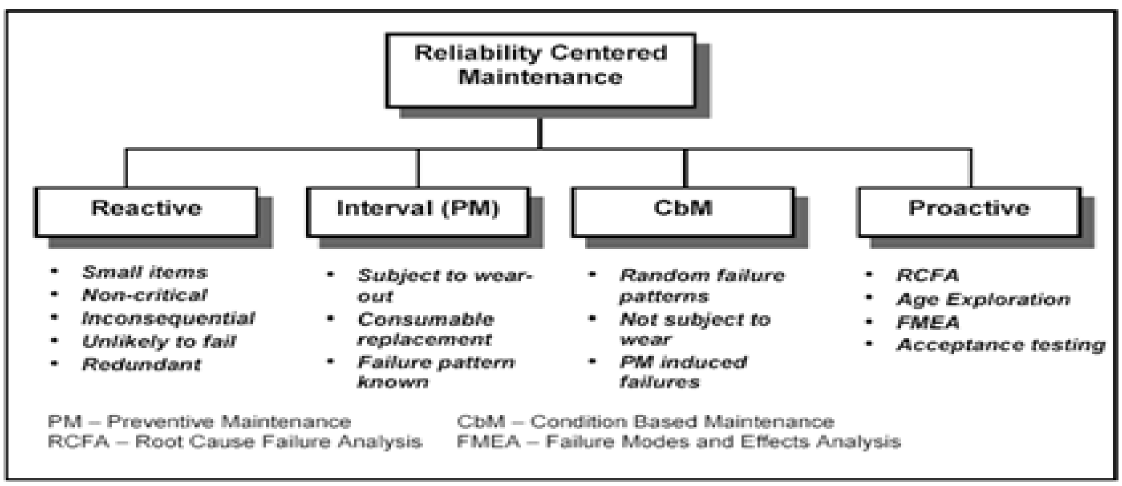


Figure (3.5), Components of an RCM (Program National Institute of Building Sciences)

These principal maintenance strategies, rather than being applied independently, are integrated to take advantage of their respective strengths in order to maximize facility and equipment reliability while minimizing life-cycle costs. RCM includes reactive, time-based, condition-based, and proactive tasks. In addition, a user should understand system boundaries and facility envelopes, system/equipment functions, functional failures, and failure modes, all of which are critical components of the RCM program.

3.3 Manufacturing management literatures

3.3.1 Computer integrated manufacturing

With the increasing use of computer numerically controlled (CNC) machine tools, and the development of sophisticated computer software packages designed to carry out administrative functions such as production scheduling and control, automatic materials ordering, etc., numerous attempts have been made to marry up these activities, and so create as automated a factory as possible. This is usually referred to as computer-integrated manufacturing (CIM), and is yet another attempt to minimize the time taken to bring a new product to the market place. One area at the heart of any CIM system is the linking of computer-aided design (CAD) with computer-aided manufacturing (CAM). CIM systems consist of subsystems that are integrated into a whole. These subsystems consist of the following:

- Business planning and support;
- Product design;
- Manufacturing process planning;
- Process control;
- Shop floor monitoring systems; and
- Process automation

Organizationally, these sub-systems are usually divided into business planning functions and business execution functions. Business planning functions include activities such as forecasting, scheduling, material and resource planning, invoicing, and accounting. Business execution functions include production and process control, material handling, testing, and inspection. An efficient CIM system requires a single database which is shared by the entire manufacturing organization. Databases consist of up-to-date, detailed, and accurate data relating to products, designs, machines, processes, materials, production, finances, purchasing, sales, marketing, and inventory. (Kalpakijian.S and Schmid.S, 2000)

3.3.2 Toyota production systems; JIT production system and lean production system

A basic principle of JIT is that goods are made not only in exactly the number required, but also at the last possible moment, while still meeting the required delivery schedule. JIT basically means to produce the necessary units in the necessary quantities at the necessary time. To be more specific, JIT seeks to achieve the following goals; zero defects, zero set-up time, zero inventories, zero handling, zero breakdowns, zero lead time, lot size of one (Browne.J, 1996). Where the most important goals which linking to the maintenance management system is based on support function of the maintenance in order to achieve the zero breakdowns, zero lead time, zero set-up time and zero defects goals.

3.3.3 Kaizen systems (Imai.M, 1997)

In the context of kaizen, management has two major functions: maintenance and improvement. Maintenance refers to activities directed toward maintaining current technological, managerial, and operating standards and upholding such standards through training and discipline. Improvement refers to activities directed toward elevating current standards. Kaizen signifies small improvement as a result of ongoing efforts. The major systems that should be in place in order to successfully achieve a kaizen strategy are;

- Total quality control/ total quality management
- A just-in-time production system/ lean production system
- Total productive maintenance
- Policy deployment
- A suggestion systems
- Small-group activities

3.4 Maintenance/manufacturing integration literature review

Maintenance, production, quality and Out-sourcing maintenance system losses

There are three main types of maintenance system in form of overall equipment effectiveness; the first one related to availability and maintainability improving in order to increase the uptime of the equipments as a one of maintenance objectives, the second one is related to the performance rate of the equipment where the maintenance system aims to improve the production rate. Finally, the third type related to the quality of the finished goods by maintaining the manufacturing conditions in order to reduce the rework or scrap percentage. There are many types of empirical operational losses collected and classified by Al-Najjar.B (2002) as a case study in the Volvo trucks component AB in Köping, and table (3.1) represent these losses. Where the maintenance stoppage time is consists of the following elements: maintenance personnel response time, fault tracing, waiting time for resources, repair time, and starting time.

Table (3.1), operational time losses

No.	Type	Categories
1	Stoppages	Long stoppages - failures - planned maintenance - unplanned-but-before-failure replacements Short stoppages
2	Stand	Hanging over a new item
3	Meeting/information	Machine stopped because of personnel discussion
4	Quality stoppages	Due to Quality problem or Waiting for measuring results
5	Tool changing	
6	Adjusting	
7	Lack of resources	Materials, tools, out-sourcing maintenance

Maintenance and out-sourcing maintenance; contracting individual workers and integrating them with the in-house staff can lead to inefficiencies and conflicts, as these contracted staff may not know the routines, equipment, or working procedures and rules, thereby reducing the productivity of the entire crew. (Duffuaa .S et al, 1998)

3.5 systems engineering and six sigma methodologies

From industrial needs to industrial satisfaction using Systems engineering; The systems engineering is about creating effective solutions to problems, and managing the technical complexity of the resulting developments. At the outset, it is a creative activity, defining the requirements and the product/process to be built. Then the emphasis switches again, to integration and verification, before delivering the system to the customer. The later phases might involve mass production or to single customer paying for a one-off development, even while components are being developed, systems engineering performs a crucial role in technical management. Stevens.R et al, (1998)

Systems engineering must bridge the abstract early stages and the grimy detail of implementation. Systems engineering first establishes what is feasible, and then creates the architecture for the system to be produced. Systems engineering understand the technical issues, translate them into user requirements. The systems engineering role must handle whole life cycle in a balanced way. The life cycle defined the order in which information must be produced, and the users, developers and designers each have responsibility for separate parts of the information, Buede.D, (2000). The systems engineering phases (Karlson.A and Bard.H, 2002-2007) are:

1) **Define the problem and extracting needs**
   The understand the problem means determine the life cycle processes and stakeholders requirements
2) **Extracting requirements**
   A System is commonly defined to be "a collection of its elements and procedures organized to accomplish some common objectives." The stakeholders for the system hold these objectives. The objectives of the systems engineers are to provide a system that accomplishes the primary objectives set by the stakeholders, including those objectives associated with the creation, application, and updating of the system. A major characteristic of the systemising the situation is the attention devoted to the entire life cycle of the research. This life cycle has been characterized as "birth to death." Buede.D, (2000). the systems engineers shall define the requirements of the new design, firstly, they define the research life cycle processes, and then they define the research stakeholders within those processes. Finally, they extract the requirements from each stakeholder group.
3) **Define the system & its boundary**

   According to Karlson.A and Bard.H (2002-2007) there are three step of this phase:
   - Generate, evaluate and select the conceptual solutions
   - Determine the vision and acceptance criteria of the selected concept
   - Determine the context diagram of the selected concept
   - Define the system requirements: functional (capabilities) and non-functional (characteristics) requirements
4) **Design the architecture**
   The system development includes three separate architectures (functional, physical, and operational) as a part of its process. The functional architecture

defines what the system must do, that is, the system's functions and the data that flows between them. The physical architecture represents the partitioning of physical resources available to perform the system's functions. The operational architecture is the mapping of functions to resources. Buede.D, (2000)

5) **Verification & integrations**

System Integration is the process of assembling the system from its components, which must be assembled from their configuration items. Qualification is the process of verifying and validating the system design and then obtaining the stakeholders' acceptance of the system design. Recall that verification is the determination that the system was built right; while validation determines that the right system was built. The operational validity is the matching of the capabilities of the designed system to the operational concept; this naturally occurs late in the integration phase after the designed system has been verified. In addition to that, the conceptual validity, requirements validity, and design. Validity is important aspects of validity and need to be addressed early in the design phase. Stevens.R and et al, (1998).

Six sigma methodology: the managerial thrust of a six sigma program is to effectively provide a framework and associated methodologies to analyze and evaluate business processes with the overall goal of reducing waste. The six sigma improvement process typically begins with identifying a problem to be solved and then defining a project to solve that problem. The process used by the project team is often referred to as DMAIC, which stands for define, measure, analysis, improve, and control. (Davis.M and Heineke.J, 2005)

3.5.1 Methods and Techniques

Auditing (Harvey H.Kaiser, applied management engineering, and PC, 1991)

The purpose of a maintenance management audit; **is to ensure that management is carrying out its mission, meeting its goals and objectives, following proper procedures, and managing resources effectively and efficiently.** An audit of a specific functional service area, such as maintenance management, focuses on efficiency of operations. In contrast to the more traditional measurement of manufacturing productivity, where units of labour and material can be compared to costs and rates of production, factors must be identified that can lead to improvements in both cost efficiencies and levels and quality of service. (Kaiser.H, 1991)

Process modelling (Davis.R, 2001)

Business modelling methods; the whole point of business modelling is it have a consistent way of documenting and analysing whole business, a global modelling method would be the ideal, but of course no such method exists. However, there are a number of well-known businesses modelling methods (ARIS, Catalyst, Zackman Framework, etc.) and standards such IDEF. These methods all have slightly different approaches and emphasis; some are specific to particular vendor.

Business modelling tools; one of the hardest parts of establishing a common modelling approach for a process is to ensure some degree of standardisation. Using a modelling method provides a framework for standardisation and using a tool helps enforce that standard. You can use a method without the support of a tool, but using a tool makes it much easier. Tools normally come with pre-defined symbols, diagrams types and relationships which all help the users to follow the method.

Brief summary of ARIS Toolset;
ASIR is not, strictly speaking, a toll, but a concept. The Architecture Integrated Information Systems (ARIS) was developed by Professor August-Wilhelm Scheer. The concept is intended to provide a framework that spans the gap between theory and information and communication technology. The core of the ARIS concept is the representation of business processes in diagrammatic form as chains of Events and process tasks. Each model contains many items (objects) and many connections (relationships). In order to provide structure the models are organised into four Views:

- Organization view – static model of the structure of the organization. Includes: people resources, technical resources and communication networks.
- Data view – static models of business information, includes: data models, knowledge structure, information carriers, and technical terms and databases models.
- Function view – static models of the process tasks. Includes: function hierarchies, business objectives, supporting systems and software applications.
- Process (control) view – dynamic models that show the behaviour processes and how they relate to the resource. Data and functions of the process environment. Includes: event-driven process chains, information flow, materials flow, communications diagrams, products definitions, flow charts and value add diagrams.

The first three views concentrate on the structure of the organization, while the process view concentrates on behaviour.

Process Measurement: Based on the problem formulation of thesis we try to find the most suitable measurement method for which support the developed model, where in the TQMain theory prof. Al-Najjar and et al. (2001) was developed a modified version of the previous measures to fit the measuring processes of the integrated systems.

Method I: overall process efficiency
The performance measure used in TQMain is overall process efficiency (OPE), a modified version of OEE. It is a breakdown of OEE into its basic factors. The definition of OPE is: "a measure of process effectiveness which reveals the contribution of basic process element to the process total effectiveness, e.g. the effect of environmental conditions on machinery availability, performance of manufacturing procedures or product quality". As shown in the following table (3.2)

I. The *machinery availability rate* is the time the process is really running, versus the time it could have been running. A low availability rate reflects downtime losses: process failures and setup and adjustments.

II. The *performance rate* is the quantity produced during the running time, versus the potential quantity, given the designed speed of the equipment. A low performance rate reflects speed losses: Idling and minor stoppages and Reduced speed operation.

III. The *quality rate* is the amount of good products versus the total amount of products produced. A low quality rate reflects defect losses: Scrap and rework and Start-up losses.

Table (3.2), overall process efficiency

overall process efficiency	*machinery availability rate*	*performance rate*	*quality rate*
OPE =	**[1-(Ns*Ta)/Tl]**	*** [1-(Nf +Nc +Ns)/ N]**	*** [1-(Nm*Tas+Trs)/T0]**
Parameters definitions	Ns: total number of stoppages Ta: average stoppage time T1:loading time	Nf: number of rejected item due to technical- based stoppages Nc: number of rejected item due to common causes Ns: number of rejected item due to special causes N: total produced number of items	Nm: number of minor stoppages Tas: average stoppage time Trs: time losses due to reduced speed T0: operating time

For the data collection of the required parameters, most of practical literature reviews indicate to use the man-machine chart (worker- machine chart) and especially to show the stoppages, non-utilized time, interfaces between the manpower like an operator and the resources like a machine.

Method II: Man machine chart

When a person and equipment operate together to perform a productive process, interest focuses on the efficient use of the person's time and equipment time. When the operator's working time is less than the equipment run time, a man –machine chart is a useful device in analysis. If the operator can operate several pieces of equipment, the problem is to find the most economical combination of operator and equipment, when the combined cost of the idle time of a particular combination of equipment and the idle time for the worker is at a minimum. Chase.R and et al, (2006)

Table (3.3), Multi –Man & Multi -Machine chart

Person				machine	
Person 1 (operator)	time	Person 2	time	Turing machine	time

summary			
	Person 1	Person 2	machine
Idle time			
Working time			
Total cycle time			
Utilization percentage			

Process FMECA (Davis.M and Heineke.J, 2005)**:** Failure Modes and Effects Analysis, or FMECA, is a methodology for identifying the potential failure modes that a product or process may encounter, assessing the risks associated with these failure modes, prioritization of these failure modes according to their urgency, and prevention of the more urgent failure modes, i.e., the ones that are most likely to cause serious harm to the company. There are many types of FMECA, but the most widely used are probably the following: 1) System FMECA, which is used for global systems; 2) Design or Product FMECA, which is used for components or subsystems; 3) Process FMECA, which is used for manufacturing and assembly processes; 4) Service FMECA, which is used for services; and 5) Software FMECA, which is used for software. In the semiconductor industry, the Design or Product FMECA and the Process FMECA are the most frequently encountered FMECA versions. Despite the existence of many types of FMECA today, the basic structure is as shown in the table (3.4):

Table (3.4) FMECA table

Process:					FMECA Type:						FMECA Date:					
FMECA Team Members:											Rev __ / Rev Date:					
Process Description or Purpose	Potential Failure Modes	Potential Effect(s) of Failure	SEV	CLASS	Potential Causes/ Mechanisms Of Failures	OCC	Current Design/ Process Control Prevention Detection	DET	RPN	Recommended Actions	Who When	Actions Taken	SEV	OCC	DET	RPN

Cause-effect analysis: Process Cause & Effect Analysis (Chase.R and et al, 2006) A cause is anything that affects a result. But in root cause analysis we generally think of causes as bad. Therefore we need a different term to include both adverse influences and beneficial influences. For example, a factor (X) that has an impact on a response variable (Y); a source of variation in a process or a product or a system.

Pugh evaluation matrix: Refers to a matrix that helps determine which items or potential solutions are more important or 'better' than others. It is a scoring matrix used for concept selection, in which options are assigned scores relative to criteria. The selection is made based on the consolidated scores. Before you start your detailed design you must have many options so that you choose the best out of them. This tool is also known as 'Criteria Based Matrix'. The Pugh matrix allows you to

1. Compare different concepts
2. Create strong alternative concepts from weaker concepts
3. Arrive at an optimum concept that may be a hybrid or variant of the best of other concepts

The Pugh matrix encourages comparison of several different concepts against a base concept, creating stronger concepts and eliminating weaker ones until an optimal concept finally is reached. Also, the Pugh matrix is useful because it does not require a great amount of quantitative data on the design concepts, which generally is not available at this point in the process. (www.isixsigma.com)

IDEF0 method (www.idef.com**)**: IDEF0 is a method designed to model the decisions, actions, and activities of an organization or system. IDEF0 is useful in establishing the scope of an analysis, especially for a functional analysis. The "box and arrow" graphics of an IDEF0 diagram show the function as a box and the interfaces to or from the function as arrows entering or leaving the box. To express functions, boxes operate simultaneously with other boxes, with the interface arrows "constraining" when and how operations are triggered and controlled. The basic syntax for an IDEF0 model is shown in the figure below (3.6).

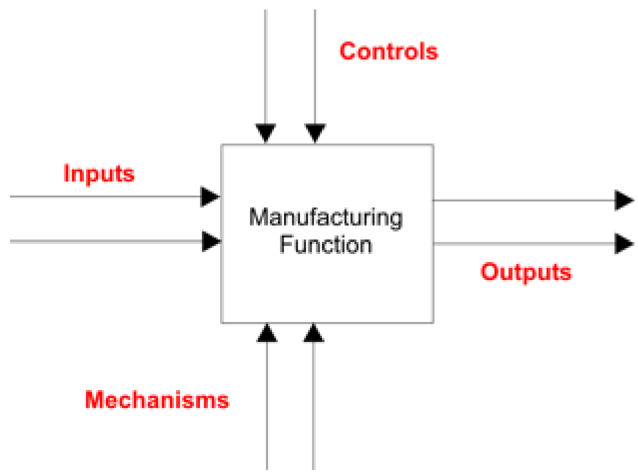


Figure (3.6), IDEF0 Box and Arrow Graphics

4. Developed Model

Chapter Four

The specific objectives of this chapter are:

- To discuss the available literatures in the field of maintenance integration.
- Based on above, to develop a model that contribute the filed of Maintenance integration and improvement directions.

The organization of this chapter is as follows:

- Model literature survey.
- Modelling basic concepts and approaches
- Overall modelling processes; draw up the overall developed model, and discuss the Model structure and characteristics.

4.1 Model literature survey

The classification of the collected literature is based on the main questions of our research; “what to integrate?” The collected literature should be able to support the researcher to define the basic integration relationships between the maintenance and other operational systems specially the productions´ systems, in addition to, “How to integrate?” Is the second questions for the collected literature, where this part was oriented to collect the most theoretical and practical methodologies which used in this field of research, in order to integrate the industrial systems. Based on the most recent paper which had reviewed the literatures of maintenance management topic, done by Amik Garage and S.G. Deshmukh, a total of 142 papers were collected and analyzed. A board classification of this literature in to six areas, these areas are: Maintenance optimization models, Maintenance techniques, Maintenance scheduling, Maintenance performance measurements, Maintenance information systems; and Maintenance policies.

According to this classification our research related to the last literature area “maintenance policies”, a total of 5 papers in this filed “maintenance integration” ,two in 1999 , 2000 and two in 2001 and finally one in 2002.

No.	Title	Authors	Year
1	Integrated maintenance and production control of a deteriorating production system	Iravani & Duenyas	2002
2	An integrated maintenance management system for an advanced company	Tu et al.	2001
3	Relationships between implementation of TQM, JIT, and TPM and manufacturing performance	Cua et al.	2001
4	Design of maintenance system in MRPII	Ip and Fung.R	2000
5	Company-wide integration of strategic maintenance: an empirical analysis	Patrik Jonsson	1999

Moreover, the authors use one university publication which is the base of there research, this publication has title “A model to integrate maintenance in the company business for improving profitability and competitiveness: application examples” done by Prof. Basim Al-Najjar (2005) and the authors have been discussed the content of this literature and gave it number six in their literature survey.

No.	Title	Authors	Year
6	A model to integrate maintenance in the company business for improving profitability and competitiveness: application examples	Prof. Basim Al-Najjar	2005

Summary of the literature

I. Iravani & Duenyas; they formulate the integrated decisions of maintenance and production using a markov decision process, so they have presented an integrated maintenance/repair and production/inventory model, where they also have presented in the results that making maintenance and production decisions separately can be rather costly and that there are significant benefits to making these decisions in an integrated fashion.

II. Tu et al; they developed and implemented a model of integrated maintenance system using the maintenance performance auditing, Reliability centered maintenance planning and controlling, condition monitoring and on-line feedback as an integrating methods in this model.

III. Cua et al; it is an investigation of the implementation of three programs (TQM, JIT, and TPM) working simultaneously together, and the impacts of these manufacturing programs. This paper presents an integrating framework and helps to untangle the overlaps between the three programs where each component of their integrating framework represents a different aspect of improvement initiatives aimed towards product, process, and equipment development.

IV. Ip and Fung.R.; the paper describes some research work that has been carried out using the integrated definition method (IDEF) model to systematically integrate maintenance into MRPII system. This particularly important with the increasing complexity of modern machine tools and production systems. The authors had used the top-town method in order to represents the entire system to more detailed subsections. The key success factor of this developed integrated system rests on the timely information collection and analysis. That means Integration of maintenance management into MRPII; to manage their production planning and scheduling as well as the maintenance activities is the effective use and coordination of information in the MRPII system.

V. Patrik Jonsson; this paper discusses the maintenance and production interface, and emphasizes the importance of integration for organizational design and strategic planning. The author describes the contextual factors for integrating of maintenance into the company systems; production process, industry, company size and breakdown consequences, which could help to explain differences in benefits.

VI. Prof. Basim Al-Najjar; the paper was discussing how maintenance should be integrated with plant other activities, such as operation and quality to avoid overlapping and frictions between the working areas and consequently financial losses. The develop model aims to determine how to maintain the quality of the input elements involved in the production process and establishing maintenance requirements (user requirements) for achieving business objectives cost effectively using maintenance function deployment (MFD) method which is a developed application version of the quality function deployment (QFD) in order to add a missing part concerns maintenance aspects. . The key successes factors of this developed integrated model are to integrate by define the personnel responsibilities and authorities and define common database. The interesting features in this paper that it takes in consider the financial aspects and needs of the integration process and discuss the cycle of integration process.

Classification of the literatures

In order to get the benefits of the collected literature the authors of this thesis have made a detailed discussion on these areas/ sub-areas along with critical observations on each of them. Firstly, the classification of the available literature in the field of maintenance integration have suggested six area; integration importance, integration management, integration methods and techniques, Integration performance measurements, integration applications area, and integration execution and losses. Each of the above six area have been discussed in detail in this section.

1) Maintenance integration importance; the scope of focus here not only upon the direct but also indirect maintenance costs and loss of revenue due to poor availability which is the effects of poor maintenance integration. Jonsson (1999) and Al-Najjar (2005).
2) Maintenance integration management; most the six papers have been discussed one or more issues related to maintenance integration field. In general, maintenance integration management covers five aspects: the first one is the perspectives of the integration: socially (Cua et al 2001), technically (Cua et al 2001, Al- Najjar 2005), economically (Jonsson 1999, Al- Najjar 2005). The second one is integration levels; engineering, planning, operations, marketing and financial (Ip et al.2000), in addition to these the database level of integration (Al- Najjar 2005). The thired one is integration elements: inputs (Al- Najjar 2005), mechanisms (Ip et al.2000), outputs and controls. The fourth one is integration components (Ip and Fung.R.2000) and their interfaces (Al-Najjar 2005). Finally, integration life cycle: development (Ip et al.2000, Al-Najjar 2005) and design (Ip and Fung.R.2000 by using IDEF, Cua et al 2001), construction (Ip and Fung.R.2000), testing (Ip and Fung.R.2000, Cua et al 2001), distribution (Al- Najjar 2005 by using MFD), operation and maintaining of integration process, updating and continuous improvement of the integration model (Al- Najjar 2005 because of the developed model based on PDCA cycle).
3) Maintenance integration methods and techniques;

- Integrate by organization management; define clear structure, policies, responsibilities and authorizations (Al- Najjar 2005),
- Integrate by process management; define applicable functions in terms of sequence and time (planned and/or conditional) schedules for the different working system operations and requirements supplying schedules (Iravani & Duenyas 2002).
- Integrate by control management (Tu et al 2001); define clear control points with measuring techniques and deviation analysis tools in order to ensure the effectiveness and efficiency of operations flows: decisions and steps.
- Integrate by data management (Al- Najjar 2005); data preparation system, data collection system, data analysis system.

4) Maintenance integration performance measurements; define measurable factors to evaluate the performance of integration process, measurement method (collection and analysis), where Al- Najjar 2005 has been developed the MFD model based on the economical aspects.

5) Maintenance integration applications; maintenance integrated production (Jonsson 1999, Ip and Fung.R.2000, Tu et al 2001, Cua et al 2001, Iravani & Duenyas 2002, Al- Najjar 2005), maintenance integrated quality (Cua et al 2001, Al- Najjar 2005), maintenance integrated human resources (Cua et al 2001, Al- Najjar 2005), maintenance integrated out sourcing, maintenance integrated logistics (Iravani & Duenyas, Cua et al 2001).

6) Maintenance integration execution and identify and/or eliminate losses (Al- Najjar 2005); identify missing parts, overlapping, and frictions in the integrated: organization, processes, controls, data and information system. Also generating, evaluating and selecting the most cost effective solution.

Some observations and contributions

There is a lack of empirical studies explaining of how should the maintenance integrating with company systems and it not simple to apply (Jonsson 1999), Al- Najjar (2005) discussed in detailed levels the difficulties of maintenance integrated implementation process and he has founded and defined some of the overlapping and frictions between company systems. The most interesting feature of Ip and Fung.R (2000) paper the method of design the integrated system where they had been used the systematic approach for the design. The authors try to ask two questions; the first one is, if the company wants to build a maintenance integrated system how it could be able to build it without overlapping and frictions, they means how to define theses losses in the design stage which is less costly than in operations – when the system running- stage. The second question focus on the existing maintenance integrated system, how companies will define the overlapping and frictions in their system, then how they will generate, evaluate and select the most cost effective solution and how to design this selected solution. Karlson.A and Bard.H (2007) describe the two pronged approach for completeness of systems or integrated system consists of capabilities (input/output requirements) and characteristics (non- functional requirements), for the first type researchers use different methods likes use case scenarios, flow charting etc. and for the second type they use checklists, QFD (where it is a platform of MFD model), etc. Thus, the authors will define the user/stakeholders and systems requirements in order to improve the integration of the studied case study using the system engineering approach where it deals with capabilities requirements (using use-cases). The problem addressed in this research is; how to analysis and design the integrated operations management system in order to eliminate/reduce the integration losses between the working areas/systems in the companies.

Constructive Features and evaluative criteria of the developed model

The following table (4.1) represents the most common features in any maintenance integrated system according to the previous literature review. In addition to, the evaluation process has done for the six collected literature (see last two tables). Based on the following table (4.1) the authors have defined the most important factors and features which should be taken in consider in the development stage of this developed model. Features for the developed model were categorized as follows;

- Type 1(see table 4.1), Exploration features; there are some missing features that were not taken in consideration like the out-sourcing maintenance system, the process of extracting the capabilities requirements of the system, overall integration process between the integration levels and finally the design method which is a very important issue.

- Type 2(see table 4.1), Explanation features; There are practical weaknesses with some features like the social perspective of an integration process, integration scheduling, integration controls, integration measurement method, defining the integration life processes of the integrated system, identifying integration losses within these processes and break-down structure of the integrated system, finally there is weakness within the generation/evaluation/selection processes for select the cost effective solution.

- Type 3(see table 4.1), Advanced- description features; the matrix recommended us for more empirical descriptive studies in order to improve the practical considerations about it.

Table (4.1), Constructive Features and evaluative criteria matrix

Features & Criteria	Literatures number						Weakness types
	1	2	3	4	5	6	
Maintenance Integration importance							
Define economical/marketing aspects	X	X	X	X	X	X	
Define cost reduction aspects	X	X			X	X	
Maintenance Integration management; perspectives, levels and elements							
Socially- oriented practices			X				Type 2
technically- oriented practices			X	X		X	
economically- oriented practices	X	X			X	X	
Integration organization structure		X	X	X			
Integration planning and controlling	X	X		X			
Maintenance Integration methods & techniques							
integrate the organization/ staffing (plans)			X	X	X	X	
integrate the processes and (functions, schedules)	X						Type 2
Integrate the controls (flows, control points, measurements, deviations)		X					Type 2
integrate the data & information systems (preparation, collection, analysis)				X		X	Type 3
Integration performance measurements							
Define Measurable factors	X	X				X	
Measurement method						X	Type 2
Integration applications							
Maintenance integrated production	X	X	X	X	X	X	
Maintenance integrated quality			X			X	Type 3
Maintenance integrated human resources			X			X	Type 3
Maintenance integrated out-sourcing							Type 1
Maintenance integrated logistics	X		X				Type 3
Integration's execution and problems							
Define the life cycle processes of the integrated system						X	Type 2
Extracting user requirements					X	X	Type 3
Extracting system requirements- capabilities							Type 1
Extracting system requirements- characteristics					X	X	Type 3
breakdown structure of the integrated system					X		Type 2
Define boundaries and interfaces	X	X	X	X		X	
Identify missing parts, overlaps, and frictions in the integrated organization, processes, controls, data						X	Type 2
Define the integrations between integration levels; organization, processes, controls and data							Type 1
Generate solution/s						X	Type 2
Evaluate solution/s						X	Type 2
Select the cost effective improvement solution						X	Type 2
Design functional, physical, operational architecture							Type 1

4.2 Modelling basic concepts and approaches

Modelling is something that we all do, whether it is a conscious or an unconscious activity. It precedes the formulation of an opinion. The statement that the conduct of meeting was poor is based upon an implicit model of what a good meeting is like. An analyst visiting a factory for the first time and observing that the process of production scheduling could be improved is likewise basing this opinion on some implicit model of production scheduling. In latter case, before a decision is reached on what to do about it, an explicit model would probably be produced. And because modelling is so fascinating there is a great danger than it can become an end in itself. The measure of success in modelling is not that you can produce model that is bigger and more sophisticated than anyone else is but that it adequately answers the original question [problem formulation] for which it was developed. So we should have a clear definition of what means by model? Gigch.J, (1978)

A model is the explicit interpretation of one understands of a situation, or merely of one's ideas about that situation. It can be expressed in mathematics, symbols or words, but it is essentially a description of entities, processes or attributes and the relationships between them. It may be prescriptive or illustrative, but above all, it must be useful.

Davis.M and Heineke.J, (2005)

In general, models may be illustrated by reference to four kinds of concept;

- As an aid to clarifying thinking about an area of concern
- As an illustration of a concept
- As an aid to defining structure and logic
- As a prerequisite to design

Prior to any study some appreciation of the situation will need to be acquired and issues such as the following will need to be considered:

(a) What is taken to be the boundary of the area under study?
(b) What interactions are assumed to exist in relation to this particular boundary?
(c) What kinds of activities are likely to be present within this area?

A number of concepts can be transferred from one discipline to another and in bringing about this transfer a clear definition of the concept is necessary. So, the use of such a concept may assist in understanding the production management process itself or help in defining information flows and responsibilities. Insight into a situation may frequently be enhanced by the development of a model, which illustrates interactions in the form of cause-effect or producers-product relationships. After that, design activity comes to defining how to achieve a particular purpose. Prior to design, however, the stage of defining what is to be designed. Take, for example, the design of manufacturing plant. It is assumed that, as the result of some long- to medium-term planning activity, a decision has been reached to invest in a plant to produce a particular range of manufacturing products to satisfy a perceived market need. Davis.M and Heineke.J, (2005),

4.3 Overall modelling processes

The application of a methodology may involve the use of technique, but it is the methodology, which determines if a particular technique is appropriate, or not. So we have two approaches; technique oriented and problem oriented, to be ‘technique oriented’ is to introduce the danger in the problem situation will be distorted to fit the technique. It is a danger in the sense that, although a solution is guaranteed, the solution may not actually remove the initial concerns. A more successful approach is to be ‘problem oriented’ and to allow the situation to distort the way the analysis is being carried out. Thus what is needed is a methodology within which an exploration can be accommodated of the significance or implications of adopting a particular stance in relation to the problem situation. Systems engineering methodologies are based upon the paradigm ‘optimization’ whereas the check land methodology takes the paradigm to be one of ‘learning’. This shift has been necessary given the increasing concern for ill-structured problems to which there are no such things as ‘right’, or optimized, answers. Davis.M and Heineke.J, (2005),

In essence the methodology can be described as a three-stage process of analysis which uses the concept of a human activity system as a means of getting from ‘finding out’ about the situation to ‘taking action’ to improve the situation. Stages are as follows: finding out, selection, model building. Take in mind the comparison and recommendations for change which play an essential role in order to taking action. Davis.M and Heineke.J, (2005),

4.3.1Finding out (model)

What? The Requirements and defining the studied system, it means, model creator has to create a definition of the system; components, functions, system’s external systems, and system’s context. According the introduction chapter, where the problem was defined, the studied system or the system of interest is the operational system, which is one part of the whole manufacturing process and the other three subsystems are; production management system, maintenance management system and quality control system, those three subsystems represent the external systems which are impact and impacted by the system of interest. The context of the system is a set of entities that can impact the system but cannot be impacted by the system like the outsourcing maintenance and material, tools, and spare parts suppliers. As shown in the figure 4.1.

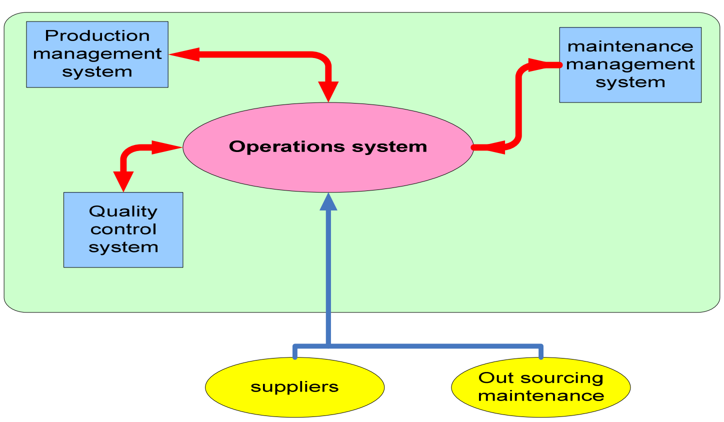


Figure 4.1 Contextual view of the research

Why? Requirements are the cornerstone of the modelling process: originating requirements provide operational statements by the stakeholders concerning their needs: derived requirements enable the developers of systems to partition the problem into components that can be worked in parallel while maintaining design control through the requirements partition and the interfaces between the components: derived requirements enable the verification of the configuration items and component during the qualification activity during development; and originating requirements provide the means for validating the system's model during qualification.

How? By develop the operational concept; it is prepared from the stakeholders of the model and describes how these stakeholders expect the model to fit into their world, so the objectives of each stakeholder group are suggested in table 4.1:

Table (4.1), Model life cycle, stakeholders and requirements

Model life cycle	stakeholder	requirements
Development	Supervisor , Subject key authors & researchers	• The model should be consistent correct • Model should fit to purpose
	Case company	• Model should fit to the situation
Conversion	Case company	• Able to ease to implement
Training	Industrial trainer	• Able to be ease to understand the structure
	students	• Model should be related to my knowledge
Operations/maintenance	users	• Model should has logical sequence • Model should be capable to develop our experiences
	Developer & updater	• Model should take in consider the continuous improvement cycle • Model should support by some informational system
refinement	researchers	• Model should has interchangeable modules

4.3.2 Selection (methodology and theory)

What? It means select the theoretical and methodological approaches in the model development process; actually, it is related to the methodological approaches subject which was previously discussed. The main three part of the selection process are:

1. the methodological approach; structure of the model which explain the features of the relations between X's and Y's (inputs and outputs): inputs and feedbacks;

this relation explain the recourses for each function of the system of interest , boundaries and interfaces an impacts, control points and measurements and mechanisms and corrective actions.

2. Procedural methodology (model sequence); Define the problem and extracting need, Extracting requirements, Define the system & its boundary, design the architecture, verification & integrations.
3. Required theories (model mechanisms); the author have been selected the required theories which support the developed model by define the inputs and the outputs of each step of this modelling process. As shown in table 4.2.

Note: read the table from left to Wright and top-down. And remember that the outputs are the inputs for next phase.

Table (4.2), Model; processes, inputs, methods and outputs

Phases & steps	inputs	Mechanisms & controls	outputs
1) Define the problem and extracting need	Process recourses Process model Process performance Process failures experiences	Process auditing Process modelling Process effectiveness measures Process failure analysis Process causes-effect	Defined process stakeholders Defined Needs
2) Extracting requirements	Stakeholders´ Needs	Users Requirement analysis	Well defined stakeholders requirements
3) Define the system & its boundary • Generate, evaluate & select conceptual solutions • Define system context • Define system requirements	Well defined stakeholders requirements	Pugh matrix Context diagram Capability & Characteristics analysis	Conceptual solutions System requirements • Context diagram sheet • System decomposition • Use- case scenarios
4) design the architecture	System requirements	Functional analysis Physical architecture synthesis	IDEF flowchart
5) verification & integrations	Design architecture	Verification and integration analysis	system verification's activities checklist

4.3.3 Building the Model

Model thinking and strategy

The developed model was built based on three idea; the first one the idea of continuous improvement in order to improve the model quality, the second one the systems engineering philosophy as way for analyzing existing systems and designing improved system in other words "from AS IS systems into TO BE system", in order to perform the model capability, finally, the six sigma methodology and tools in form to reality enhancing where the cooperation (see table 4.3)between the systems engineering tools and six sigma tools give the model the ability to be close to the analyzed case and improved situation.

Table (4.3), Model thinking ideas

Continuous improvement cycle	Systems engineering phases	Six Sigma tools
Plan	Define the problem and extracting need	Defining techniques Defining techniques
	Extracting requirements	Analyzing techniques
	Define the system & its boundary	Improving techniques
	Design the architecture	Control techniques
	Verification & integrations	Improving/control techniques
Do (Apply TO-BE system)	Define modification requirements	Defining techniques
Check (Measure & evaluate)	Extracting modification requirements	Defining techniques Analyzing techniques
Act (Define practical problem)	Modify TO-BE system	Improving/control techniques

Model structure: cycle, loops, phases and steps

Inside the developed model there is one external cycle which is the Continuous Improvement cycle with many iterative internal processes take the circle shape of loops and feedbacks in the model figure (see figure 4.2). While the general analyzing and designing processes were rolled by using the five phases of systems engineering methodology:

1. Phase 1: Define the problem and extracting need; the purpose of this phase is to define the process and the systems within this process in addition to analysis each of these systems and break down them into components detailed levels via the sub-systems level. In purpose of specific defining the configurations items of these basic components; characteristics, problems, and needs for improvement. The used methods and techniques are the planned and empirical descriptions of these systems, flow charts drawings, data collection forms, and measurement forms.

2. Phase 2: Extracting requirements; it is an analysis processes done based on the inputs which collected in the defining phase to extract the user /stakeholders requirements.
3. Phase 3: Define the system & its boundary; six sigma powerful support method systems engineering where six sigma provide the improving techniques to extract the basic improvements requirement relate to the system, based on that systems engineering can generate the conceptual solutions for the improvement requirements. The second step is to evaluate the conceptual solution using Pugh matrix in purpose to select the cost effective conceptual solution, the third step it a collection some processes: draw the context diagram of the TO-BE system as a clear representation of the internal and external systems that might affect or affected by the TO-BE system. The next step it is drawing the use-case scenarios as a capability analysis step to determine the functional requirements of the TO-BE system, also to determine the non-functional requirements.
4. Phase 4: Design the architecture; after the extracting the TO-BE system requirements (functional and non-functional) the development process of the functional, physical and behavioural architecture are ready to perform his processes. First of all, defining the TO-BE system; components, assemblies and sub-integrated systems in order to perform the whole picture of the TO-BE system taken in the consider interface managing of the clustering process using IDEF flowchart to represent this picture.
5. Phase 5: Verification & integrations; in this phase to simulate the whole system and establish verification requirements in order to satisfy the stakeholders of the developed model.

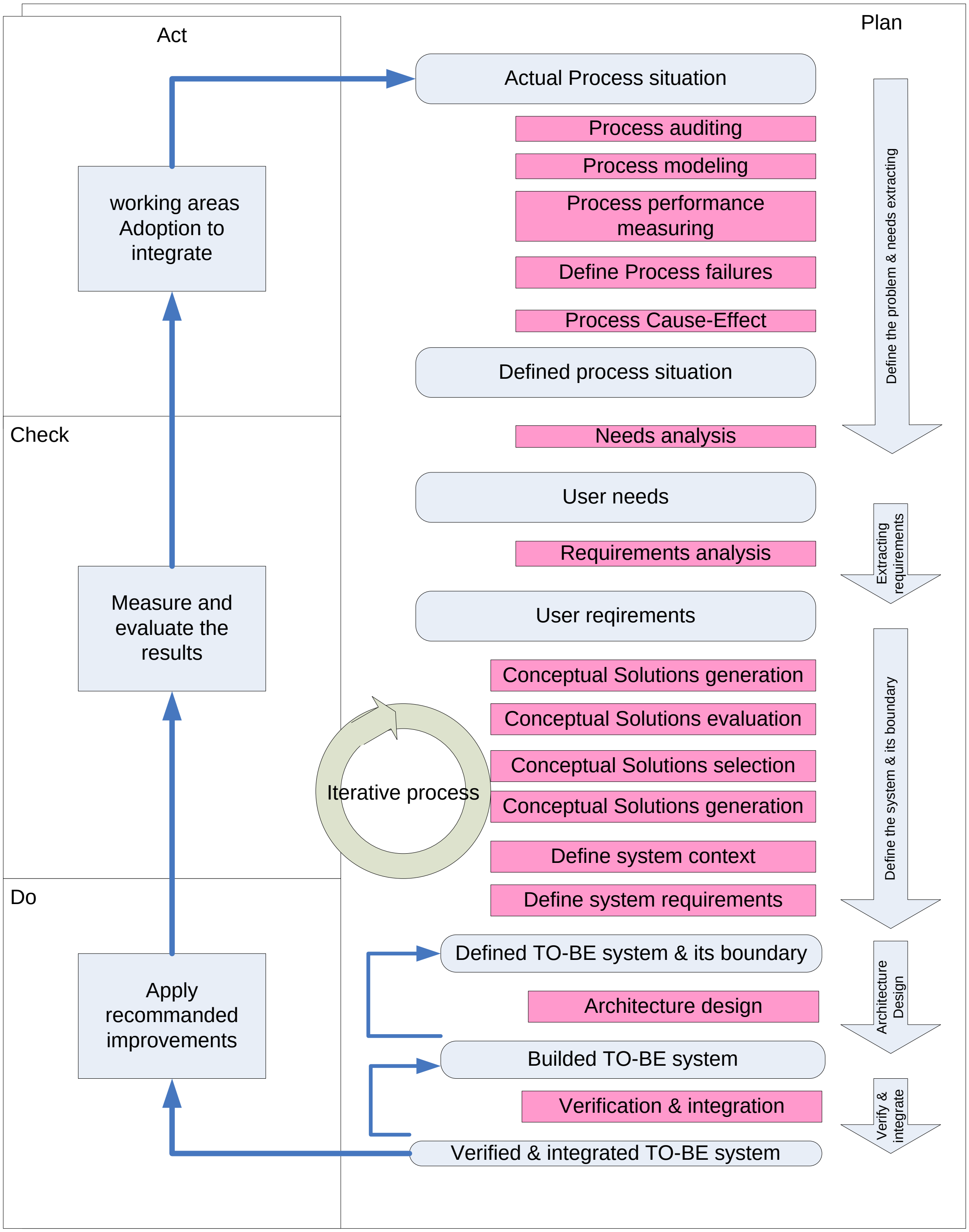


Figure. 4.2 Conceptual model for identify and improving the process integration between working areas

Chapter Five

5. Empirical findings

The specific objectives of this chapter are:

- To show the validity of selection and design the problem case study.
- To describe the empirical information that required for testing the research hypotheses and conduct the research objectives.

The organization of this chapter is as follows:

- Case company description.
- Description of the case study; processes, operations and systems.
- Description of the integrated situation within the selected case study.
- Description of the data sources, types and collection processes.

5.1 Case company

Willo is one of Sweden's leading companies within metal processing. The company is located in Växjö, from where they supply leading high-tech industries with high quality components where the demands for precision, fine quality finish and overall quality are extremely high. The company has about 70 co-workers.

Willo's customers are mainly found within the nuclear power, medical-technical, packaging, defence and hydraulic industries. As partner's Willo Maskin contributes to finding the right solutions for their customers' requirements for complex components, already in the design phase. Willo also provide other services for instance the company can offer part-systems or after-treatment like assembly or installation.

History; In 1956 Willy Loeffel founded a company called Willo Maskin. With him from his homeland, Switzerland he brought a spirit of enterprise, technique and a feeling for quality. The company expanded and received more and more complex and advanced assignments from defence, packaging and other industries. Today, Willo has developed into a cutting edge company within metal processing. Since 1995 it's the Swanström/Loeffel family that owns Willo Maskin.

Business concept; ”Willo Maskin shall be the market leading supplier of small, complex components to leading, high-tech industries who set high demands in terms of precision and quality"

Quality; When the company talks about high quality, they mean a high integral value for their customers. There shall be quality throughout the whole value chain, not just in the end product, but though all contacts with them. Willo was amongst the first companies in the engineering field to quality assure its operations, in accordance with the ISO 9002 quality assurance system.

Production process; Willo´s Production process develops all the time, because of offensive and strategic investments they are in his front edge of technology. The company's employees transform the technical knowledge to effective and high-class products. The company works with most metals mainly, stainless, steel, aluminium, titanium, zirconium, and brass.

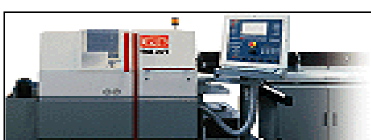
Production system; Willo Maskin AB doesn't use a traditional production line system when producing its products. One product can be dispatched between several machines and each machine can produce many different products. This requires a lot of setup time, but gives in return great flexibility. Therefore the company has deferent machines and some are weary old and some are very modern, fore some rezone the old machine has been forgotten when it comes to prevented maintenances.

The Product; The task that was provided from Willo was to investigate the production process of a shaft, which is a product that is rather new for the company. It is a product that is used in the dentinal business. The product is very small and has are made in a material that is called titanium. The difficulties of producing the product are mainly the dimensions and Surface finish.

Production operations; The shaft that is investigated has a few operations today. First, the raw material is put in the module that is attached to the machine Traub TNL12. The operator puts in the material that is in four-meter rods. In the module there is pneumatic that push the rod in the machine. Then the rod is going through case to fix it. It is put in the case to get the right size to. In the next operation the rod is turned in a lathe to get the right dimensions. In this operation the rod is turned and taped. After all the machining is done the rod is cut to a finished product.

5.2 Case study; selecting and description.

Workstation description; Willo maskin AB has different types of CNC machines to fulfill his production requirements. Willo work with the majority of metals like; steel, stainless/acid-resistant, brass, aluminium, titanium and zirconium. The classification of the CNC machine inside Willo was based on the type of needed machining operations and product material types, so it has 6 CNC machines and is used for highly precise products such as medical-technical and nuclear power. The selection process of the chosen workstation for our case study was according to many aspects: Because of its a new machine, and its one of the most expensive workstation in this company, so its a strong reason to studying the behaviour of the sub-system within this workstation, to take care of it in a proper way, to satisfy the company investment wishes. The Importance of the selected machine is due to the operation sensitivity where the machine capable to produce very small elements with high qualities, such as technical elements for dentil application. In addition, the Simplicity and clarity of sub-systems operations within this workstation are very useful features to enhance case study purpose; Production, maintenance, and quality operations. The chosen workstation (as shown in figure 5.1) is a computer numerical controller machine manufactured by TRAUB. Where TRAUB, well known for flexible CNC turning machines and experts in Swiss-turning, has been part of the INDEX Group since 1997. TRAUB has become a single source supplier for their customers based on application-oriented production solutions. TRAUB products have a loyal customer base due to product quality and technology, as well as outstanding service capabilities. The machine type is TRAUB TNL 12, which is a highly precise sliding headstock technology from the building block system.



TRAUB-TNL-12

Highly precise sliding headstock technology from the building block system

Figure 5.1, Selected machine

5.2.1 Production operations*;* the main goal of the production operation is to producing optimal number of acceptable product, within the limited time. Specifically, in this case study the author focus on the production systems that are related directly to the selected workstation. There are three steps as a pre-request to starting the production stage of the product production cycle as shown in the figure (5.2).

1. Understanding the drawing, which received form the customers and the defining the manufacturing parameters and features.
2. Preparing (writing and simulating) the CNC programming codes for the whole product.
3. Planning the resources and the operations; planning in the case company involves four elements: scheduling, labour planning, equipment planning, and cost planning.

   - Scheduling involves specifying the start, duration, and end of the various activities
   - Labour planning involves allocation of personnel, distribution of responsibilities and resources
   - Equipment planning involves identification of types and need of equipment
   - Cost planning involves identification of costs and when they will occur

4. Installation operations should be done in a proper way.
5. Test the first specimen of the product.
6. Production time; produce, control the planned amount of the products and monitor, maintain the manufacturing machines and facilities. The figure (5.3) shows the actual activities between the subsystems within the production time

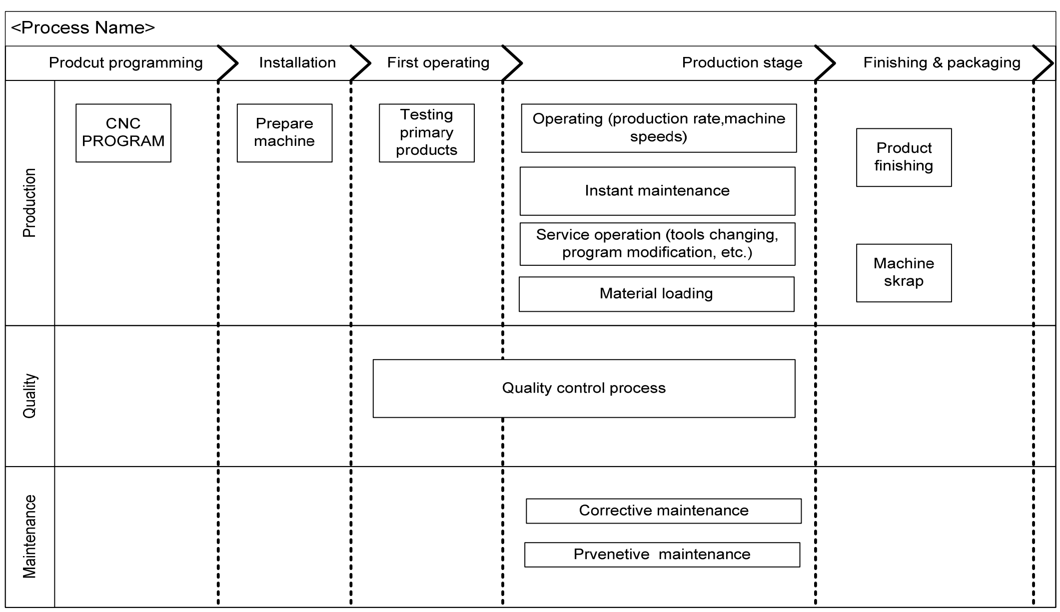


Figure (5.2), production stages with the working operations

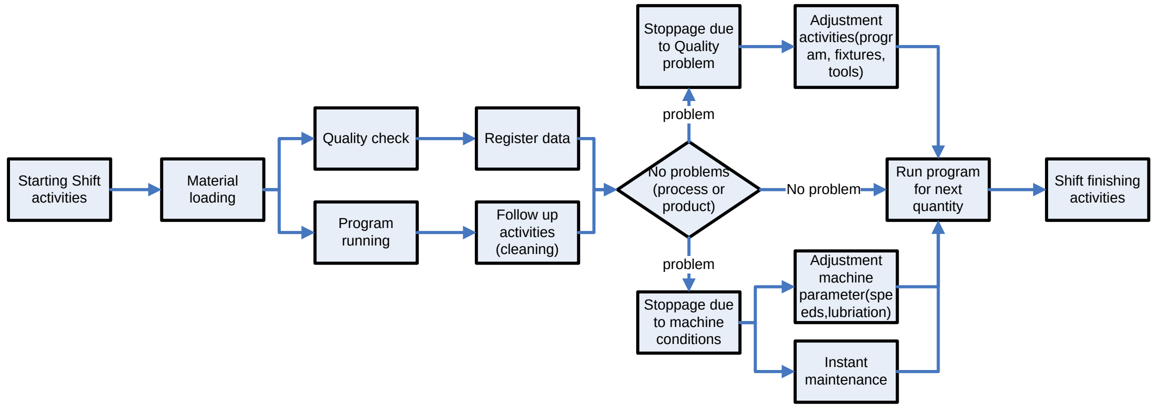


Figure 5.3, actual relations between working area sub-systems

From the information system view: the drawing done by the CAD software like AutoCAD, then transferred into another software to input the manufacturing parameters; cutting speed, cutting tools, feed rate and references points etc, by the CAM software by CAM- model. After that, they transfer it into CNC-simulator program to generate the CNC code.

5.2.2 Maintenance operations

Description; The authors try to describe the real situation of the maintenance operations as a critical subsystem working together to provide the best fitting within production operations to gain acceptable results in the quality operations. So, in general, for all workstations, the maintenance objective is to reduce the adverse effects of breakdowns and to maximize the availability of facilities at a minimum cost. Establishing flexible strategies and policies is the most significant step to gaining the maintenance goal. Mainly, production supervisor explain that until now the most maintenance strategy which used in the corrective maintenance, done by external company (manufacturer) not but by maintenance department that reduce the working pressure within this department, so it pay for each machine per year to do the maintenance job, while production supervisor the this strategy is effected by the time when the workstation is going old, the reason behind this future change it will be the age - failure relationship for this CNC workstation , so now there is no failure because it is new while in the future it will be a lot of maintenance work which will affect the production subsystem.

Functions and responsibilities; Maintenance subsystem is responsible for directing all operations related to the maintenance, repair and upkeep of the equipment, grounds, and machinery and maintenance operations of this workstation. It directs the installation of new machinery and equipment. Administrates and creates the preventive, corrective and predictive maintenance programs and processes. Also, there are other special responsibilities such as ensuring the correct installation of new machinery and equipment for production process and evaluates the results after the installation, establishes maintenance plans and goals, including improving manufacturing processes, installation of new machinery or the completion of a project, ensures effective control in maintenance and repair problems and establishes workable and efficient solutions. It ensures the correct maintenance of computer numerical controller, sensors and related controls.

Maintenance subsystems; each subsystem is aim to perform its functions. In general, the maintenance operations are to perform all the required functions of the different subsystems; corrective, preventive, instant, and outsourcing maintenance. Also it is important to know the interfaces types between those subsystems. The authors have described the actual situation of the maintenance operations cycle in specific to the subsystems.

Maintenance information system; the case company use the "TT- Underhåll" software as a computerised maintenance management system, consist of five modules; (1) Objects, (2) Failures, (3) Preventive (4) Storing, (5) Purchasing.

Maintenance preventive system, it is for the workstation is mainly related to the turning machine, where there are - according to machine manual - different levels of servicing the machine;

- Level A; daily and weekly service activities.
- Level B; service job after 2000 operating hours, like control the oil levels and changing the filter set in the pressure filter.
- Level C; service job after 4000 operating hours, like change the hydraulic oil, control the feeding axles.
- Level D; service job after 8000 operating hours. Like controlling all servo-motor in the machine.
- Level F; others maintenance like changing the hydraulic after 6 years.

All of these descriptions about the machine servicing have been taken from the machine manuals, also it inputs for the planned maintenance scheduling where the maintenance staff enter the planned period in the maintenance software to give them signal when the servicing time will come.

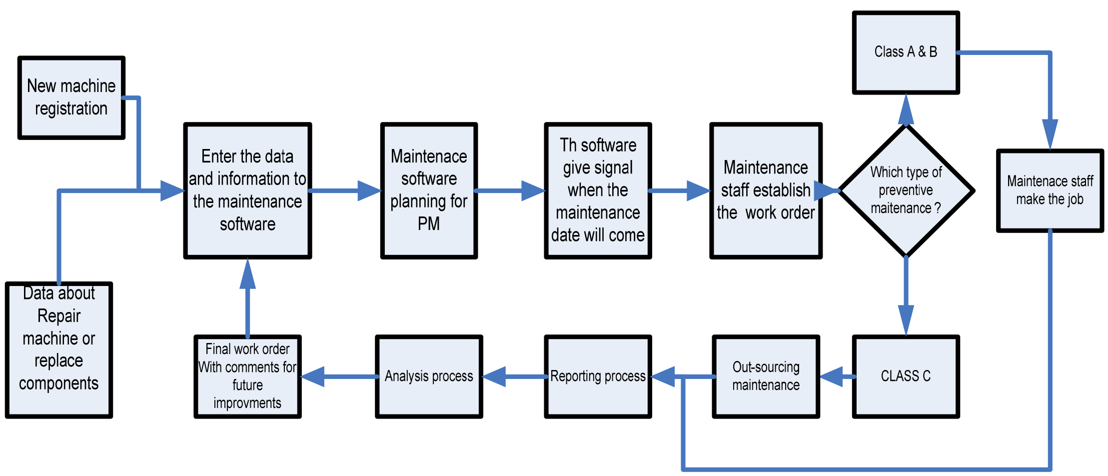


Figure (5.4), maintenance system flowchart

Maintenance corrective system; Describing the different maintenance types in form of flowcharts is a powerful way in order to define the basic activities which shape the whole process in addition to the resources, decisions and the loops of feedback and iterations loops. First of the all, there are three types of manpower who work within this flowchart; operator and production supervisor, maintenance staff, and out-sourcing maintenance staff. Mainly, they have two challenges; how to find the problem cause/s and how to solve it. Due to the weakness in the reporting process within this cycle, all of them should start extremely from the first stage, in other word; every staff should make their own procedures to fix the problem. If the out-sourcing maintenance is working, they generate a different work order which will not save in the company database.

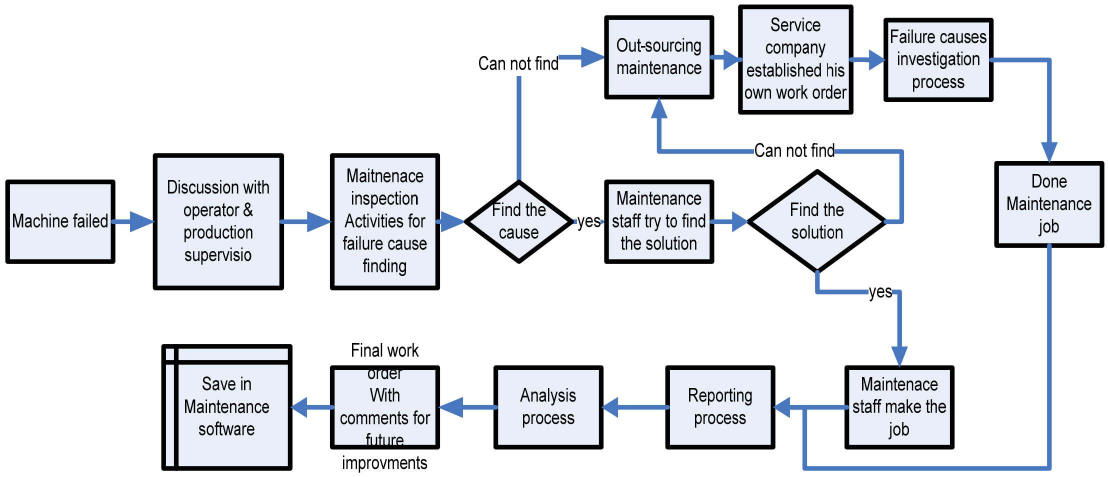


Figure (5.5), Corrective maintenance flowchart

Maintenance service & out-sourcing system; the observations about the out sourcing staff work are mainly consist of three part;

- The process of contact the best out sourcing company to do the maintenance job, and how the maintenance staff select the best out sourcing company, where it is according to the machine type and the knowledge and experiences of the out sourcing company, to get the most cost effective alternative.
- the way of performing the job; out sourcing companies have a special diagnosis tools and technologies, beside the well organized functional work like the checklist, failure histories, report as a way to describe the problem, define the followed procedure in order to solve it, and define the requirements(materials, tools, components, equipment, etc).
- The interface with the internal maintenance staff of the company; it has a one direction interfaces, it is means, there is no technical feedback about the problem, because they work without any sharing- may be in the beginning only- with the operators or maintenance staff. They only were reporting the costs of the whole activities.

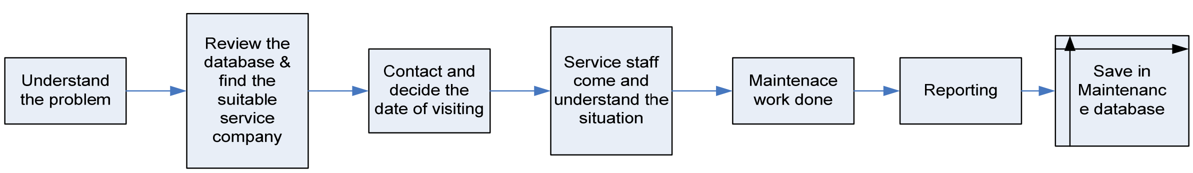


Figure (5.6), Out-sourcing maintenance flow chart

Instant Maintenance system; is the most important maintenance type in this case study, due to the frequencies and severities. According to the production supervisor and operators the most frequent problems of the workstation are solved by the instant maintenance actions, but the difficulties to perform those actions are due to the nature of this types that depend mainly on the machine histories and experiences. In other words it the feedback system but for the machine not like the quality control systems which concern about the product. So this type is based on how the workers document their experiences. For example, the operator know directly the solution if the cutting path is not straight that the pneumatic valve is the cause. Here the knowledge develops form the empiric into the theory in form of procedures. The figure (5.7) expresses the detail process of these maintenance type actions.

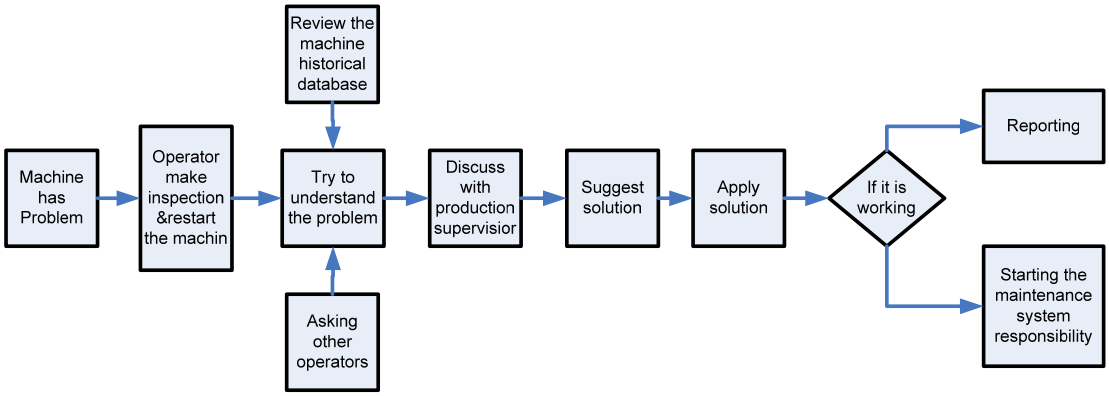


Figure (5.7), Instant maintenance flowchart

Follow- up system (see figure (5.8)); the main function of this subsystem is to control the manufacturing auxiliary requirements like the fixtures, machine different oil and the cutting tools. In addition to, control and do some technical and functional tasks; technical like inspection and machine measurements, functional like take care of the visual management task.

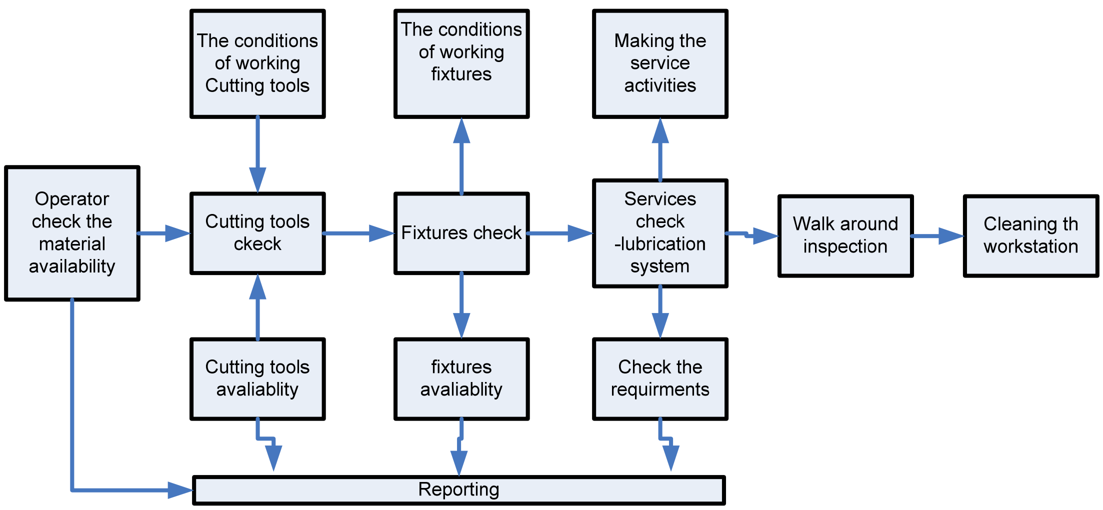


Figure (5.8), follow up system flowchart

Procedures; The authors describe the procedures of the maintenance operations in detail for the selected workstation, and started from the planning phase until the implementation phase. First of all, the maintenance operation of the selected workstation is depended on the technical stoppages and condition of the product (if there is some quality defects due to technical problems), that is called conditional maintenance operations, in same time according the service manual there is planned maintenance operation, actually, the first part of operations have a difficulties to schedule, plan and manage them, that due to the conditionality of occurrences.

5.2.3 Quality operations

Mainly, the quality operation is summarized as quality checking of the product, preparing the acceptable limits of the dimensions tolerances and surface finish levels, because there are many technical difficulties to get prise dimensions and accepted surface finish. Setting guidelines of planned checks, so there are different types of checks:

- Every working hour (done by operator),
- Every daily work (done by operator),
- Every daily work (done by quality department),

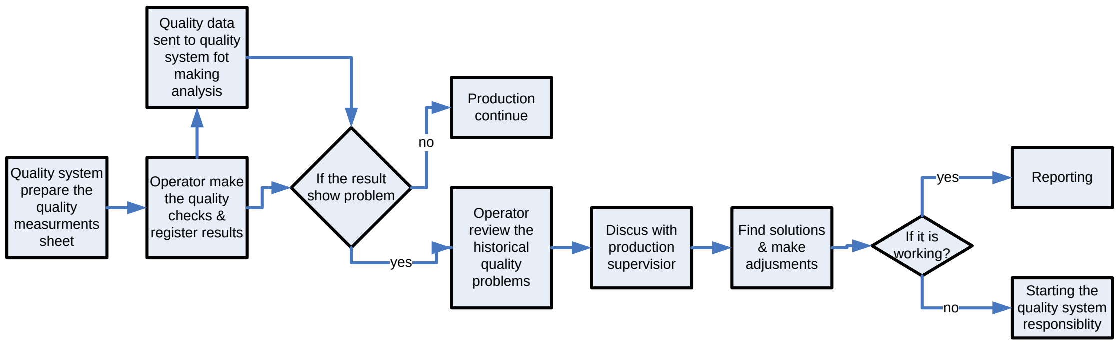


Figure (5.9), quality control flowchart

5.2.4 Employee competence

Generally, when we take about the employee within working area, we directly talk about the operator who is operating the machine who plays an essential role in any production process, and always he/she has specific function within this process. But according to our observations, the employee within the CNC workstation has different functions to do within his/her working time, it works as integrator, that means he/she has beside his/her operating job, he/she take care about the main aspects; loading the raw material, operating the operations program, modify some technical parameter for optimal processing operations, maintaining the processing condition before and during machine processing, checking the product quality characteristics such as some dimensions and surface finish, cleaning the machining module (it is apart of the workstation) and it difficult task to do it in proper way (the difficulties appear in cleaning the small chips) which cause in long term of time problem between machine parts and product surface finish problems. Also the operator is responsible to change the cutting tools based on the produced product surface finish.

The operator explain that he has other activities within his working time; direct productive (as mentioned), indirect productive such as working as partner of 5% with the production supervisor to write optimal program code and non-productive activities such as rests time.

5.3 Integrated working areas situation

Integrated workstation has internally strong to integrate different subsystems where the company develops a set of working principles to improving the integration process in order to improve the organization's performances.

The integration goals established according to the previous sub system goals ' maintain the operability at an acceptable quality, time, cost levels ' was appeared in terms of subsystems goals; production, maintenance, quality and employee (operator, production supervisor). It means that the production subsystem maintain the working method which it was used so the production department try to build a well-conceived action plan, that what is very much required in manufacturing firms is to integrate different subsystem in coherent manner. There are many working ideas that the production department applied it toward integrate the subsystems, but the detailed implementation plan is not available as standardized documentation. Thus, the authors try to fix all those integration requirements from different perspectives and by using different data collection (qualitative and quantitative) techniques such as interviews with the responsible of each subsystem and observations of the real studied situation. The figure (5.10) shows the production process for m the receiving the material until the finish goods, where it explain also the role of the three subsystems within this workstation. The main relationship between the production and maintenance systems according to the failure or stoppages of the machine, while the relationship between the quality, maintenance and production system is based on the product defects (dimensions and surface finish)

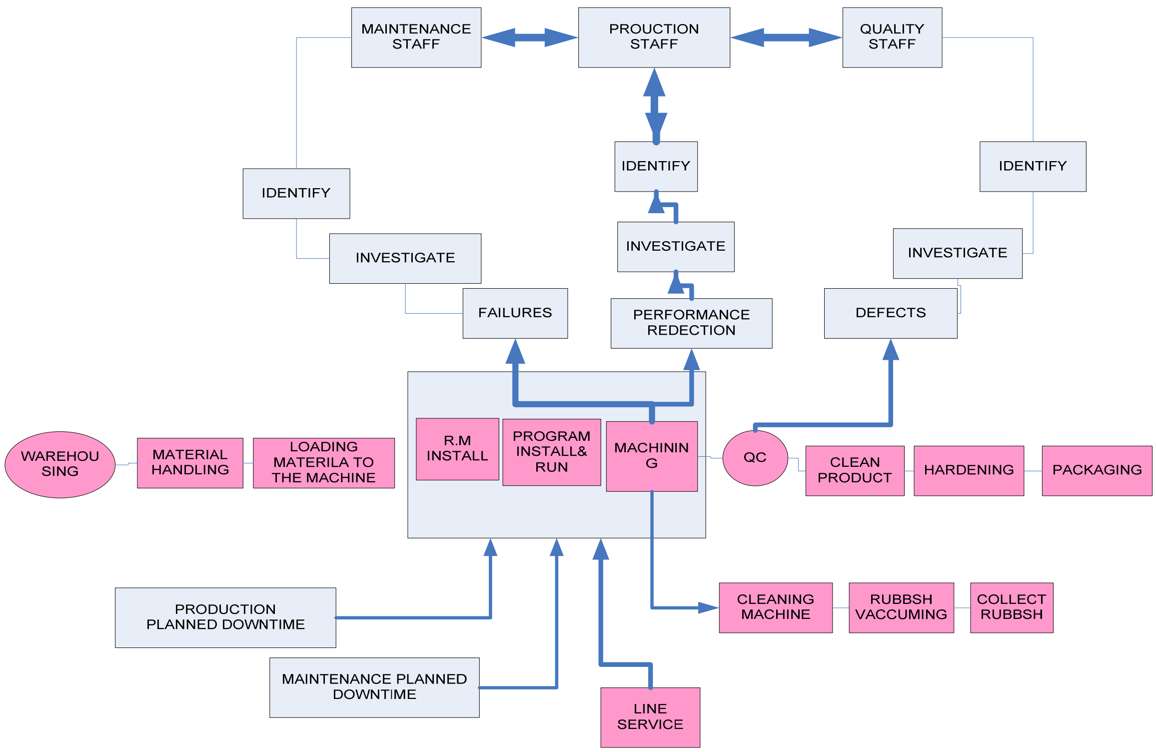


Figure (5.10), working area interfaces

The workers and subsystems staff was explained for us the common systems what they use to perform the functions and activities, the table (5.1) describe the systems, which are play, the most important role in the relation within the selected workstation subsystems.

Relation and interfaces network; the integrated maintenance systems have different relations with the working areas, these types of relations could be system/s to system/s relations like the relation between the maintenance planning system with the production planning system to make a common working plan and schedule which take in consider the planned downtimes, or could be function/s to function/s like when the maintenance staff work to solving the shutdown problem function, they should interface with the other functions from other systems; operator, production supervisor, CNC program, machine history records, quality control sheet, etc. integration situation is a network of interfaces within the following main systems and subsystems inside the working area.

Table (5.1), working area systems and sub-systems

Main systems	Sub-Systems
Production	Programming system
	Requirement planning system
	Machine installation system
Operations	Operator jobs system: Machine operation Walk around inspection Attachment & removal of materials Adjustment Machining system Measurements
Maintenance	Maintenance planning
	Maintenance preventive system
	Maintenance corrective system
	Maintenance service & out-sourcing system
	Instant Maintenance system
Quality	Quality control system
Follow up	Cleaning Straightening Spot checks

5.4 Data types, sources and collection processes

5.4.1 General data types;

In order to collects the real qualitative and quantitative data, which describe the real situation of this integrated manufacturing process, the author as mentioned in the methodology chapter that systematic observations and structured interviews are the used methodological techniques. So the authors made forms to collect the data according to each phase of our case study phases.

Table (5.2), basic data types, sources and collection methods

Sub system type	Specific area	Data, information; descriptions	the used collection method type
Operator	Organization	- Functions (generated by prod.dept) - Responsibilities (generated by prod.dept)	
	Process	- installation(generated by prod.dept) - procedures(generated by prod.dept)	- documents
	Data	- Use Job flow card (generated by prod.dept)	
	control	- shifts schedule (generated by prod.dept)	
Production	Organization	- goals & strategies - subsystems descriptions - responsibilities (generated by prod.dept)	- interviews - descriptive notes - documents
	Process	- policies (generated by prod.dept) - inputs and resources - preparation operations (generated by prod.dept) - production sequence / job instruction (generated by prod.dept)	- descriptive notes - interviews - instructions - instruction -

	Data	- generate Job flow card - analysis the data (use) "SYS produktion" software	
	control	- production time planned production schedule sheet	
Maintenance	Process	- servicing plan - Cutting tools operating time plan - flow modifying plan (generate by prod.dept)	- machine manual
	Data	- input data (generate) - analysis data (use) "TT- Underhåll" software	- machine manual
	control	Economical control - Job bill (generate by out-sourcing staff).	Job and purchasing parts Bills
Quality	Organization	- certificates and standards	
	Data	- input data (generate) - analysis data (use)	- Quality Control sheet - product drawings
	control	- quality distributions diagrams	

5.4.2 detailed data types and resources

In order to clearly understanding the studied situation based on different categories like organization, process, information, and controlling aspects. There are many different methods and techniques, where the author tries to select the most suitable methods which satisfy the problem formulation purpose in addition to fit with the primary empirical problem description which had been described in the previous headlines. The table (5.3) show the validity of the selection process by explains the main reasons of selection.

Table (5.3), design data collection methods

Step name	Purpose
Auditing	• Define the **structure** and the situation of the working maintenance subsystems; • Define the static situation of the integrated working area. • Define the missing parts, weaknesses of the existing situation
Performance measuring	• describe the actual implementation of the workstation subsystems plan • Define the **dynamic** situation of the integrated working area. • Define the effectiveness of the actual working schedule.
Modelling	• Define the actual workstation processes; • Define the process elements within the systems; data collection and analysis • Define the flow of the knowledge within the systems. • Describe the databases and soft wares; functions, inputs, and outputs
Process FMECA	Define the actual interfaces and problems; inside the workstation subsystems and within workstation process

Chapter Six

6. Analysis of the case study

The specific objective of this chapter is
To deal deeply with the case study in order to treats the empirical findings from the previous chapter, where the authors defined and collected part of the required data.
Here the structured data was analyzed which direct fit with the selected analysis methods and techniques.

The organization of this chapter is as follows:

- Outline of the analysis techniques
- Analysis of systems; descriptions, structured techniques
- Conceptual Design an integrated system.

Analysis; from Empirical findings (Eggs) into results (Honey)

6.1 Phase 1: Define the problem; situation and conditions
Mainly, the purpose of this phase is to summarise the overall systems descriptions in order to have a well-defined process situation. The second step is to summaries the outputs of the detailed data collection techniques; maintenance management auditing, and production process modelling. Figure (6.1) show the road of the analysis work for the defining step until defining the improvement requirements.

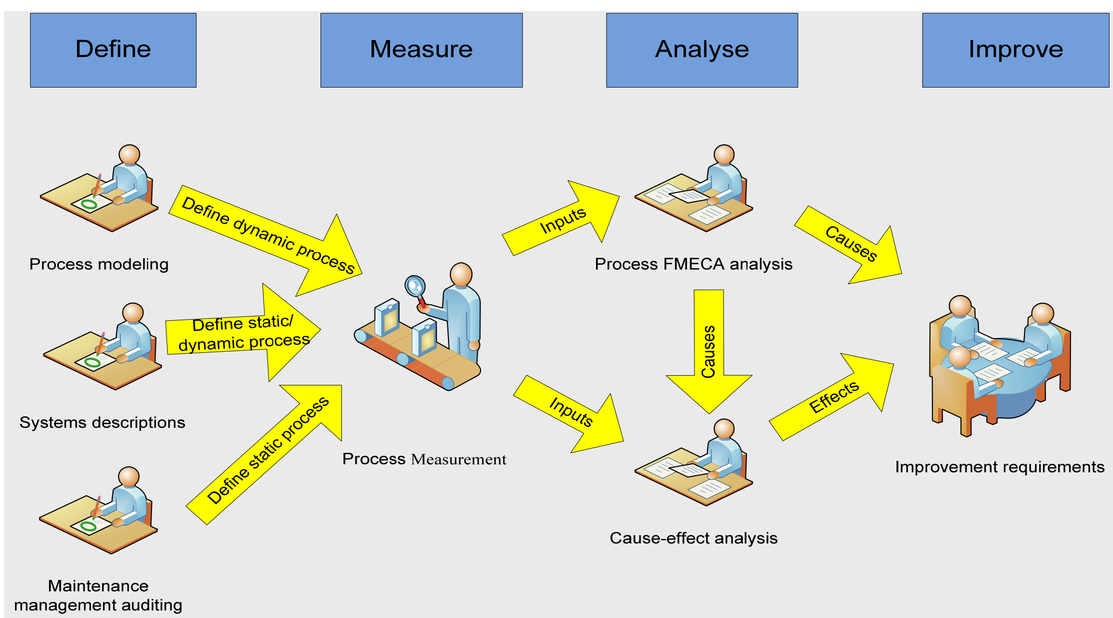


Figure (6.1), form problem defining until improvement requirements

6.1.1 Analysis of manufacturing systems descriptions.

Production operations

There are some observations on the description of the operating manufacturing system as shown in the following table (6.1). Based on the table (6.1), there are some operations affecting the maintenance operations in direct and indirect way. Direct operations like the planning and scheduling and indirect operation which the most important part for the integrator who will integrate the system, these indirect operations like installation, set up, and CNC program activities. In general, figure (6.2) summarise the operations within the manufacturing process.

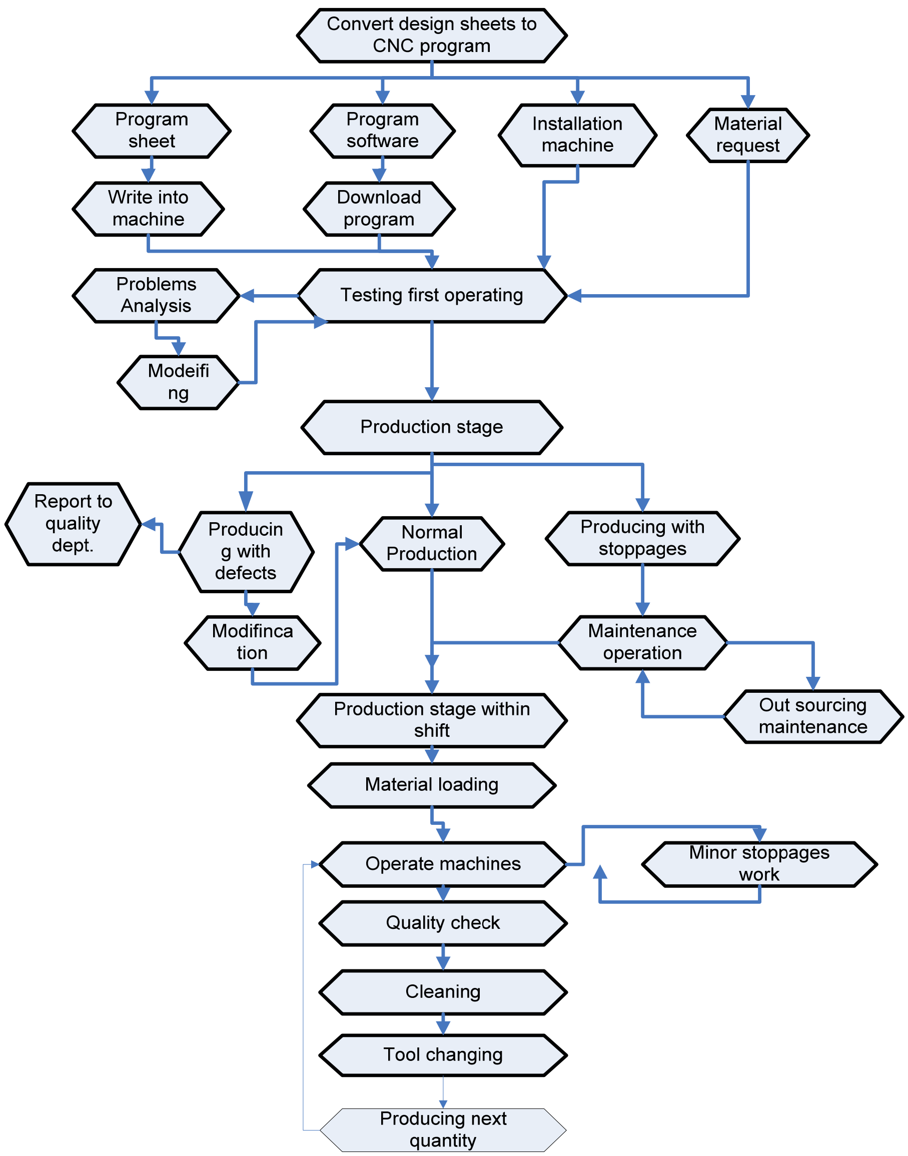


Figure (6.2), production operations from design to finish products

The authors describe the operation in form of problem causes and effects to be effective for the next step of analysis. Most of production staff descriptions express the problem in generation of standard form within manufacturing process in addition to miss-use of these forms if they generate some of them. For example, the first type like the operator does the installations without a standard installation worksheet while he has a standard sheet for problems registration which he miss-use this worksheet due to some know-how problems. Thus, any system which is responsible to generate any worksheet should be responsible to train or teach and follow up the using of what it generates.

Table (6.1), production operations cause-effect analysis

Operation	Problems and effects	Causes and suggestion
Preparing CNC program	- maintenance worker need time to understand the program (it is a coders without description)	Program description in each of codes line with relation to the movement axis, tools.
Planning the resources and scheduling	- naïve planning approach	No cooperation with maintenance and quality operations
Installation	The work done without real documented procedures and feedback document	There is no installation sheet
Set up operations	The work done without real documented procedures and feedback document	These is no set up operation sheet
Controlling, Monitoring, maintaining	The documentation activities are specifically for the product not for process No checklists for controlling	Missing sheet for operations registration and checklists for operation control

Maintenance operations

The observation on maintenance department and their activities will divide to two parts: general policy, subsystems and their execution tactics. The general policy of the selected CNC machine and even the other CNC machines is a limited preventive and outsourcing corrective maintenance policy, in easier way, the company plan for preventive maintenance only based on the manufacturer manual and it clearly that no planning based on operator or maintenance staff experiences and the reason behind this situation is due to ineffective feedback actions because if there is a corrective maintenance it will be done by outsourcing staff without house maintenance supervision in order to learn or document the work. This used policy reflects the integration situation between the maintenance subsystems. The second point of the observations is related to the subsystems and their flowcharts as follows:

1) Preventive maintenance:
   - If you analyse the job levels (A and B) of this maintenance type, it’s actually should be related to operators.
   - The planned job as documented in the machine manual are not same as the actual job ,for further analysis of this situation, authors have been used cause-effect analysis technique.
2) Corrective maintenance:
   - The complicated job here is how to manage the three types of manpower, and how they interface each other. The one of integration weakness within this subsystem is the reporting of the job where none of them write anything about his work, they only use the oral communication, in other words, the experience transfer method is not effective.

- Most of machine failures need in addition to maintenance work, it needs diagnosis and engineering efforts in order to identify and solve the problems.
- Most of the maintenance worker difficulties are in the failure/faulty finding, because if the maintenance workers have ability and knowledge to find the failure causes it will be less costly and will be more cost –effective integrator tool than the outsourcing one. Figure (6.2) express the situation of maintenance work in a selected day. Form 8:00 until 13:00 o'clock, the operator, production supervisor and house-maintenance workers try to identify the failure reasons in order to repair the machine and take it working again. Also, the out-sourcing maintenance take a time in order to identify the failure but in a systematic way which the company miss it. This systematic way can save money through saving the waste time for all of workers and make the process role incrementally not each of them start again from the zero. In addition to that, if the house maintenance worker can identify the failure reasons, they can repair it or replace the failed component(s), and in this case, the company will save the outsourcing costs.

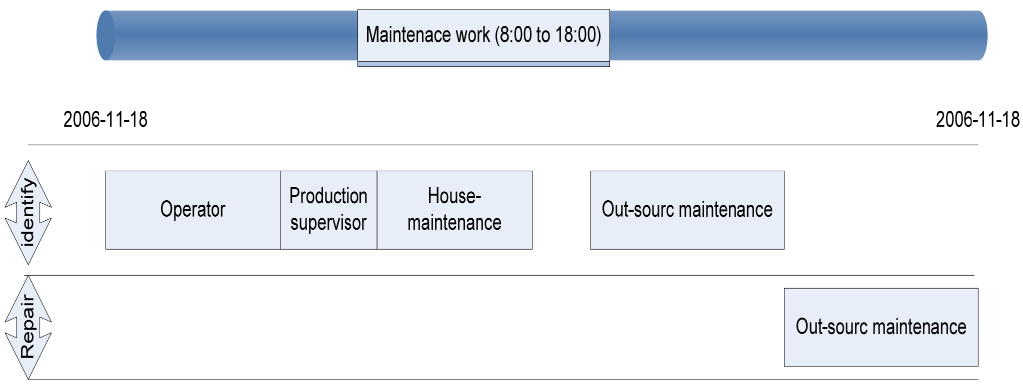


Figure (6.3), Actual time periods of maintenance work

3) Maintenance service and out-sourcing:
   - The process of company knowledge transfer, here most of corrective maintenance experiences are transfer out side the company without any reporting the technical issues. The final report of the out-sourcing worker it is a report of costs, and problem title without problem description in order to use it for future work.
   - Out sourcing maintenance are well organized team, follow high managing and controlling procedures
   - The out-sourcing company has own schedule in order to plan and schedule his job in other companies, because of that the wait time is one of the outsourcing problems.
4) Instant maintenance:
   - Most of the daily and weekly maintenance work is within this type.
   - Instant maintenance is highly depending on the histories of the machine modification and failures in addition to previous maintenance experiences.
   - Always the reporting come like a final step in the maintenance process where it should be also done between the process steps in order to report specially the details before forget.
5) Follow up:
   - Control the manufacturing auxiliary requirements and inspection activities which is directly interfacing with production planning system, production purchasing system, maintenance planning system

- This system is the basement for the TPM implementation.

The third point of the observations is the maintenance management software "TT- Underhåll", actually, it work like a database more than as analysis software based on the following analysis table (6.2).

Table (6.2), Maintenance management software analysis

Module	Function	Problems	Reasons
Objects (machines)	To register (archive) the information about machine	Worker do not register all data	- worker don't know what to register
Corrective Failures	To register the machine failures	Difficulties to write the failure description	Worker don't know how to describe
Preventive schedule	- To display the weekly schedule or work - To generate work order	It is weekly schedule not daily or hourly - incomplete work order	Due to Software abilities
Storing	Show the stored components	_	_
Purchasing	Show all information for order new component	_	_
suppliers	Show all suppliers or service company information	_	_

Quality operations

Description of the quality system includes the system's functions and levels, our observation on this description that quality control system do not has a specific schedule for the data collection and analysis in order the reduce the interface with the operations activities. These interfaces will be discussed in the process measuring technique.

Employee competence

The most important and first integration tool is the operator who integrates or work between the interfaces of the working systems like production, quality, and material stores, while the weakness which happen in some of activities it is based on operator knowledge and the hidden responsible of the weakness causes is the system which prepare for the operator the detailed procedure "what to do" in addition to the integrator system – which is missing in most of operations- who prepare for the operator "what and when to do" .

Integration operations

The interview which have been done by the authors are not enough to define the real situation of the integrated workstation, and the relationship is not simple as what was expressed in the description, because inside this relation there many of interfaces which increase the waste of time and cost of work accomplishment such as lack of communication e.g. the production supervisor take using planning or programming terms like some code about x-axle displacement while the maintenance worker take using technical term like the mechanism of this displacement. Thus, one of them should understand the other in order to get the benefits of the discussions.

Data types and resources

The analysis of the data types and resources through the selected process are based on three categories; data preparation stage (stage of establishing standard data collection forms), data collection (stage of fulfilling the prepared forms), and data analysis stage (stage of processing the collected data). The following analysis table (6.3) shows the existing part of data flow system though the process steps in order to highlight the missing or weak parts.

Table (6.3), Process data flow analysis

Activity	Data Preparation	Data collection	Data analysis	Effects
Drawing of CAD	●	●	●	Maintenance worker take time to understand the product description
Manufacturing process data	●	●	●	Maintenance worker take time to understand the operations description
Manufacturing equipment data	○	○	○	Maintenance worker take time to understand the equipment description
CNC program	○	●	●	Difficulties to understand
Quality control	○	○	○	Define the relation between the quality measurements and the used equipment, program and tools.
Production schedule	○	○	●	Miss the ability to analysis the deviations in order to develop real schedule.
Installation	●	●	●	The production staff can not define the wastes within installation operations in order to eliminate these wastes.
Set up &Testing operation	●	●	●	The production staff can not define the wastes within setup operations in order to eliminate these wastes.
Follow up operations	●	●	●	Difficulties to control follow up operations, because there are stoppages due to non- controlled operations
Corrective maintenance	○	○	●	Reduce the ability to maintain reoccurrence failures
Preventive maintenance	○	○	●	Reduce the ability to plan a real schedule for maintenance operation in order to fit with production's operations.
Instant maintenance	●	●	●	Reduce the ability to eliminate the minor stoppages or improve the operations
explanation:	○ Used	● Missed		

Description of data flow analysis: table (6.3) consists of three parts; activities, actual situation of data flow, and the effects of the missing or incomplete parts with the data flow processes. The reader can observe some of critical points such as:

- The effects of missing data preparation step; it is the most important step in the data flow which is like the basement for the other following steps. The missing of this step come from lack of knowledge about the benefit of prepares a system for data collection and analysis in purpose of defines the required improvement action.

- The effects of missing data collection step; in order to collect a data, the collector need a standard form to collect, sometime there is a prepared form but the collector not use it, the reasons behind this observation are due to some missing parts of the whole collection process such as collection schedule and controls, for example, the worker may forget to collect in some situation if there is no fixed schedule to reminder him. Also, some the prepared forms for data collection are not used-friendly, for example, the prepare data form of problem registration is a sheet include a space for problem description, while most of worker can not describe the problem, they like a form of selective description of questions because it need shorter time and ease to fulfil it.
- The effects of missing data analysis step; the basic observation of this category is "the operator said: why I should collect data while we do not analyse it?", this statement proof for us that in order to motivate the data collection step the system should has data analysis tool , and this tools should fit the situation.

6.1.2 Analysis of Maintenance management auditing.

Purpose; Kaiser.H (author of maintenance management auditing book) had defined the general purpose as "the purpose of a maintenance management audit is to ensure that management is carrying out its mission, meeting its goals and objectives, following proper procedures, and managing recourses effectively and efficiently. While our purpose is to define the key element of the maintenance management systems and their situations in order to explore the relationships between the subsystems interfaces and the overall effectiveness measure and the integrity with other operational systems.
Applied description; the review process outlined in this thesis is designed to evaluate the effectiveness of the existing maintenance management program, by assessing each of the key elements. The effectiveness analysis procedure includes a numerical rating system to identify and measure each of the key elements. Note that some of the review process depending on the size of the facility, the schedule, and the resources available for completing the process, because the total rating number for all the key elements is 960 points, while the author identify and measure for 523 points because of the size of the facility in addition to requiring assistance of consultant and outside consultant. Detailed process is shown in appendix 5.
Results; the result as shown in the table (6.4) is 184 of 523 points, in other scale, it is 34.6 %. Kaiser.H took 25% increments of the effectiveness scale and assigned breakdown points for the ratings of poor, fair, good, and excellent, according to this scale our case study are in the fair situation.
there are some item should develop inside the auditing process such as out sourcing system and its effectiveness, detailed maintenance tactics like reliability based replacement, condition monitoring. The auditing process deals with the structure not with the process, it means, how to audit the processes effectiveness.

Table (6.4), effectiveness rating summary

Item action	No.	Rating	Target	Percentage %100
organization	1	43	124	34.68
Workload identification	2	54	80	67.5
Work planning	3	24	116	20.69
Work accomplishment	4	27	108	25
Appraisal	5	36	104	34.62
Total		184	523	34.6

This stage is especially for the integration aspects in order to define, firstly, the relations between key elements of maintenance management program and how they affect each other, secondly, to define the interfaces (effects) with the other operational system of the facility and how they affect them. The figure (6.4) represents the down-up-down shape of the key elements effectiveness and the author analysed and classified the reasons behind the high and low rating into two categories; missing items and in-complete items. The following point will discuss the previous observations:

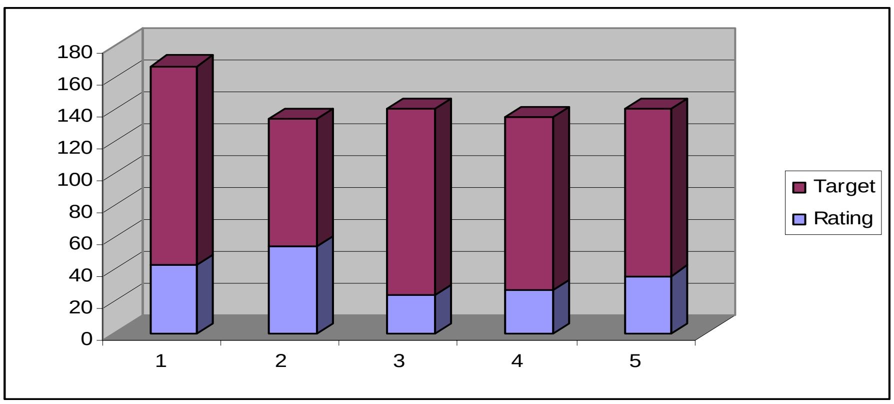


Figure (6.4), key elements; rating and target

- Missing and incomplete items; the first key elements is an organization and its functions, where there is a weakness in the following functions; non-documented organizational structure, policies, rules, and services which affect by lowering 45% of the total effectiveness process in this key element. The second key element is the workload identification which is the up movement in the rating figure but there is a documentation weakness in the work request procedure which affect by lowering 20% of the total rating. The third key is the work planning which the lowest score in this auditing process, there is totally missing part like the alternatives and improvement work (affect by 17%), and mostly missing part like establishing effective priority criteria, good work classification system, and incomplete work order preparation, this in completion are affect the total rating score by 62% (for example if you have 30 point target and your actual score is 10 and you have miss 20 points, so it means 20/30 equal 66.66% the missing effect percentage). The fourth key is the work accomplishment which is the second lowest score due to the effect (75%) of missing craft and material availability system and incomplete scheduling and planning procedures, training program, and supervisory operations especially with the out-sourcing maintenance staff. Finally, appraisal systems where the score shows some company interests in this filed through the new computerized maintenance management system ,but the effective problems (65.4%) locates between the missing performance and productivity measurement systems and incomplete (only the first registration without updating the information) equipment history records system. Table (6.5) represent the effects of missing and in-complete items firstly on the maintenance management program due to the incremental and sequence characteristics any program and secondly on the other operational systems like production and quality.

Table (6.5), Effects of missing and incomplete items

Missing and incomplete items	Effects within maintenance management program	Effects with other systems
Non-documented organization structure	Non effective work planning	Weakness in the responsibility control
Non-documented rules, and services	Weakness in the decisions making process for work planning and scheduling and accomplishment system	Weakness in the communication
work request procedure weakness	Weakness in controlling the requests which important for work planning and scheduling	Affect the production work planning and scheduling system
Missing the alternatives and improvement work	It affect all the key elements of the program	It effect the production equipment availability and quality assurance system
effective priority criteria	It affect the work execution	It affect the supporting function of maintenance to the operations system when they do non prior work like maintain old machine while the CNC machine wait also the maintenance work.
work classification system weakness	It affect the work execution	It affect the supporting function of maintenance to the operations system
incomplete work order preparation	- It affect the work execution (maintainability) and maintenance schedule - affect the improvement system by missing the detailed description and workload identification system	It increases the unavailable time for production, which affect the production schedule
missing craft and material availability system	It affect the work execution (supportability) and maintenance schedule	It increases the unavailable time for production, which affect the production schedule
incomplete scheduling and planning procedures	It affect the scheduling performance It affect the out sourcing schedules	It affects the production schedule and operator management specially when there is out sourcing service work it means no production.
training program weakness	It affects the work execution	It affects the work communication with other operator or managers such as understanding the problem and

		deal with the CNC machine alone
supervisory operations weakness	- It affects the productivity of the work for the out-sourcing work. - loss the know-how of work execution which is the next execution work	It affect the unavailable time for the production It loss the know-how of improvement action for stoppage prevention
performance and productivity measurement systems	It affect the improvement action of the program by knowing the actual position of this program and weak points	It affect the improvement decisions actions
Incomplete equipment history records system	It affect the saving current data process It affect the structured review of the program It miss the analyzed routine practice	It affect the stoppage solving situation by knowing the previous stoppages and improving experience of the machine

- Discussion; there are some item within the maintenance management program while it ruled and controlled by the production management staff such as budget requirements for maintenance and repair and the budget execution plan.

6.1.3 Analysis of Manufacturing Process modelling

Purpose; the authors aimed by applying this modelling method to describe hoe the functions allocations in the real operations model which enable them to be put in context with the resources needed to deliver it and the environment in which it operates.
Applied description; the ARIS modelling outputs is to have a representation of the complex process flows in form of functions, events and rules, in relation to the systems, databases, knowledge, information carriers, resources, objectives and measures. For the integration process aspect the authors try to define the detailed elements and their interfaces within the real process by describing the ownerships, boundaries, interfaces , documenting flow of the work, and describing the controls points and measurements points.
Results; table (6.6) represent the quantitative information about manufacturing process elements in order to understand the volume of this process. Applications systems are production software which use to get information about production quantity and schedule, maintenance management software effective for information registration and simple registration for the preventive maintenance based on the manufacturer manual, the most important application system is the machine computer which perform many task like download the NC program, installation operations, adjustment operations and display the working program. There are four Databases; production database, material stores, maintenance and quality databases and one external database for the outsourcing staff. There are four types of knowledge items within the process in form of operating procedures: running procedure, instant maintenance procedures, diagnosis checklist and out sourcing diagnosis checklist. The processes have ten information carriers and interface eleven times to make the decisions. The only production measure is calculate the produced units every shift and there also quality measure by calculate the detect units. Resources of this process consist of one CNC machine with three different equipment kits: for operator, maintenance staff, and outsourcing maintenance staff and two outsourcing company; one for servicing the machine and the other is the manufacturer.

Table (6.6), Quantitative element analysis of process modelling

Category type	Description	No.
Application Systems	software	3
databases	Functional and technical databases	5
Knowledge	Operating procedures	4
Information carriers	File, document, card, telephone, fax, folder, etc.	10
Controls and decisions	Operating control, rules	11
Measures	Production rate, defect rate	2
Recourses	Machine, equipment, apparatus, Outsourcing	1 machine, 3 equipment kits, 1 apparatus, 2 outsourcing company

The second category of the analysis is related to the type of the relationship between process elements and the following table (6.7) the real relationships types within this manufacturing process. Also, it shows how much the system use the elements and in which way they use these elements, these relation explain the interfacing between processes and subsystems, for example, if the relation "is required for" use with the "run the machine" step ,to relate the knowledge sheet "running procedure" to the step.

Table (6.7), relationship analysis of process model

Element type	Relationship type	No.
Organization	Executes	14
	Contributes to	1
	Must be informed about	3
	Is technically responsible for	4
Application system	Uses	3
	Subsumes	0
	Is represented by	1
	Can support	0
Databases	Is input for	3
	Has output of	1
	Changes/updated	4
Knowledge	Is required for	4
	Creates	3
	Has knowledge of	2
	Creates outputs to	0
Information carriers	Has output of	3
	Provides inputs for	7
	Lies on	3
Products	Produces	0
Measures	Supports	1
Resources	Is consumed by	0
	Is used by	4
	Is operating resource of	1
	Is defined	0

Further more, the authors show a comprehensive analysis for each step of the selected process – based on ARIS flow charts- in purpose of defining the missing and incomplete items and relations for each step which clearly represented by appendix (6.1). The observations on the mentioned appendix are like follows:

- Some of the application systems are not available for all workers.
- Most of databases are used without incremental updating.
- Most of the knowledge items are not documented, it such an experience owned by some workers.
- Most of the critical steps are not supported by standard information carriers which use to carry and document the actual work observations in order to use it in the improvement process for this specific step.
- The unique process measurement is for quality aspects, while the production work and all the maintenance work was not supported by measuring operations.
- There are two products of this process one of them the finished goods and the other is quality statistics, the first one is clear, but the second one express the hidden product of any process which is the knowledge, according to that, the maintenance work should generate some levels of knowledge in order to prevent or rapid repair for the future reoccurrences.

Finally, the total analysis of the modelling techniques are summarised in the table (6.8), which categorised into different aspect based on the previous analysis.

Table (6.8), Effects and causes of weakness elements and relations

Problem Causes	Effects	Suggestions
Missing relation (Gaps)	No transformation of information, decisions, and know ledges,	Establish the missing relation between working subsystems externally and internally
Missing element (Gaps)	No processing actions for the resources	Support each step within the process by the missing element
Interaction (Non-clear relation)	Improper (effective but not efficient) transformation of information, decisions, and know ledges,	• Set new targets • Redesign life cycle processes of information management
Overlapping (Redundancy)	improper processing actions for the resources	• Establish systematic work procedures • Define responsibility zones chart (chart which define responsibility between workers)

6.1.4 Analysis of measuring phase.

Purpose; the measurement method is to define the dynamic situation within the manufacturing process using the observations , and it give the system analyser more knowledge about practical operations in addition to planned pictures of operations.

Applied Description; the first look on the observation table show the reader the difficulties of collection this observed data, where the authors have been observed many times in different shifts in order to increase the validity of the collection process, finally, authors choose the worst-case of the collected data, in other words, they have been selected the worst shift (high stoppages and technical problems) in purpose of showing the real situation and express the integrity of the operational systems and how they affect each other, in addition to above, to calculate the overall process efficiency for this shift. The observed data show different types of stoppages: production stoppages, maintenance stoppages and quality stoppages. The length of the collection process is approximately 450 minutes.

Table (6.9), working time results

Items	Min	%
Total time	450	100
Working time of the 1st machine	300	66.67
Working time of the 2nd machine	144	32

While the calculation of overall process effectiveness will not be valid based on some observations collected and worst case selection, the most important point for the integration aspects is how to measure in order to define a hidden waste within the selected process. In the selected case -table (6.9) - it represents the availability of two machines which is not high, but the reader should remember that it is for one day and the purpose of selection is to focus a light spot on the all probable waste types even thought which are negligible in order to have a robust improved system.

6.1.5 Analysis of Process FMECA.

Purpose; this structured approach to identify, estimate, prioritize, and evaluate risk of possible failures at each stage of the process.
Applied Description; it begins with identifying each step of the process and listing the potential failure modes, potential causes, and effects of each failure. A risk priority number (RPN) is calculated for each failure mode. It is an index used to measure the rank importance of the steps listed in FMECA chart. These conditions include the probability that the failure takes place (occurrence), the damage resulting from the failure (severity), and probability of detecting the failure (detection).
Results; the authors select the high RPN steps as a target for improvement process. And in following table the authors suggested a recommended action to eliminate the failure condition by assigning a responsible person or department to determine the improvement requirements.

Table (6.10), FMECA analysis

RPN groups	Step(s)	Cause(s)	Recommended action(s)
A (150-121)	Register problems	No systematic and user-friendly system	Systemise the problem registration
B (120-73)	Take decision	Unclear decision making process and missing some inputs	Define clearly thee decision making process and its inputs
	Installation operations	No standard operating procedures	Establish a standard operating sheet
C (72-50)	Production Planning	Weak scheduling system	Integrate the maintenance schedule into production schedule
	Shift changing	Weak information transfer process between shifts operator	Systemise the information transfer process between workers
	Quality Control	Missing to fit a QC schedule within operation schedule	Integrate the quality control operations into production schedule
D (48-1)	Not important for analysis		

6.2 Phase 2: extracting requirements

There are two sources for the improvement requirements; the first one is the derived requirements that type is based on the structured techniques and second one is the originating requirements that type is based on stakeholders needs. The analysis was explained for us that derived requirements are related directly to the system, sub-systems, and components requirements in order to translate the originating requirements into engineering terminology. The following step is organizational steps in order to collect all the requirements that have been derived form the empirical findings. Table (6.11 – appendix 6.2) show this step in a proper way. The derived requirements were written in order to represent the features of the new solutions for the studied problem.

Based on the previous techniques that defining the studied situation, the stakeholders are changes from techniques to another, in order to collect most required needs in order to improve form their point of views, beside the systems integrator who try to collect the entire requirement in order to constructs or re-design a new integrated situation. Figure (6.5) expresses the system stakeholders based on the life cycle processes that has a holistic view of the system from the development stage until the updating stage through different stages, one of the most important of these stages is the operation stage and its requirement because most the real problems appear in this stage and it will be less costly if the system developer take the requirements within his consideration of development stage.

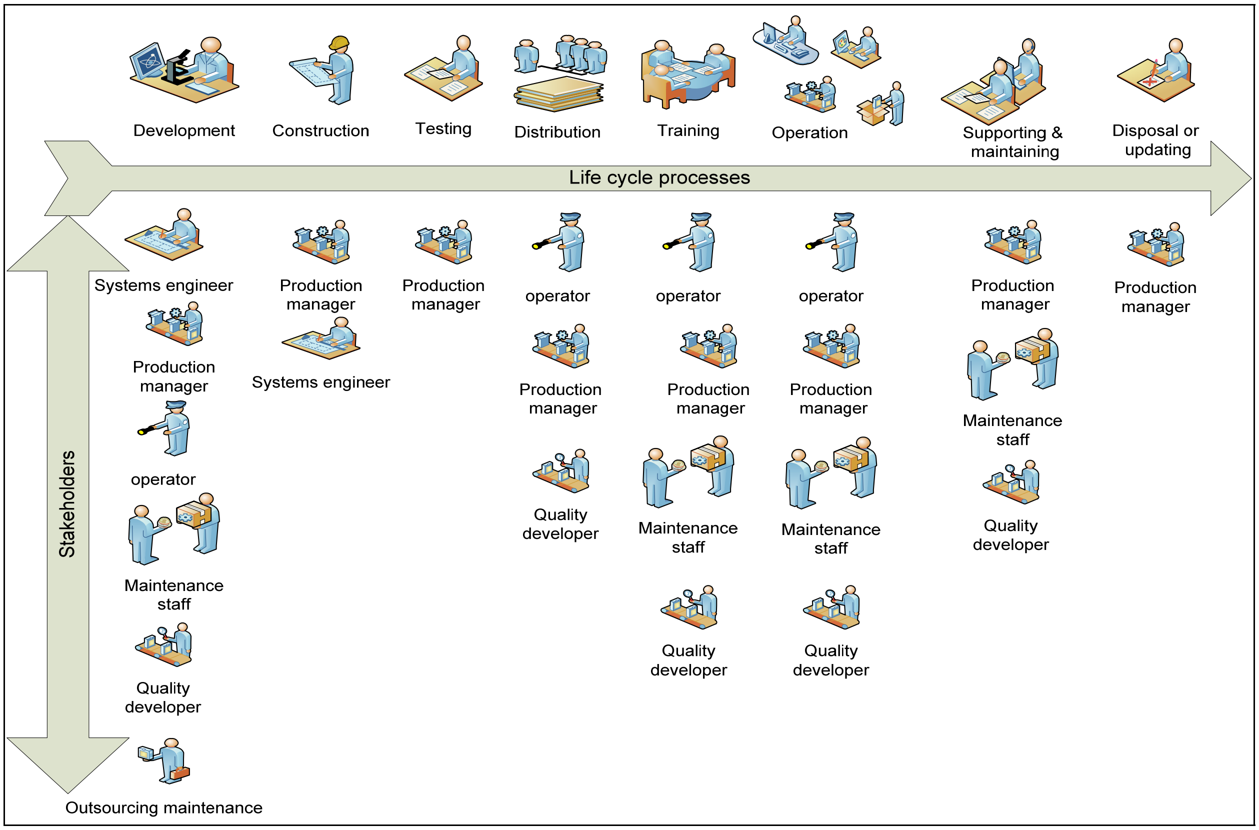


Figure (6.5), life cycle processes and stakeholders

Most of the originating requirements were indirectly collected within the systems descriptions, while here the authors have been classified them in clear table (6.12 - appendix 6.2) based on the concept of life cycle processes and stakeholders. The extracted requirements have been extracted based on appendix (6.2) which includes 49 collected and derived requirements. Table (6.13)

Table (6.13), Traceability check for extracting requirements

Original requirements (appendix 6.2)	Extracted requirement number	Statement
2,7,14,20,46,	REQ 1	the system shall identify the required knowledge, procedures, and information for all operations activities
32,33,38,44,45,46,	REQ 2	the system shall able to plan a real production plan with supportive maintenance plan
1,9,10,12,31,44,	REQ 3	the system shall be able to schedule operations (producing, maintaining, quality controlling) activities
13,17,21,30,36,37, 40,43,44,47,49	REQ 4	the system shall be able to execute the value-added operations activities and transactions
4,6,15,16,18,27,35,48	REQ 5	the system shall be able to control the organizational structure , process and data for the operations activities
3,8,19,28,29,35,42	REQ 6	the system shall be able to analysis and develop the required knowledge, and evaluations information for all operations activities
5,11,22,23,24,25 ,26,34,39,41,42,	REQ 7	the system shall be continuously improve the weak points within the operations activities

6.3 Phase 3: Define the system & its boundary

6.3.1 Conceptual solutions generation process

Based on the improvement requirements there are such of many solutions in order to eliminate or reduce the effect of operational problems within manufacturing companies. Let us to understand the descriptions of the generated conceptual solutions.

Concept 1: based on requirements number (1, 2, 3, 4, 5, 6, and 7) the generated concept is to design Common management system: planning, scheduling, identification, execution, controlling, computerized systems and continuous improved systems. The conceptual solution is based on integration theory- which have been discussed it in the literature review chapter- in purpose of constructs a integrated system ,it means, a robust basement for all of working systems and be able to interface smoothly with new technological changes. The interesting feature of the integrated system is self –organized with close loop feedback system in order to give any system the ability to improve him. The solution deals particularly with the external interfaces of the working system such as production, maintenance (house and out-source) and quality based on the requirement which mentioned in the first line.

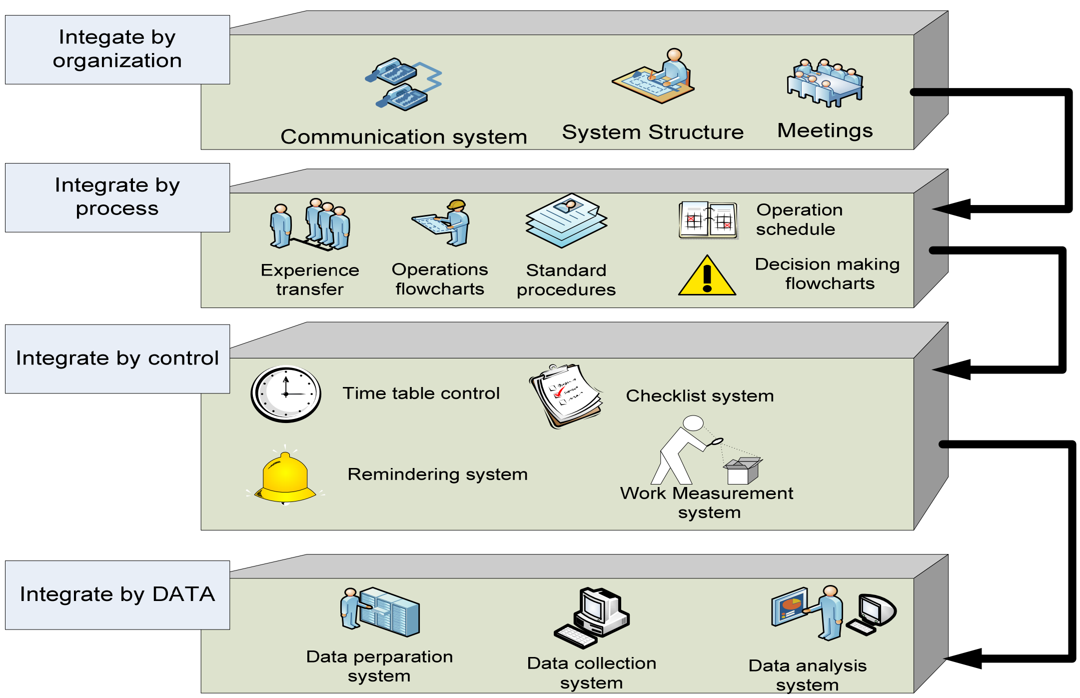


Figure (6.6), multi- levels integrated system management

Concept 2: based on requirements number (4 and 5) the generated concept is to Design Computer integrated maintenance management system: this solution it is a combination of an integrated hardware, integrated software, integrated database, and an integrated network. The main purpose of the solution is to integrate the internal item of the maintenance management system to be effective in supporting the operation management system. It is a computerised network in order to manage the transactions.

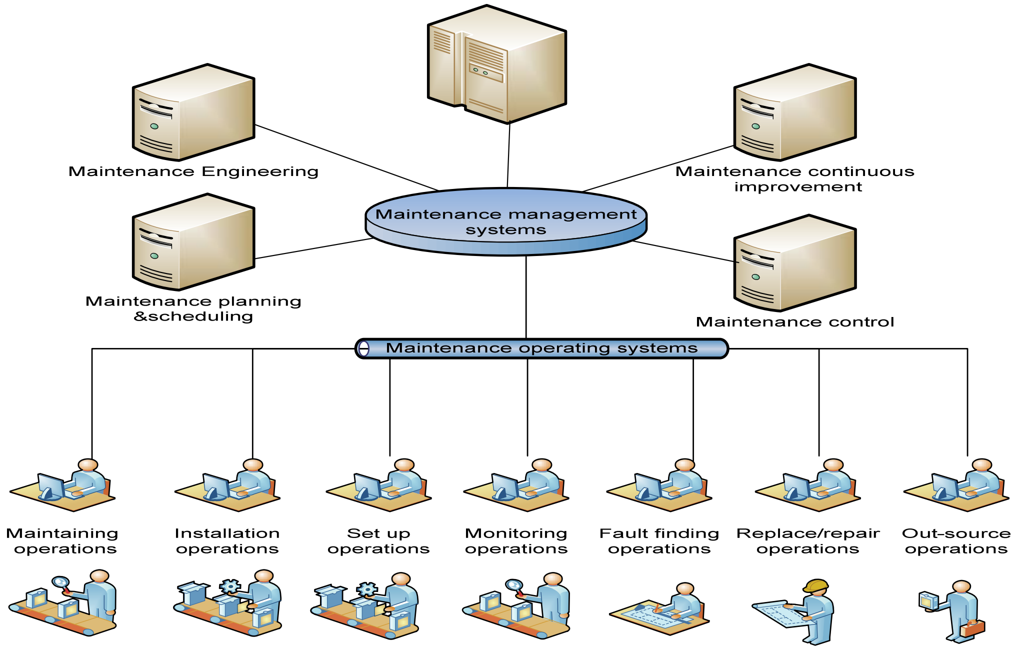


Figure (6.7), computer integrated maintenance management systems structure

Concept 3: based on requirement number (6) the generated concept is to Improve the maintenance management information system (MMIS): MMI System is a system to manage the information which generates or uses by the selected system where it deal with the internal levels: databases level, work transaction levels, analysis management level and decision making level.

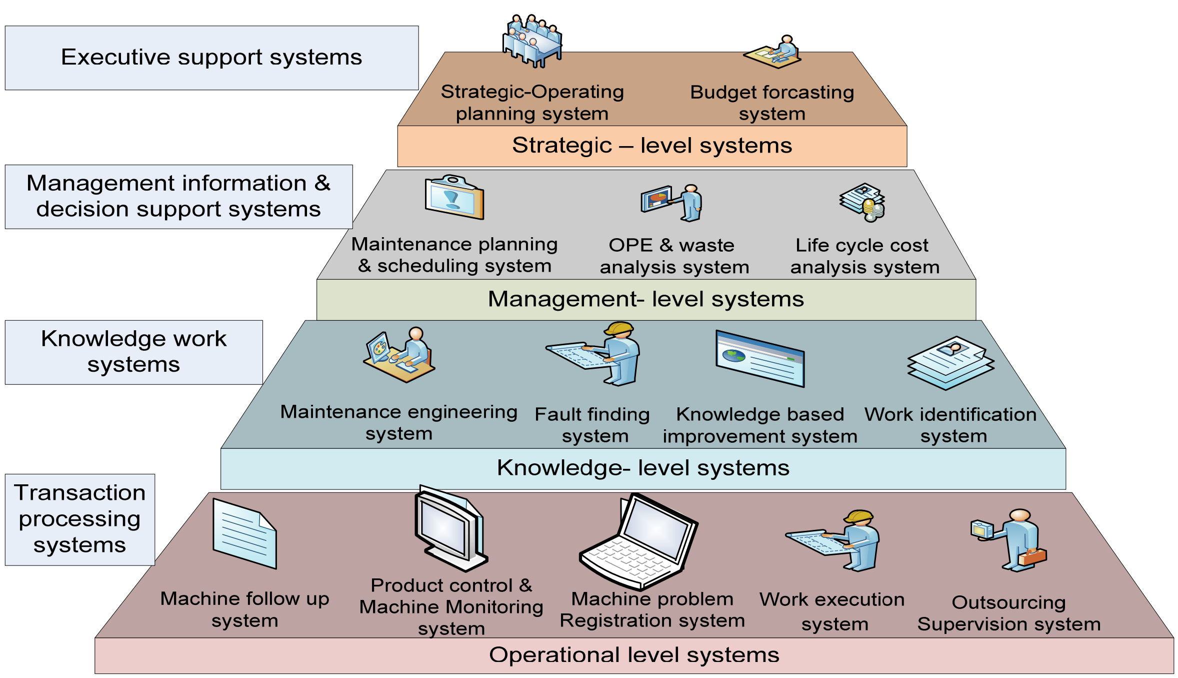


Figure (6.8), major types of maintenance information systems

Concept 4: based on requirements number (4 and 7) the generated concept is to establish a designed TPM system: some of the collected stakeholder's requirements are related to some missing parts of total productive maintenance system which they try to implement it. While the analysis results of the structured techniques were strongly expresses the weakness of TPM implementation process due to an effective integration between the system pillars. Thus, the idea of implement the TPM system is very powerful but it need like a basement system in order to do successfully implementation and get the benefits.

Concept 5: based on requirements number (4 and 7) the generated concept is to Improve Maintenance/operator training program: One of the ideas that came out of our improvement requirements was the introduction of what we called 'Technical Operators'- machine operators who were fully trained and capable of carrying out the first line maintenance and change over procedures which had previously been carried out by skilled maintenance technicians.

Concept 6: based on requirements number (1, 2, 3, 4, 5, 6, and 7) the generated concept is to improve the reporting system using the worksheets. The suggested documentation system was designed in order to satisfy the life cycle processes. Planning, scheduling, data collection, data analysis, controlling and improving aspects

Table (6.14), Documentation system using worksheets

Planning	scheduling	Data collection (instant &work order)	Data analysis	Improving / Controlling
Equipment solving problem plan	Daily maintenance work record	Stoppages registration sheet	OPE analysis chart	Daily maintenance sheet
Standard work sheet	Planned equipment repair report	Stoppages investigation sheet	Stoppages analysis chart	Instant maintenance labels
		Work actions sheet	Work productivity analysis chart	Pre-shift check sheet
		Equipment maintenance sheet	Equipment operation analysis chart	Shift's activities schedule
		Set up operations sheet	Set up operations analysis chart	
			Why-why analysis chart	

Concept 7: based on requirements number (1 and 2) the generated concept is to Improve Problem registration system and problem coding systems; selective description writing process. Based on the observation of workstation operation there are two types of problems one of them related to the product and other related to the process. According to this observation is easier, timely and cost effectively to coding the problems based on product causes or process cause, for example, in one case the quality control check show a bad dimensions products where maintenance worker try to define the causes of the problem and they make a diagnostic check

which take a long time, while the problem was due to some difficulties in the product design and the designed production process is not capable to obtain this level of quality target. In other case, the quality control check show a bad surface finish quality where the production supervisor thought that raw material in the cause, while the problem was due to excessive force applied by the chunk. Form the two previous cases, the coding system for production problems can reduce the time consuming to find the problem solving actions, like the production planning system, if there is a new product, they use coding for the proviso designed products in order to find rapidly the most similar product and his process plan. Here and for maintenance aspect this concept can classifying and coding the problem based no design attributes, technical subsystems of the machine (mechanical, hydraulic, pneumatic, and electrical), technical interfacing systems (electrical cables, pipes, converters between subsystem) and so no. the second point in problem registration system which based on coding system where the user can describe the problem using selection technique, thus, the user will feel the time consuming reduction for problem registration process and the supervisor will grantee that the operator will register the problem. For example, the operator will select the product type, the failed technical subsystem, the failed component in this subsystem, pre-described causes and the maintenance actions that have been done.

Concept 8: based on requirements number (1, 2 and 4) the generated concept is to Generate some NC codes for maintenance management like changing tools alarm, cleaning, This conceptual solution is orientated to improve or maintaining the machine by the programmed machining operations, the idea generated according to the operator observation when the authors have been applied the measuring technique, where they found that some of operator's activities cab done by the same program which used for machining.

Concept 9: based on requirements number (1, 4 and 5) the generated concept is to design a CNC Maintenance Integrator toolkit: the idea is based on a comparison process shall be done using specific software (e.g. Excel software) to compare the deviations in the co ordinations between the programmed sheet and the real manufactured measurement. After that, the software will determine where the deviation is occur in order to related it with the specific axel of motion (mechanical system of the machine) and the interfacing systems within the machine as shown in figure (6.9).

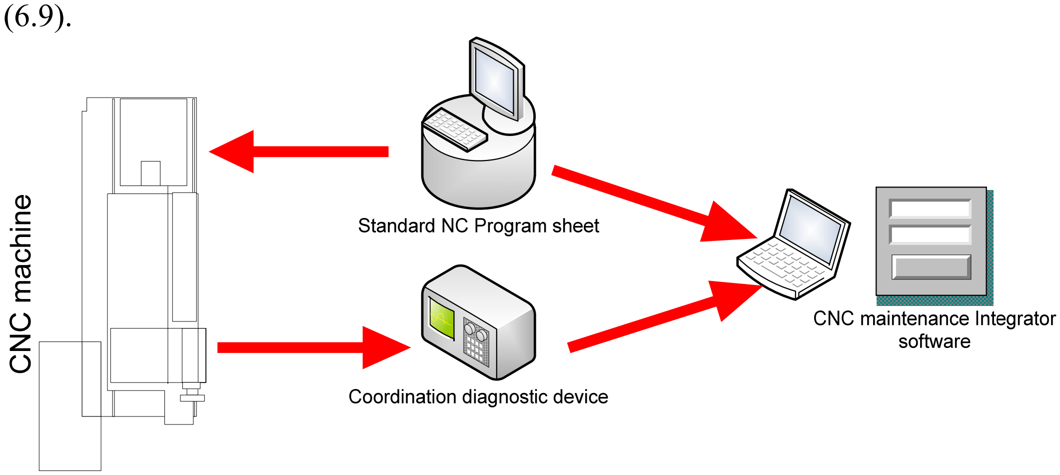


Figure (6.9), CNC Maintenance Integrator system

Conceptual solutions classification
The conceptual solution classification is important for the company application in order to select the most possible and fast conceptual solution where the company can develop the simple and small-size solution until it can develop the large one. Based on this practical fact, the authors classified the conceptual solutions into four main categories: design new system, add new subsystem, and improve some subsystems and new product as shown in table (6.12).

Table (6.15), conceptual solutions classification

Conceptual solution categories	Solution number
Design new improved system	1,2
Add new subsystems	3,4
Improve some subsystems	5,6,8
New product	7,9

6.3.2 Evaluation of the conceptual solutions

Evaluation of different conceptual solutions is based on collected evaluation criteria's. These evaluation criteria's are take different aspect like the problem treatment ability, cost feasibility and some detailed improvement aspects. Pugh evaluation matrix shows the process of this step.
Conceptual solutions evaluation process using Pugh evaluation matrix

Table (6.16), Pugh evaluation matrix

Evaluations criteria	Conceptual solutions number								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Smoothing interfaces	+	S	-	+	S	S	S	S	-
Integration losses elimination	+	S	-	S	S	S	-	-	+
Waste elimination	+	-	-	+	S	+	-	+	+
Initial cost	S	S	S	S	S	S	S	-	S
Operating cost	S	S	S	S	S	S	S	-	S
Company Knowledge improvement	+	+	+	+	+	+	+	+	+
Data flow improvement	S	+	+	-	S	+	S	+	-
Process flow improvement	+	S	-	S	S	+	S	+	-
Organization flow improvement	S	S	S	S	-	S	-	-	-
Controls flow improvement	S	-	+	-	-	+	-	-	+
Probability to success	S	S	S	-	-	-	+	+	S
Plus	5	2	3	3	1	5	2	5	4
Minus	0	2	4	3	3	1	4	4	4
Standard	6	7	4	5	7	5	5	2	3
+ means high relation type - means low relation type S means standard (normal) relation type									

6.3.3 The selected conceptual solution description

Based on the results of Pugh matrix, the selected conceptual solution should be the first one. While the second one have an interesting feature that for integration purposes firstly there a need to establish the maintenance system which able to integrate effectively with other system inside the integrate system. In situation like that, there are three different alternative, the first one is to choose the highest score alternative, or combine between some of alternatives based on take the advantages and eliminate the disadvantages, finally, to generate a new conceptual solution based on the evaluation results (Pugh matrix). The authors have been used the second one in order to get the benefit as a resultant of some solutions benefits. Thus, the mixed solution is a total of design new integrated systems, redesigned maintenance management system and improved subsystem such as problem registration system. Figure (6.10) express the idea of the mixing process which due to some relation and interfaces between the conceptual solution, our integrated system will take in consideration the idea of computer integrated maintenance management (solution 2) and maintenance management information system (solution 3) within the appraisal system of the integrated system, while it also will take in consider the new problem registration system (solution 7) within the execution system of the integrated system.

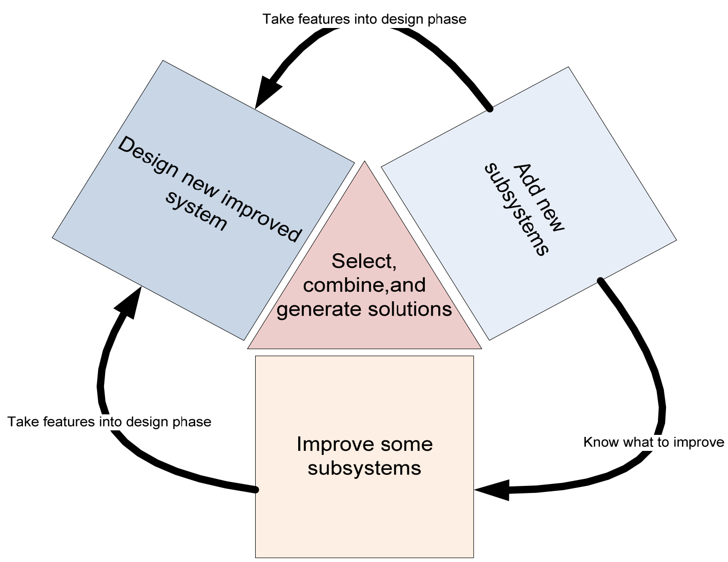


Figure (6.10), Relation and interfacing between conceptual solutions

6.3.4 Vision and key acceptance criteria of the integrated system

The vision of the mixed solution is:
"Integrate self-organized, real-planning, systematic-controlled, rapid- improving system"
And the key acceptance criteria are:

- Zero breakdowns
- Zero accidents
- Zero wastes
- Zero defects
- shall provide means for complex manufacturing process

- cost of implementation not exceeding 10% of cost saving (in order to be implemented by small companies not only medium and large companies)
- shall provide modularity of implementation (for small companies which can not implement the full system)
- shall be ready for companies use

6.3.5 Context diagram

Our human-designed system should defined the set of segments (sub-systems, humans, physical entities) which acting his behaviour, in addition to a set of interfaces which are designed to connect the segments in order to achieve the common vision or fundamental objectives. According to that, firstly, the authors use the context diagram method to define the system's context which can impact the integrated system but can not be impacted by the integrated system like also the system's external systems which interact with the integrated system via the system's external interfaces, the external systems can impact the integrated system and the integrated system does impact the external systems. The context systems and external systems play a major role in establishing the system requirements (what the integrated system need). Figure (6.11) show a all systems which impact and impacted by the developed system.

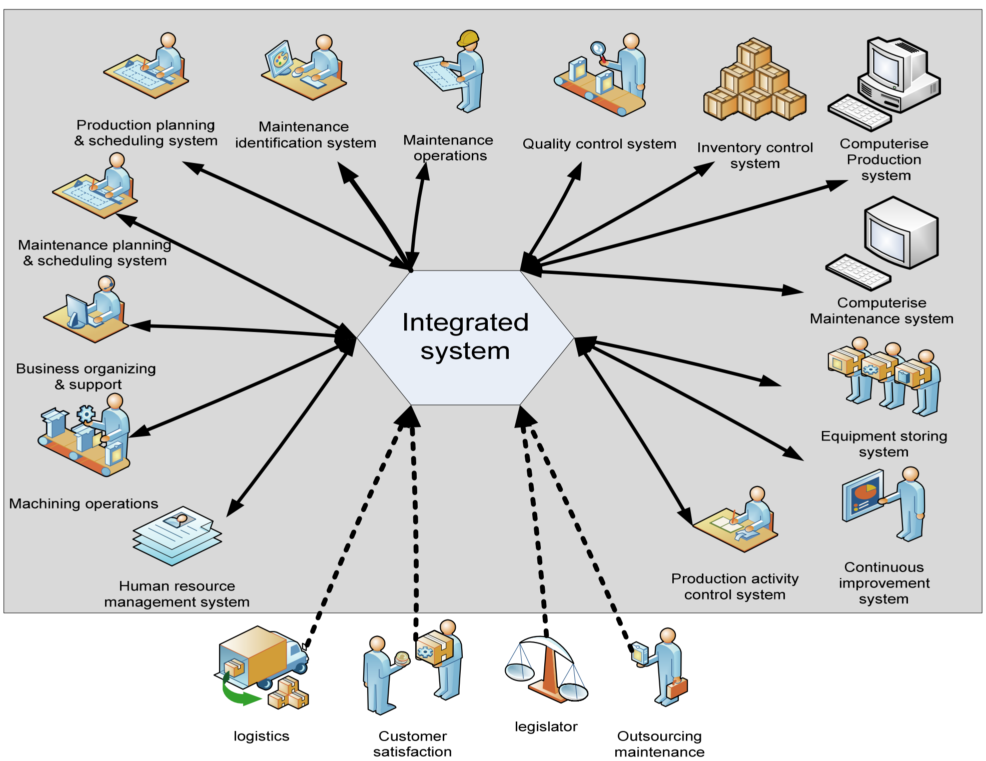


Figure (6.11), context diagram of the integrated system

6.3.6 Integration levels: systems, and sub-systems, assemblies and components

In purpose to design a real integrated system the authors have been made a research for the most used systems within the operations managements filed specifically the production management systems and maintenance management systems (which defined in context diagram), appendix 6.3A and appendix 6.3B show this collective research, these appendixes breakdown the systems into subsystems and components, while the table (6.17) constructs the component into assemblies and sub-integrated systems using bottom-up approach. The new integrated system (see table 6.17) consists of seven modules:

1) integrated engineering system
2) integrated planning system
3) integrated scheduling system
4) integrated execution system
5) integrated control system
6) integrated continuous improvement system
7) integrated appraisal system

Table (6.17), Design integrated system

Integrated system			integrated system	CODE
integrated engineering system			sub-integrated system	I .1
	production engineering system		assemblies	A.1.1
		CAD/CAM system	component	C.1.1.1
		manufacturing engineering system	component	C.1.1.2
	maintenance engineering system		assemblies	A.1.2
		machines registration system	component	C.1.2.1
		out sourcing system	component	C.1.2.2
integrated planning system			sub-integrated system	I.2
	production planning system		assemblies	A.2.1
		aggregate planning system	component	C.2.1.1
		MRP/MRPII systems	component	C.2.1.2
		inventory planning system	component	C.2.1.3
		human resources management	component	C.2.1.4
	maintenance planning system		assemblies	A.2.2
		work classification	component	C.2.2.1
		maintenance capacity system	component	C.2.2.2
		equipment inventory system	component	C.2.2.3
integrated scheduling system			sub-integrated system	I.3
	production scheduling system		assemblies	A.3.1
		master production scheduling	component	C.3.1.1
		capacity planning	component	C.3.1.2
	maintenance scheduling system		assemblies	A.3.2
		down time schedule	component	C.3.2.1
		condition monitoring schedule	component	C.3.2.2
		failure/reliability schedule	component	C.3.2.3
integrated execution system			sub-integrated system	I.4
	production operations		assemblies	A.4.1
		production & process control operations	component	C.4.1.1
		material handling operations	component	C.4.1.2
		installation operations	component	C.4.1.3
		set up operations	component	C.4.1.4

		manufacturing operations follow up	**component**	C.4.1.5
		inspections	**component**	C.4.1.6
	maintenance operations		**assemblies**	A.4.2
		preventive operations	**component**	C.4.2.1
		out-source operations	**component**	C.4.2.2
		corrective operations	**component**	C.4.2.3
		instant operations	**component**	C.4.2.4
		fault finding operations	**component**	C.4.2.5
	Quality operations		**assemblies**	A.4.3
		measure & collect data	**component**	C.4.3.1
		analyse data	**component**	C.4.3.2
integrated control system			**sub-integrated system**	I.5
	production control system		**assemblies**	A.5.1
		process control in WIP	**component**	C.5.1.1
		capacity control	**component**	C.5.1.2
		process evaluation	**component**	C.5.1.3
		inventory control	**component**	C.5.1.4
		cost control	**component**	C.5.1.5
	maintenance control system		**assemblies**	A.5.2
		work control	**component**	C.5.2.1
		material, equipment control	**component**	C.5.2.2
		cost control	**component**	C.5.2.3
integrated continuous improvement system			**sub-integrated system**	I.6
	production continuous improvement system		**assemblies**	A.6.1
		lean & JIT systems	**component**	C.6.1.1
		total quality control	**component**	C.6.1.2
		policy deployment system	**component**	C.6.1.3
		suggestion system	**component**	C.6.1.4
		small group activities	**component**	C.6.1.5
	maintenance engineering system		**assemblies**	A.6.2
		TPM systems	**component**	C.6.2.1
		RCM system	**component**	C.6.2.2
integrated appraisal system			**sub-integrated system**	I.7
	CIM databases system		**assemblies**	A.7.1
		product database	**component**	C.7.1.1
		production process data	**component**	C.7.1.2
		requirements data	**component**	C.7.1.3
	maintenance appraisal system		**assemblies**	A.7.2
		CMMS	**component**	C.7.2.1
		maintenance performance system	**component**	C.7.2.2

6.3.7 The capabilities & characteristics of the new integrated system: Use-case scenarios method

The following table (6.18) explains the capabilities (functional requirements) of the integrated system's modules

Table (6.18), integrated system capability

Module	Capability
integrated engineering system	Generate a technical parameter for product design, machine utilizing and maintaining
integrated planning system	Generate real production plan and supportive maintenance plan
integrated scheduling system	Generate a common parametric schedule for different aspects
integrated execution system	Operate a manufacturing and maintaining activities
integrated control system	Generate a close (with feedback) controls for the manufacturing and maintaining activities
integrated continuous improvement system	Generate a continuous improvement plan and actions
integrated appraisal system	Generate a supportive information transactions

The use – case scenarios of the integrated system clearly show how the user (production staff, and maintenance staff) can use the system's modules. The authors draw two use–case scenarios for two sub-integrated systems of the integrated system. The first one is to show how the integrated system will work for the single user, and second one to show how the integrated system will within multi-users like in this case between the operator, production supervisor, house-maintenance staff and out-sourcing staff in order to express the updating knowledge management.

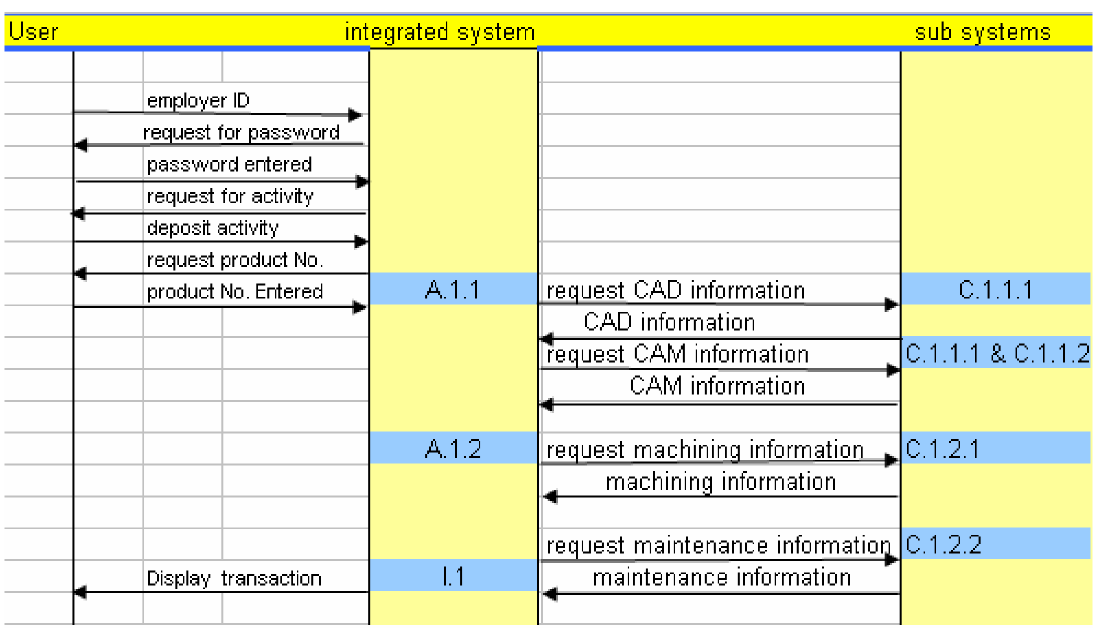


Figure (6.12), use case scenario for integrated engineering system module

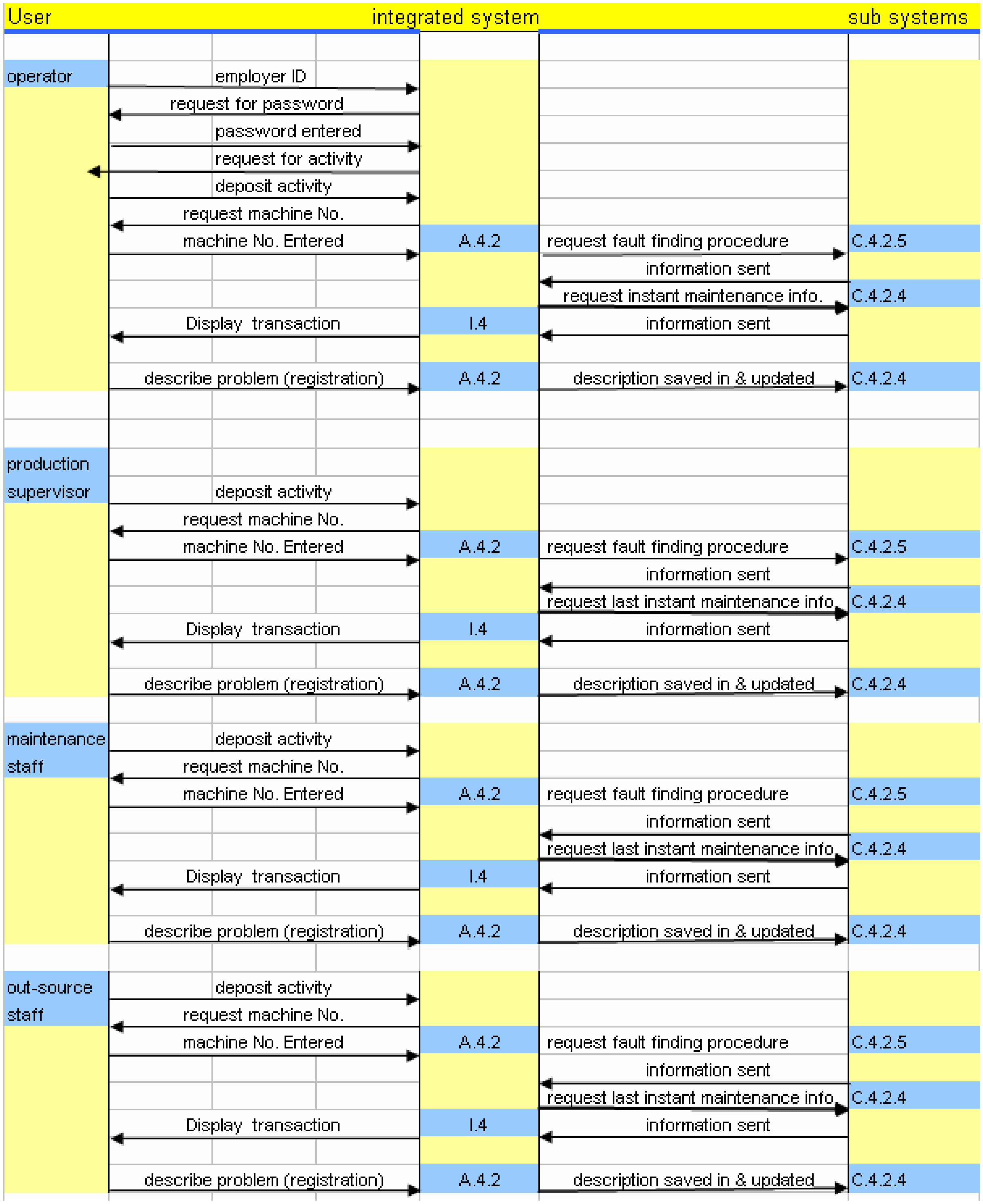


Figure (6.13), use case scenarios for problem registration system

6.4 Phase 4: Design the architecture

In this phase the authors draw up (see figure 6.14) the operational architecture of the integrated system which clearly the relation between the six functions and their inputs and outputs, in order to grantee the elimination the interfaces losses. IDEF0 concepts designed to enhance communication as shown in the figure (6.15) in order to follow with figure (6.14).

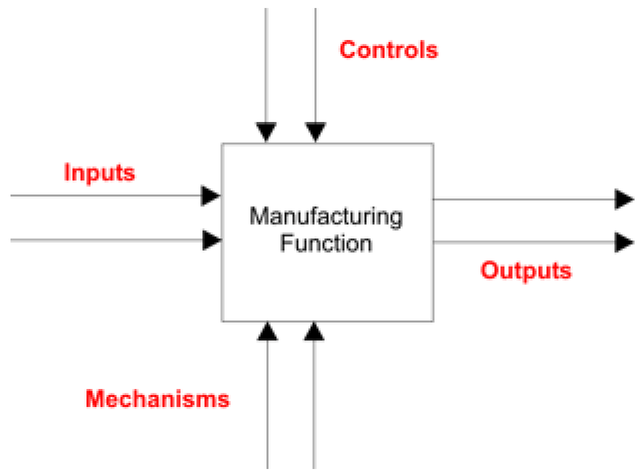


Figure (6.15), IDEF0 components (Buede.D, 2000)

6.5 phase 5: Control – verification and integration

Actually, this phase was done within a model phases in order to grantee the validity target of the research work and the developed model. It deals with the interfaces between the model phases and shows the traceability of model sequence. Table (6.19) summarise the validity and verification checks through the model phases.

Table (6.19), integrated system verification's activities checklist

No.	Activity	Reference
1	Derived requirements validity	Appendix 6.2
2	Traceability check for Extracting the requirements process	Table 6.13
3	Conceptual solution validity	First line in each concept
	Selection process quality	Table 6.16
4	Integrated system design validity	Table 6.17 & table 6.18
5	Integrated system architecture verification process	Figure 6.14

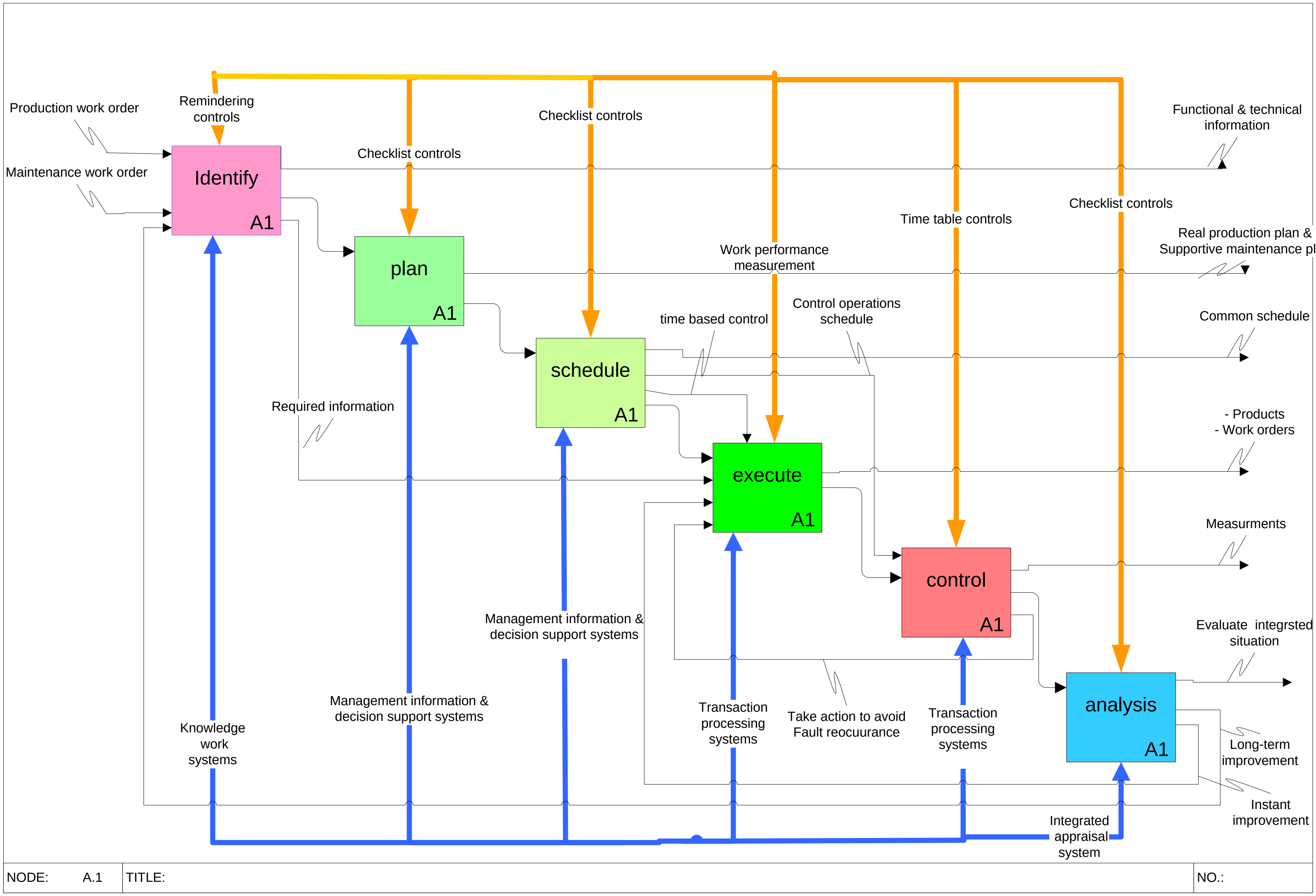


Figure (6.14), Operational architecture of the integrated system using IDEF0

Chapter Seven

7. Results & Contribution

The specific objectives of this chapter are:

- To represent the research results through the developed model
- To represent the developed model results through the designed integrated system

The organization of this chapter is as follows:

- Research contributions
- Research Results

7.1 Research contributions

There are two types of contributions in the thesis, first one is the conceptual model (chapter four) and the second one is the results of model application in case study. Mainly, the contributions that were achieved in the thesis are as follows:

- A conceptual model to develop systematically an integrated operations management system.

- An integrated methodology to show how the six-sigma methodology could support the system engineering approach (see table 4.3 – model chapter).

- An empirical model to extracting the improvement requirements of the integrated system (see phase one – analysis chapter).

- Defining the four types of interfacing losses within the integration process between operational systems.

- Defining the seven main requirements for design a system without interfacing losses.

- An integrated operations management system.

7.2 Results

The following figure (7.1) outlines the developed model results

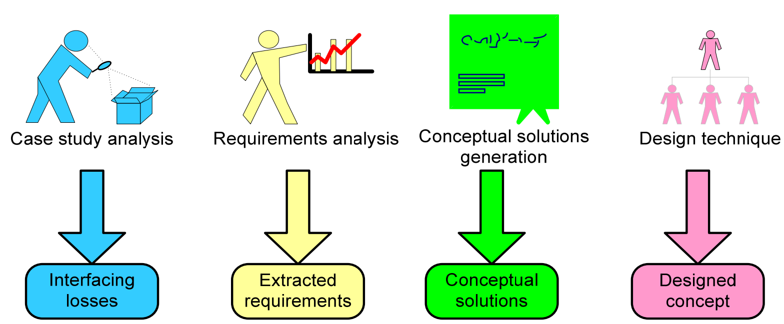


Figure (7.1), different types of results

Results in form of interfacing relations and losses: The interfacing losses that were identified within using the developed model are categories into four types as follows:

1. Losses due to weakness of integration within the organization structure and process engineering stage (organization); process and product models.
2. Losses due to weakness of integration within the process planning and control (process); monitoring, scheduling and capacity control, and executive information system.
3. Losses due to weakness of integration within the workflow control (control); actual flow of inputs and recourses.
4. Losses due to weakness of integration within the application systems (data); standard, soft wares, modules, libraries, java applets and databases.

Results in form of extracted requirements: the authors have extracted seven requirements from 49 collected requirements.

Extracted requirement number	Statement
REQ 1	the system shall be identify the required knowledge, procedures, and information for all operations activities
REQ 2	the system shall be able to plan a real production plan with supportive maintenance plan
REQ 3	the system shall be able to schedule operations (producing, maintaining, quality controlling) activities
REQ 4	the system shall be able to execute the value-added operations activities and transactions
REQ 5	the system shall be able to control the organizational structure , process and data for the operations activities
REQ 6	the system shall be able to analysis and develop the required knowledge, and evaluations information for all operations activities
REQ 7	the system shall be continuously improve the weak points within the operations activities

Results in form of conceptual solutions: From seven extracted requirements the authors have generated nine conceptual solutions, evaluated using Pugh matrix and selected the highest score concept.

Concept No.	Statement
Concept 1	design Common management system
Concept 2	Design Computer integrated maintenance management system
Concept 3	Improve the maintenance management information system (MMIS)
Concept 4	establish a designed TPM system
Concept 5	Improve Maintenance/operator training program
Concept 6	improve the reporting system using the worksheets
Concept 7	Improve Problem registration system and problem coding systems; selective description writing process
Concept 8	Generate some NC codes for maintenance management
Concept 9	design a CNC Maintenance Integrator toolkit

Results in form of design the selected conceptual solution: The selected concept was developed and designed using systems engineering approach and the results were a new designed integrated system.

Chapter Eight

8. Conclusions & Recommendations

The specific objectives of this chapter are:

- Summaries the conclusions points which were extracted based on the developed model results.
- In addition to the above, criticizes the research work in order to define the contribution of this thesis, recommend some points for the model stakeholders and suggests starting points for future researches.

The organization of this chapter is as follows:

- Acceptability test and Conclusions
- Research criticism points
- Future research works & Recommendations for the research stakeholders

8.1 Acceptability test and Conclusions

"Is the developed model results answered the question of problem formulation?" this is the statement of the research acceptability test (see figure 8.1). In other words, the acceptance test is a stakeholders (table 4.1 in chapter four) function for agreeing that the developed model, as tested by case study or otherwise evaluated by stakeholders, is acceptable.

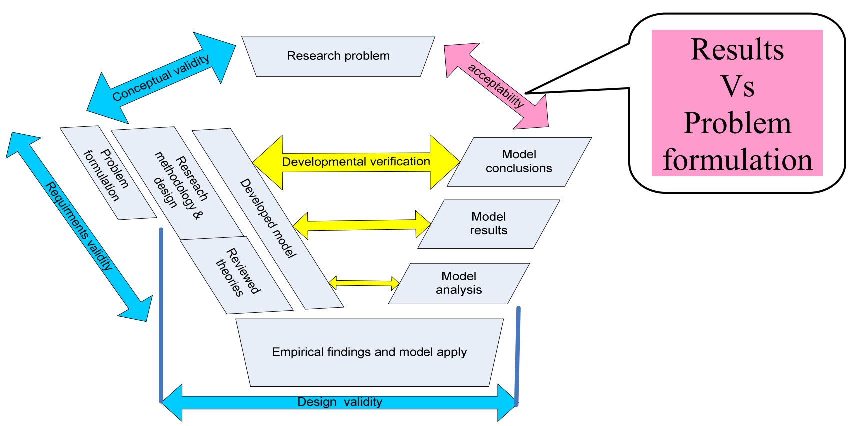


Figure (8.1), acceptability test

In detailed level of discussion, the problem formulation of the research is consists of three critical words: ***Identify, Eliminate and Design (IED)***, thus, the model was developed in purpose of develop an acceptable (applicable and feasible) model that able to identify the interfacing losses, eliminate them and design a system without interfacing losses. Figure (8.2) express how the model results answered the problem formulation questions. The model represent the obtained results to show it's applicability of identifying the interfacing losses, the model represent the second group of the obtained results to show it's applicability of eliminating the interfacing losses, where in this group, the extracted requirements have been defined what to eliminate and the conceptual solutions have been defined how to eliminate. The third group of results is to show it's applicability of designing a free-interfacing losses system.

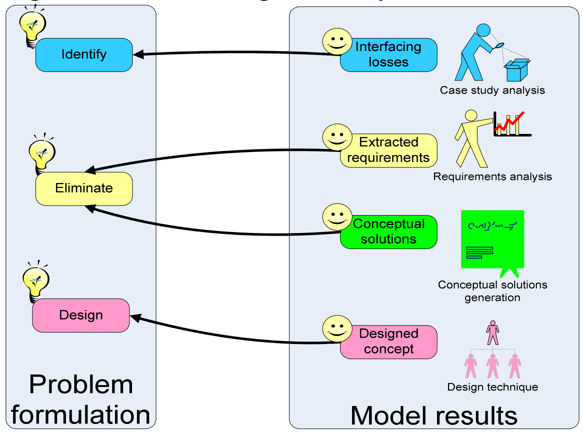


Figure (8.2), model acceptability test

Conclusions

In few words, the conclusions that can be drawn for the developed model results are as follows:

- Using the Systems engineering methodology provides the holistic implementation view and enable the users to identify, eliminate and design effective operations management system.

- Analysis the interfacing losses is the first step In order to have valid integrated operation management system

- There acceptable integrated system is the one that constructs and integrated the functional, physical resources in common operational system.

8.2 Research criticism points

Within the research and thesis documentation processes there are many problematic aspects, and the authors have categorized those aspects as follows:

a) Design research and methodology: the case company accepts the developed model results which means and proof the acceptability (applicability and feasibility) of the model. Always, the starting point is difficult until the research define the road map of the research work, thus, here the authors think that the validity of the model research conclusion depends on the number of case studies in the reality. Specially, changing the manufacturing system it will be a relevant for validate the model, because this case study is focused on one type of manufacturing system which is point automation

b) Model application: multi inter and intra-relational aspect affect the research work, and in purpose of achieve the model goals, the authors generate, combine and select some of techniques to have an applicable conceptual model inside the case study reality. Thus, there are some of decision was taken in order to solve these challenges, but some of these decision are semi-valid.

c) Research management aspects: the most critical challenge of this research is the time management, where it affects the research work in sometimes to go more deeply.

8.3 Recommendation and Future research works

Recommendation for case company

- The case company deals with problem of interfacing subsystems which affect the production rate by buying a new CNC machines in order to increase the production rate. While, this study come to highlight another way of thinking by identify why the production rate is low in order to improve it. Thus, the authors recommend to open the opportunity for the systems development works

- The case company likes the simple-fast improvement solutions where some of the conceptual solutions can be partial applied in order to achieve the some of improvement levels, therefore, the authors recommend the following points:

For operations improvement; improve the missing element & relation for the real operations flowchart (modelling charts) and shift time schedule.
For maintenance management improvement: based on auditing results, establish the missing items specially work planning and work accomplishment. Also, use a selective approach (software with selection items) for describing the machine shutdown.
For maintenance work improvement: establish the work documentation sheets in order to use the collected data for maintenance workers' knowledge development.
For maintenance – production relation improvement: use the systematic use- case scenario in figure (6.13).
For maintenance – quality relation improvement: coding the quality problems based on machining process defects and other types in order to save the time of fault finding.
For maintenance – outsourcing relation improvement: the critical part of concept one is to design a worksheet in purpose of document the outsourcing works and look for the outsourcing like an internal training courses.

Future research works

Based on the previous criticism points, the thesis open further opportunities for the future research work in order to satisfy the companies' needs, the developed model seems like the road for the improvement work within the companies and there are many features can integrated or fitted within this road. The authors highlight some future work as follows:

- **Industrial sectors**: More industrial case studies within different technological manufacturing system such as line automation systems and group automated workstations.

- **Service sectors**: Change the type of case studies, specially, within the service sectors such as banks, educational systems, medical systems, due to the parametrical feature of the developed model , for example, if the model will applied for banks organizations, only the user can define a new context diagram of the studied system in order to define the new sub-systems (transactions subsystem in banks case studies), parametrical feature means that maintenance, production ,quality systems are a functional areas (parameters of our model) they can changed to other functional area like transactions systems of service sector.

- **Research & development sectors**: The model provides the ability to develop by inserting a several supportive techniques such as use the life cycle costing approach in the conceptual solutions evaluation step.

- **Starting points for different functional research**: One of the modelling benefits is to be as basement for the future maintenance simulation project in order to generate optimize maintenance schedule and improvement aspects. In addition to that, the research through the conceptual solution part provides a beneficial idea for the Research &Development companies like the problem registration software, and the CNC maintenance integrator toolkit.

- **Implementation modularity**: Manufacturing companies have two alternatives based on their situations, they can analyze own situation by Appling the first phase of the developed model in order to determine their needs, and then they can decide if they will implement fully version of the integrated operation management or partial implementation for some weak areas.

9. References

Design research and methodology References

Arbnor, and bjerke, (1997) “methodology for creating business knowledge”, second edition, SAGA Publications Ltd.

Ghauri.P and Gronhaug.K, (2005), “research methods in business studies; a practical guide”, third edition, Prentice hall

Wiersma.W, and Jurs.S, (2005), “research methods in education: An Introduction”, eight edition, Pearson Education, Inc.

Hart. C, (2000), “doing a literature review: releasing the social science research imagination”, SAGA Publications Ltd.

Gigch.J, (1978), “applied general systems theory”, second edition, Harper & Row, Publishers.

Literature review References: Books

Al-Najjar and et al. (2001), “vibration-based maintenance: costs, savings and profits validation in two case studies”, school of Industrial Engineering, Växjö University, Sweden, Växjö university Press.

Campbell.J. (1995), “uptime: strategies for excellence in maintenance management”, Productivity Press Inc.

Duffuaa.S and et al. (1999), “planning and control maintenance systems: modelling and analysis”, John Wiley & Sons, Inc.

Kelly.A, (1984), “maintenance planning and control”, Butterworth & Co.

Kelly.A, (1997), “maintenance organization and systems”, Elsevier Science Ltd.

Sekine.K and Arai.K. (1998),“Total productive maintenance for the lean factory: innovative methods and worksheets for equipment management”, Productivity Press Inc.

Alsyouf.I,(2004),“cost effective maintenance for competitive advantages”, thesis for the degree of doctor of philosophy (Terotechnology), school of Industrial Engineering, Växjö University, Sweden, Växjö university Press.

Harvey H.Kaiser, applied management engineering, and PC,(1991), “maintenance management audit: a step by step workbook to better your facility’s bottom line”, R.S.Means Company, Inc.

Per Möller, Jurgen Steffens,and Liber AB, (1998), “underhållsteknik: faktabok”.

Chase.R and et al, (2006), “Operation management for competitive advantage with global cases”, eleventh edition, McGraw-Hill Companies, Inc.

Davis.M and Heineke.J, (2005), “Operation management; integrating manufacturing and services”, fifth edition, McGraw-Hill Companies, Inc.

Buede.D, (2000), “The engineering design of systems, models and methods”, John Wiley & Sons, Inc.

Stevens.R and et al, (1998), “systems engineering: coping with complexity”, Pearson Education Inc.

Danilovic.M, (1999), “LOOP: leadership and organization of integration in product development”, division of industrial management, Department of management and economics, Institute of technology, Linköping university.

Melan.E, (1993), “process management: methods for improving products and service”, McGraw-Hill Companies, Inc.

Kalpakjian.S and Schmid.S. (2001), “Manufacturing engineering and technology”, Fourth Edition, Prentice Hall International, Inc.

Monden.Y. (1998), “Toyota production system: an integrated approach to just-in-time”, Third Edition, Engineering & Management Press, a division of the institute of industrial engineers, Norcross, Georgia.

Browne.J and et al, (1996), “production management systems; an integrated perspective”, Second Edition, Addison- Wesley Publishing Company Inc.

Imai. M. (1997),“Gemba Kaizen: a commonsense, low-cost approach to management”, McGraw-Hill Companies, Inc.

Davis.R, (2001),“Business process modelling with ARIS: a practical guide”, Springer – Verlag LondonLimited.

Literature review References: Articles

Sherwin.D, (2000), “ A review of overall models for maintenance management”, Journal of quality in maintenance engineering, Vol. 6, No 3, pp. 138-146, MCB University Press.

Campbell.J, (1995), “outsourcing in maintenance management: a valid alternate to self-provision”, Journal of quality in maintenance engineering, Vol. 1, No 3, pp. 18-24, MCB University Press.

Al-Najjar.B, (1996), “total quality maintenance: an approach for continuous reduction in costs of quality products”, Journal of quality in maintenance engineering, Vol. 2, No 3, pp. 4-20, MCB University Press.

Garg.A and Deshmukh.S.G, (2006), “maintenance management: literature review and directions”, Journal of quality in maintenance engineering, Vol. 12, No 3, pp. 205-238, Emerald Group Publishing Limited.

Duffuaa.S and Ben-Daya.M, (1995), “improving maintenance quality using SPC tools”, Journal of quality in maintenance engineering, Vol. 1, No 2, pp. 25-33, MCB University Press.

Iravani.S and Duenyas.I, (2002), “integrated maintenance and production control of a deteriorating production system”, IIE Transactions 34, pp. 423- 435, school of business, university of Michigan, USA.

Tu.P and et al, (2001)“An integrated maintenance management system for an advanced manufacturing company”, International journal of advance manufacturing technology, Springer – Verlag LondonLimited.

Cua.K and et al, (2001), “Relationships between implementation of TQM, JIT, and TPM and manufacturing performance”, Journal of operations management. Vol. 19, pp. 675-694, Elsevier Science Ltd.

Al-Najjar.B and Alsyouf.I, (2003), “Enhancing a company’s profitability and competitiveness using integrated vibration-based maintenance: A case study”, European Journal of operational research, 157, pp. 643-657, Elsevier Science Ltd.

Al-Najjar.B and Alsyouf.I, (2002), “improving effectiveness of manufacturing systems using total quality maintenance”, Journal of integrated manufacturing systems, 11/4, pp. 267-276, MCB University Press.

Sherwin.D and Jonsson.P, (1995), “TQM, maintenance and plant availability”, Journal of quality in maintenance engineering, Vol. 1, No 1, pp. 15-19, MCB University Press.

Jonsson.P, (1999), “Company-wide integration of strategic maintenance: an empirical analysis”, International journal of productions economics, 60-61, pp. 155-164, MCB University Press.

Ip and Fung.R, (2000) “Design of maintenance system in MRPII”, Journal of quality in maintenance engineering, Vol. 6, No 3, pp. 177-191, MCB University Press.

Ahmed.S and et al, (2005), “TPM can go beyond maintenance: excerpt form a case implementation”, Journal of quality in maintenance engineering, Vol. 11, No 1, pp. 19-42, Emerald Group Publishing Limited.

Raouf.A and Ben-Daya.M, (1995), “total maintenance management: a systematic approach”, Journal of quality in maintenance engineering, Vol. 1, No 1, pp. 6-14, MCB University Press.

Jonsson.P, (1997), “the status of maintenance management in Swedish manufacturing firms”, Journal of quality in maintenance engineering, Vol. 3, No 4, pp. 233-258, MCB University Press.

Holmgren.M, (2005), “maintenance-related losses at the Swedish rail”, Journal of quality in maintenance engineering, Vol. 11, No 1, pp. 5-18, Emerald Group Publishing Limited.

Tsang.A (2002), “strategic dimensions of maintenance management”, Journal of quality in maintenance engineering, Vol. 8, No 1, pp. 7-39, Emerald Group Publishing Limited.

Abdul Raouf.S.I (2004), “Productivity enhancement using safety and maintenance integration: an overview”, Kybernetes, Vol. 33, No 7, pp. 1116-1126, Emerald Group Publishing Limited.

Nikolopoulos.K and et al, (2003), “integrating industrial maintenance strategy into ERP”, Journal of industrial management & data systems, 103/3, pp. 184-191, Emerald Group Publishing Limited.

Edwards.D and et al (2002), “An artificial intelligence approach for improving plant operator maintenance proficiency”, Journal of quality in maintenance engineering, Vol. 8, No 3, pp. 239-252, Emerald Group Publishing Limited.

Linderman.K and et al, (2004), “an integrated systems approach to process control and maintenance”, European Journal of operational research, 164, pp. 324-340, Elsevier Science Ltd.

Gulledge.T, (2006), “What is integration”, Journal of industrial management & data systems, 106/1, pp. 5-20, Emerald Group Publishing Limited.

Bamber.C and et al, (2004), “third party assessment: the role of the maintenance function in an integrated management system”, Journal of quality in maintenance engineering, Vol. 10, No 1, pp. 26-36, Emerald Group Publishing Limited.

Master Lectures References

Al-Najjar, (2005), industrial case studies course, “A model to integrate maintenance in the company business for improving profitability and competitiveness: application examples”, Draft 051011, School of Technology and design, Växjö university, Sweden.

Karlson.A and Bard.H (2002-2007), systems engineering for multi-technologies project course, “fundamentals of systems engineering”, Stevens Institute of Technology, Hoboken,New Jersey.USA and School of Technology and design, Växjö university, Sweden.

Web References

Willo Maskin AB. URL: http://www.willo.se, last Update: 2007

Plant Maintenance Resource Center, “An Introduction to Total Productive Maintenance (TPM)”. URL: http://www.plant-maintenance.com/articles/tpm_intro.shtml. last Update: 15-Nov-2006

National Institute of Building Sciences, URL: http://www.wbdg.org/design/rcm.php, last Update: 03-14-2007

Six sigma, dictionary, http://www.isixsigma.com/dictionary/Pugh_Matrix-384.htm, Modified By: ALEK DE, Last Modified: Jul. 10, 2003

IDEF0, http://www.idef.com/idef0.html, Knowledge Based Systems, Inc.

Appendix 1: Systems theory- a way to design your methodology

Systems scientists tried instead to find an optimal level of generality, as the most fundamental objective of general systems theory, we can formulate that it tried to find similarities in theoretical constructions among various disciplines as its highest purpose we can formulate that it wanted to develop a 'spectrum' of theories-a system of systems. The idea with general systems theory was that certain methods for studying behaviour were applicable to all organized living and nonliving real systems, namely, studies concerning; structures, functions and evolutions of various types of real systems.

How to design the Methodology; elements, phases and step by step

Gigch.J, (1978)

1) **Elements of design research:** elements are the components of each system. Systems elements can in turn be systems in their own right-that is, subsystems. Systems elements can be inanimate (non-living) or endowed with life (living). Most of the systems with which we deal are aggregations of both. Elements entering thee systems are called input, those leaving it are called outputs.
    1. *Conversion process*: organized systems are endowed with conversion processes by which elements in the system change state. The conversion process changes input elements into output elements.
    2. *Inputs and resources*: in the process of conversion, inputs are usually the elements upon which the resources are applied. For example, students entering the education system are inputs, whereas the teachers are one of the resources used in the process. In general, manpower, capital (which provides space, equipment, facilities, and supplies), talent, know-how, and information can all be considered interchangeably as input and resources employed in any system. When evaluating the effectiveness of a system to achieve its objectives, inputs and resources will usually be counted as costs.
    3. *Outputs*: outputs are the results of the conversion process of the system and are counted as results, outcomes, or benefits.
    4. *the environment*: it is sufficient to explain here that deciding on systems boundaries is imperative when studying open (living) systems- system that interact with other systems. Defining systems boundaries determines which systems are considered under control of the decision maker and which are to be left outside his jurisdiction (considered as "giving").regardless of where the systems boundaries are set, interactions with the environment cannot be ignored lest the solutions adopted become meaningless.
    5. *Purpose and function*: inanimate systems are devoid of visible purpose. They acquire a specific purpose or function when they enter into relationships with other subsystems in the context of a large system.
    6. *Attributes*: the system, subsystems, and their elements are endowed with attributes or properties. Attributes can be "quantity like" or "quality like- non functional." this differentiation determines the approach to be used in measuring them.
    7. *Goals and objectives*: of paramount importance to the design of systems is the identification of their goals and objectives. As we become less abstract,

statements of purpose better defined and more operational. Measures of effectiveness gauge the extent to which the systems' objectives are being met. Measures of effectiveness represent the value of the systems attributes.

8. *Components, programs, and missions*: in goal-oriented systems, the conversion process is organized around the concept of components, programs, or missions which consist of compatible elements assembled to work toward a definite objective.
9. *Management, agents, and decision makers*: the actions and decisions that take place in the system are attributed or assigned to managers, agents, and decision makers whose responsibility is the guidance of the system toward the achievement of its objectives.
10. *Structure*: thee notion of structure relates to the form of the relationships that bind the elements of the set together. The structure can be simple or complex, depending on the number and the type of interrelationships among the parts of the system. Complex systems involve hierarchies that are ordered levels of subsystems, parts, or elements.
11. *State and flows*: the state of a system is given by the value of the attributes used to characterize it. The changes from state to state which systems elements undergo give rise to flows that are defined in terms of the rates of changes of the value of the systems attributes. Behaviour can be constructed as changes in systems states over time.

Phases: step by step

Phase 1: identification of the research problem and research orienting decisions

Types of research

The bulk of research in the sciences is aimed at explaining, exploring or describing the occurrence (or non-occurrence) of some phenomenon. Although some studies combine, to varying degrees, these three purposes, the distinctions between them need to be understood. This is because the different purposes have implications for the design of research, the ways in which it is presented (its style) and the ways it is intended to be understood. Only by understanding the reason for different styles will you be able to evaluate them on their own merits and in terms of what the researcher intended to produce. The following Table shows some of the characteristics of different types of research.

Type	Purpose and features
Basic research	To contribute to theory or knowledge by formulating and testing hypotheses, Applying a theory or method to a new area, and evaluating the generalizability of propositions across time and space. Research questions are often of a what and why form
Applied research	To produce recommendations or solutions to some problem faced by specific group pf people in situation. The aim is to take theoretical insights and apply these in real world situations. Research questions are often of a how and when form Both qualitative and quantitative data are used
Summative evaluation	To summarize and assess the main benefits of a policy, programme or

	products in order to judge it effectiveness or applicability to a specific situation or in a range of context. The question might be "how did changes to organizational structure changes motivation levels?" Abstraction and quantitative data are usually evident
Formative evaluation	To make improvements to a specific programme, policy or set of activities at a specific time and place, with a specific group. The aim is to focus the research, using case-study method and qualitative evidence.
Action research	To help a group to help themselves through the research. The aim is to empower the respondents to research themselves and their situation and on this basis take responsibility for their own situation, make recommendations, possibly implement those own recommendations, and perhaps even evaluate the implementation.
Illuminative evaluation	To make key behaviours or attitudes in a given context visible for contemplation. The aim is to enlighten policy makers or practitioners to the dynamics of behaviours in comparable situations in order that those behaviours can be understood and attended to in more appropriate way.
ethnomethodogy	To describe the ways in which people make the sense they do in and through the ways they communicate.

What analytical approach is used? Inductive and deductive;

Ghauri and gronhuag (2005) was illustrated that study area [actual problem] as the production facility and use place of theory, so researcher or user must select adequate theories and methods and adjust them to the actual problem, that why they described the two strategies, which explain the answer of the following question;

What comes first: theory or research [study area]?

The distinctions between the following two strategies are:

- Theory before research, and
- Research before theory.

In the first case, present knowledge allows for structuring the research problem so that the researcher knows what to look for, what factors are relevant and what hypotheses should be tested empirically. While in the second case, the prime task is to identify relevant factors and construct explanations (theory), which helps researchers when applying present insights to specific problems, new observations and new questions may give rise to a search for new explanations, methods or techniques.

Orientation of research; qualitative and/or quantitative

Normally is methodology separated in to two different perspectives. This is made by the basis whether hard facts or soft figures are being sought. These different methods are called quantitative and qualitative respectively. The most significant difference between these two is how figures and statistics are being handled. The choice of methodology should be selected on basis of the issue that is investigated.

The word quantitative is originally from the Latin's quantum – which means quantity, an adjective that indicates that an analysis has been done with "mathematical methods" An observed phenomenon have been summed up to a few variables, which later (possibly) are processed statistical. With Quantitative methods you concentrate on things that can be measured. The view on reality is static and people are seen as objects.

For example laboratory experiments, measurements and statistics.

Qualitative methods are the methods that are use in order to process qualitative data, often-different kind of texts so that the results come out entirely linguistically, which means not based on quantitative calculations. With qualitative methods, one concentrates on the features and characteristics on something. The method are entirely social scientific and emanate from reality observations. For example: observations interviews, text-picture analysis. Hart. C, (2000)
Quantitative and qualitative methods are nothing that is mutually exclusive. It is quite common for researchers to collect their data through observations and interviews, methods normally related to qualitative research. But the research may code the data collected in such a manner that would allow statistical analysis. In other words, it is quite possible to quantify qualitative data. Ghauri, Gronhaug (2005).

Phase 2: extracting the research requirements
A System is commonly defined to be "a collection of its elements and procedures organized to accomplish some common objectives." The stakeholders for the research hold these objectives. The objective of the researchers for a research is to provide a research that accomplishes the primary objectives set by the stakeholders, including those objectives associated with the creation, application, and updating of the research. A major characteristic of the systemising the research is the attention devoted to the entire life cycle of the research. This life cycle has been characterized as "birth to death." Buede.D, (2000)
So, the research shall be define; how s/he define the research stakeholders and how s/he extracting the research requirements. Actually in this phase the research understand the basic requirements of its research such as; the required data, and the suitable methods of collection the required data, and the probable analysis methods, which are called "Originating requirements." Originating requirements are statements by the stakeholders about the research's capabilities and characteristic that defines the constraints and performance parameters within which the research is to be designed.

Phase 3: define the design research and its boundary
Collect the available methodologies (Arbnor, and bjerke, 1997)

- *Analytical approach*: the whole is the sum of its parts.
  According to the analytical approach, a causal relation exists between two groups pf factors, X (the causes, sometimes called independent variables), Y (the effects, sometimes called dependent variables).
- *The systems approach*: the whole differs from the sum of its parts. This means that not only the parts but also their relations are essential. Knowledge developed through the systems approach depends on systems. The behaviour of individuals, as parts of a system, follows systems principles; that is, individuals are explained in term of systems characteristics. Consequently, the systems approach explains or understands parts through the characteristic of the whole.
- *The actors approach*: in the actors approach, systemic characteristics are not relevant to understanding businesses and organizations. Interest is instead directed toward the finite provinces of meaning held by leading actors in a particular social context. Organization as such cannot act, only their individual members can. According to this concept, systems-as these are understood by the systems approach- are not real. The actors approach asserts that such systems exist only in the head of the systems

approach researcher/consultant/investigator and are therefore not based on the way actors interpret themselves in relation to their own experienced and constructed totality of meaning structures. The following table summarise the three methodological approaches.

	The reality and finite province of meaning
Analytical	Whole Is the sum of the Its parts Knowledge does not depend on individuals.
Systems	Whole differs from the sum of its parts. Knowledge depends on systems.
Actors	Whole exists only as meaning structures. Knowledge depends on individuals.

1. **Evaluate and Select the research methodology; giving reasons**

The evaluation process of different types of methodologies should be based on specific criteria; concerns, paradigm, thinking processes, output, method, emphasis, and outlook. In following table will showed the examples of those criteria's

Criteria	Alternatives
Concerns	Substance, Content, Causes Structure & process Method, Purpose & function
Paradigm	Analysis of systems and component subsystems Design of the whole system
thinking processes	Deduction and reduction Induction and synthesis
Output	Improvement of the existing system Optimization of the whole system
Method	Determination of causes of deviations between intended and actual operations (direct costs) Determination of differences between actual and optimum design (opportunity costs)
Emphasis	Explanation of past deviations Predictions of future results
Outlook	Introspective: from system inward Extrospective: from system outward

2. **Define the research objectives; Goal of research**;

Within any type of research there can be different types or combinations of the research act. The research design might be shaped by the goal, which could be exploratory, descriptive or explanatory. The following table shows different goals of research.

Type	Goal
Exploratory	• To satisfy curiosity, provide better understanding or for general interest. • To examine the feasibility of further study by indicating what might be relevant to study in more depth. • To provide illumination on a process or problem
Descriptive	• To understand a common or uncommon social phenomenon by observing the detail of the elements that makes it a phenomenon in order to provide an empirical basis for valid argument.
Explanatory	• To explain the cause or non-occurrence of a phenomenon; • To show causal connections and relationships between variables of the types" if A then B"; • To suggest reasons for events and make recommendations for change.

3. Identify research content and context; develop the research requirements

Ultimate presumptions; the ultimate presumptions define the researcher's view of social world and the way in which it may be investigated. It shows how the researcher looks at reality, ideals, science, ethics, etc. according to arbnor and bjerke (1997). Because when considering assumptions about grounds of knowledge, the researcher should determine his position on issue of whether knowledge is something that can be acquired on the one hand, or something that has to be personally experienced on the another hand.

*Paradigm***;** Carrying out the literature reviews involves two elements: finding appropriate literature, and processing the literature. Finding a literature; a good way to start is by asking your tutor or supervisor to give you a starter list of key articles. Alongside these procedures, the value of informal, random methods should not be ignored. Informal methods are probably of most value for exploratory searches where openness to new ideas from unexpected sources is to be valued. Formal methods are particularly appropriate for the synoptic review. Processing the literature; the amount of literature available on different topics varies enormously. One way of organizing your material is by means of relevance funnel. The funnel is divided into three zones. The innermost zone represents literature that is very close to your topic. It includes, for example, model papers. The intermediate zone represents material that is directly relevant but not quite close. The outer zone represents material that relevant but more remote. Wiersma.W, and Jurs.S, (2005)

*Methodological approaches***;** Arbnor and bjerke (1997) illustrated that knowledge can be developed using one of the following three methodological approaches: analytical approach, systems approach, and actors approach. In order to select the most suitable methodological approach for certain research, the author/s should define:

- Systems relations, the concept of "relation" can have both a concrete and an abstract meaning. Researchers talk about different stages of production process as a flow of information progressing among different decision makers at the different stage, this gives the concept of relation a concrete meaning. In abstract meaning a researchers might want to understand how a group's unity functions. The differences between the two meanings are, on the whole, a result of how the relations are structured.
- System environment, which is defined as "the factors that are important to the system to consider but are beyond its control".
- Systems components, subsystems, and super-systems, it makes possible to talk about various magnifying levels for systems, a low magnifying level means that a model contains a number of derails.
- System state and system behaviour, stressing the different characteristics of model states of real systems is traditionally called a structural perspective. A processual perspective of real system may alternatively be intended to indicate the flow of different components and relations over time.
- Systems analysis, systems construction,; systems analysis means to depict a real system in a systems model without changing the real system, and to make clear to oneself the internal and external factors influencing this system. Systems

construction means to depict a potential real system in a systems model, this model will be the basis for constructing a new real system, this real system may in turn be a development of another existing real system that has been depicted and clarified through a systems analysis.

Operative paradigm; Methodology is the understanding of how methods are constructed, that is, how an operative paradigm is developed. An operative paradigm relates a methodological approach to a specific area of study. Operative paradigm consists of two important parts: methodical procedure and methodic.

Methodical procedure	Methodic - Data required defining	Define Data resources	Data collection	Data analysis	Build the methodology

- Methodical procedure refers to the way the creator of knowledge incorporates, develops, and/or modifies some previously given technique in a methodological approach. (Adapting a technique),
- Methodic: incorporate the techniques made – into – methods into study plan and how study is actually conducted. (Applying this adaptation).the following table (Wiersma.W, and Jurs.S, 2005) shows the readers different types of research methods.

Method Type	Characteristics	Question asked	Techniques
Experimental	At least one variable is manipulated, Subjects are randomly assigned to experimental treatments	What is the effect of the experimental variable/s?	Experiment
Quasi-experimental	At least one variable is manipulated, Intact, naturally formed groups are used	What is the effect of the experimental variable/s?	Experiment
Non-experimental	The incidence, relationships, and distributions of variables are studied. The variables are not manipulated but studied as they occur in a natural setting	What are the characteristics of the variables? What are the relationships and possible effects among the variables?	Survey Observational-Case study
Historical	A description of past events or facts is developed.	What was or what happened?	Historical-Case study Testing &assessment
Ethnographic	A holistic description of present phenomena is developed.	What is the nature of the phenomena?	In–depth ethnography

Case study, is used extensively in qualitative research, a case study is a detailed examination of something; a specific event, an organization, or a system. In planning a case study there are several issues the researchers may find useful to consider;

1) The particular circumstances of the case, including: (a) the possible disruption to individual participants that participation might entail; (b) negotiating access to people, ownership of the data, release of the data.
2) The conduct of the study including;(a) the use of primary and secondary sources; (b) the opportunities to check data; (c) data collection methods- in the interpretive paradigm case studies tend to use certain data collection methods, e.g. semi-structured and open interviews, observations, narrative accounts and documents, diaries, may be also tests, rather than other methods, e.g. surveys, experiments.

- Data types and resources; ***Wiersma.W, and Jurs.S, (2005)*** provides a rough catalogue of types of data. The categories are not of course watertight, with many possible overlaps. The following table declares several different types of data with their characteristics and how to collect each type.

Data type	Characteristics	How collected
Description of behaviour	What people are seen or heard doing or saying	Observations notes
Description of events	Piece of behaviour defined either by the people in the setting or by the researcher	Ditto
Description of institution	The way the setting operates in terms of regulations, tacit, rules, rituals.	Ditto
Description of appearance	What the setting or people in it look like	Descriptive notes, diagrams, drawings, etc.
Description of research events	What people say or do in interview, focus group, etc	Observations notes
Account	What people say or write to the researcher interview	Interview, questionnaires, transcription.
Talk	What people are heard saying	Transcription, verbatim notes
Behaviour in setting	What is actually seen happening	Recording
Document	Piece of writing belonging or pertaining to the setting	photocopy

- Data collection; may be interactive or non-interactive, interactive techniques involve the researcher interacting with subjects who are being studied, where non-interactive are not. Among the numerous methods of data collection, those most commonly used include observation, interview, collection and review of related documents, taking specimen records, and talking oral histories. Conducting an interview is an example of an interactive data collection technique. While reviewing historical documents is a non-interactive data collection technique.
- Data analysis; is a process of categorization, description, and synthesis. Thus the data analysis requires organization of information and data reduction. The data may suggest categories for characterizing information. Comparisons can be made with initial theories or working experiences. Early data collection might suggest a hypothesis or theory, and then more data might be collected to support, disconfirm, or extend the hypothesis or theory. Initial descriptions of causes and consequences may be developed. So the information needs to be organized, and through this organization there should be data reduction. This process is called coding.

Study area; by focus we are refereeing to the specific dimensions and aspects of the topic that were studied. There are, in the main, three areas that a study can focus on: characteristics, orientations and actions. Characteristics are usually taken to be measurable or recordable attributes, such as age, sex, location and the like. The orientations of individuals might be their beliefs, attitudes, personality traits and the like. Actions are taken to be what people do.

4. Develop model for researching

Models, abstractions of reality, are critical in the research development. These models start as very high level representations that address what needs the research should meet and how the research will meet these needs. Every modelling technique is a language used to represent reality so that some question can be answered with greater validity that could be obtained without the model. There are different types of models based on the question that can be answered by the model, as discussed in following table (Wiersma.W, and Jurs.S, 2005)

Model Type	Description
Descriptive (or predictive)	Attempts to predict answers to questions for which the truth may or may not be obtained in the future. Descriptive models are the most commonly used in science and engineering
Normative	Address how individuals or organizational entities ought to think about a problem and guide decision making.
definitive	Addresses the question of how should an entity be defined. The focus is building a definition of how the research is being designed.

Research Design features

Very few accounts of a piece of research include the original design plan or proposal. Any master's and doctoral theses should express in the original proposal by which the research was designed. It is possible, however, to recover the design features and methodological choices of a piece of research from the published work. The features outlined in following table are the main features of research design.

Issues	Options
What is the purpose of the study?	Basic, applied, summative, formative, action, illuminative, ethnomethodology
What is the scope of the study?	What is included, excluded, why and to what effect?
What is the focus for the study?	People, policy, programmes, breadth versus depth, case study, survey, comparative, and so on.
What are the units of analysis?	Individuals, groups, programme components, whole programmes, organizations, critical incidents, time periods and so on.
What types of data were collected?	Qualitative, quantitative
How were the data managed?	Organization, classification, presentation, referenced, indexed, and so on
What analytical approach is used?	Deductive, inductive
How is validity addressed in the study?	Triangulation, multiple data sources, multiple study
When did the study occur?	Currency of findings, long-term investigations, short and snappy, phased and piloted
How is the study justified?	Literature review and analysis, problem definition, practical outcomes, intellectual endeavour and so on

Non functional characteristics (reliability, validity, reality, capability, integrity)
Validity of research: in general, for something to be valid we want it to be based on fact or evidence, that is, "capable of being justified." Becoming more specific, validity involves two concepts simultaneously, internal validity and external validity. Internal validity is the extent to which results can be interpreted accurately, and external validity is the extent to which results can be generalized to populations, situations, and conditions.
Reliability of research: refers to the consistency of the research and the extent to which studies can be replicated. We sometimes distinguish between internal and external reliability. Internal reliability refers to the extent that data collection, analysis, and interpretations are consistent given the same conditions. External reliability deals with the issue of whether or not independent researchers can replicate studies in the same or similar settings. Will researchers be able to replicate studies, and, if so, will the results be consistent? If research is reliable, a researcher using the same methods, conditions, and so forth should obtain the results as those found in a prior study. Buede.D, (2000), and Stevens.R and et al, (1998),

Research interfaces
Interfaces are common failure points on researches, an interface is a connection resources for hooking to another system's interfaces(an external interface) or for hooking one system's component to another (an internal interface). The researches designers identify the interfaces, both internal and external, and allocating items (inputs and outputs) to the defined interfaces. Once these tasks are completed, the requirements for each interface must be derived from existing system –level requirements. Finally, alternative interface architecture alternatives must be examined, including the needed functions and the most cost effective alternative chosen. Buede.D, (2000), and Stevens.R and et al, (1998)

Phase 4: define the research architecture design
The research development includes three separate architectures (functional, physical, and operational) as a part of its process. The functional architecture defines what the research must do, that is, the research's functions and the data that flows between them. The physical architecture represents the partitioning of physical resources available to perform the research's functions. The operational architecture is the mapping of functions to resources. Buede.D, (2000)

Phase 5: research integration and qualification: validate and verify
Research Integration is the process of assembling the research from its components, which must be assembled from their configuration items. Qualification is the process of verifying and validating the research design and then obtaining the stakeholders' acceptance of the research design. Recall that verification is the determination that the research was built right; while validation determines that the right research was built.
The operational validity is the matching of the capabilities of the designed research to the operational concept; this naturally occurs late in the integration phase after the designed system has been verified. However, conceptual validity, requirements validity, and design. Validity is important aspects of validity and need to be addressed early in the design phase. Stevens.R and et al, (1998).

Appendix 4: defining, measuring and analysis techniques: step by step

Step	Process auditing	process modelling	OPE using man-machine chart	process FMECA	process analysis
1	conduct preliminary program review (using Guidelines Checklists)	define objectives	define all the required parameters	Understanding of the Process to be subjected to FMECA	Draw the boxes (each box to represent a major step) and label each one.
2	compile effectiveness rating (using effectiveness rating worksheets	capture requirements	collect the required data (parameter)	Breaking down of the process into its steps (steps are also known as items)	Determine the titles of the major arms or bones, which may vary for each of the steps.
3	identify opportunities for improvement	conceptual design	apply the method	Identification and assessment of the following for every item listed: function(s), potential failure mode(s), failure mode effect(s), failure mode cause(s), and controls for detecting or preventing the failure mode(s);	observations to generate causes at each step of the process
4		detailed design	make the analysis	Evaluation of the risks associated with the failures modes and prioritizing them according to importance;	Clarify all causes to make sure everyone has the same understanding of what they mean.
5			validate and verify		Ask “Why” five times. This is a technique developed by Toyota, to get past the symptom and down to the actual cause. This can be linear or random. Ask “Why” until it becomes a ridiculous question to pose.
6					Collect and analyse data to verify whether each is a valid cause.

Appendix 5.1 – maintenance management audit

Item action	Comments	Rating	Target
Organization			
Structures, Documentation not prepared. Organization chart, functional statement, job description, active updating procedure.	Not written	0	28
policies, rules, services, Documentation not prepared, general policies (written, and distributed), complete policies, and active updating procedure.	Not written	0	28
functions, independent work control function (established, assigned), all basic work responsibilities assigned process and manage total workload overview evaluation for effectiveness		27 9 9 9 0	36
staffing, work reception, planning staff (adequate, trained) inspection staff (adequate, trained) management analysis function		16 0 8 8 0	32
total		43	124

<u>Notes about organization</u>; shop organization and supervision which are two points related to the maintenance organization auditing, but because the maintenance department are small in the company, so those activities are within production department.

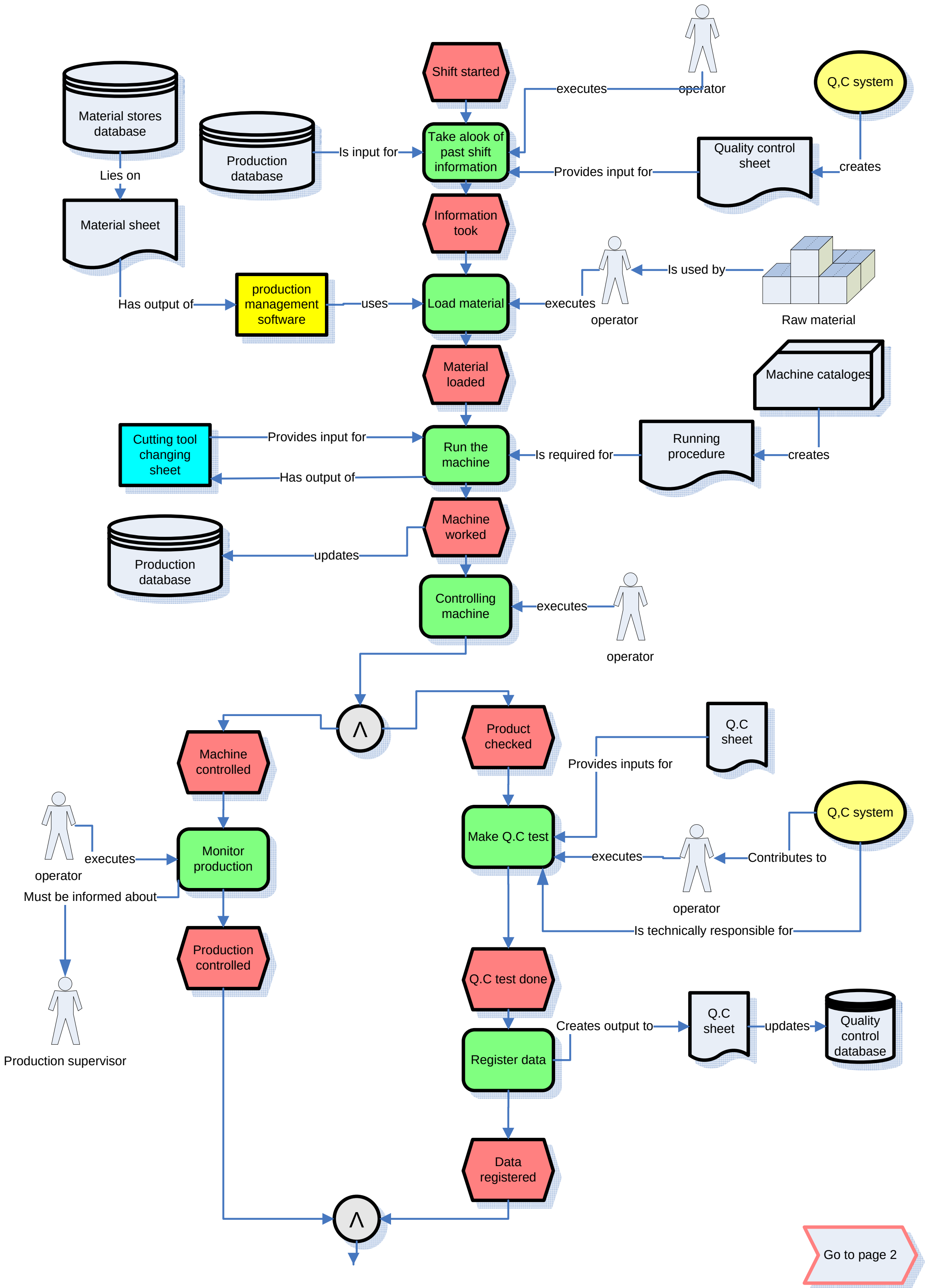
Workload identification	Comments	Rating	Target
Facilities inventory, Records are not prepared or outdated Current facility list – general data incomplete Current facility list – general data complete Current facility list – detail data complete Active updating procedure		20 5 5 5 5	20
facilities condition inspection,	This function is external resource job.		
work request procedure, procedure not documented or outdated procedure documented or distributed authorization controlled structured processing status feedback provided to requestor		0 0 0 0 0	16
equipment inventory, Records are not prepared or outdated Current equipment list – detail data incomplete Current equipment list – detail data complete Current equipment list – computerized data complete Active updating procedure		10 5 5 0 0	20
preventive maintenance equipments,	This function is external resource job.		
service work,	This function is external resource job.		
routine work, -classified separately, work order with general specifications -work order specifications quantified -work orders scheduled weekly in accordance with planned -work accomplished ±10% of schedule		24 6 6 6 6	24
total		54	80

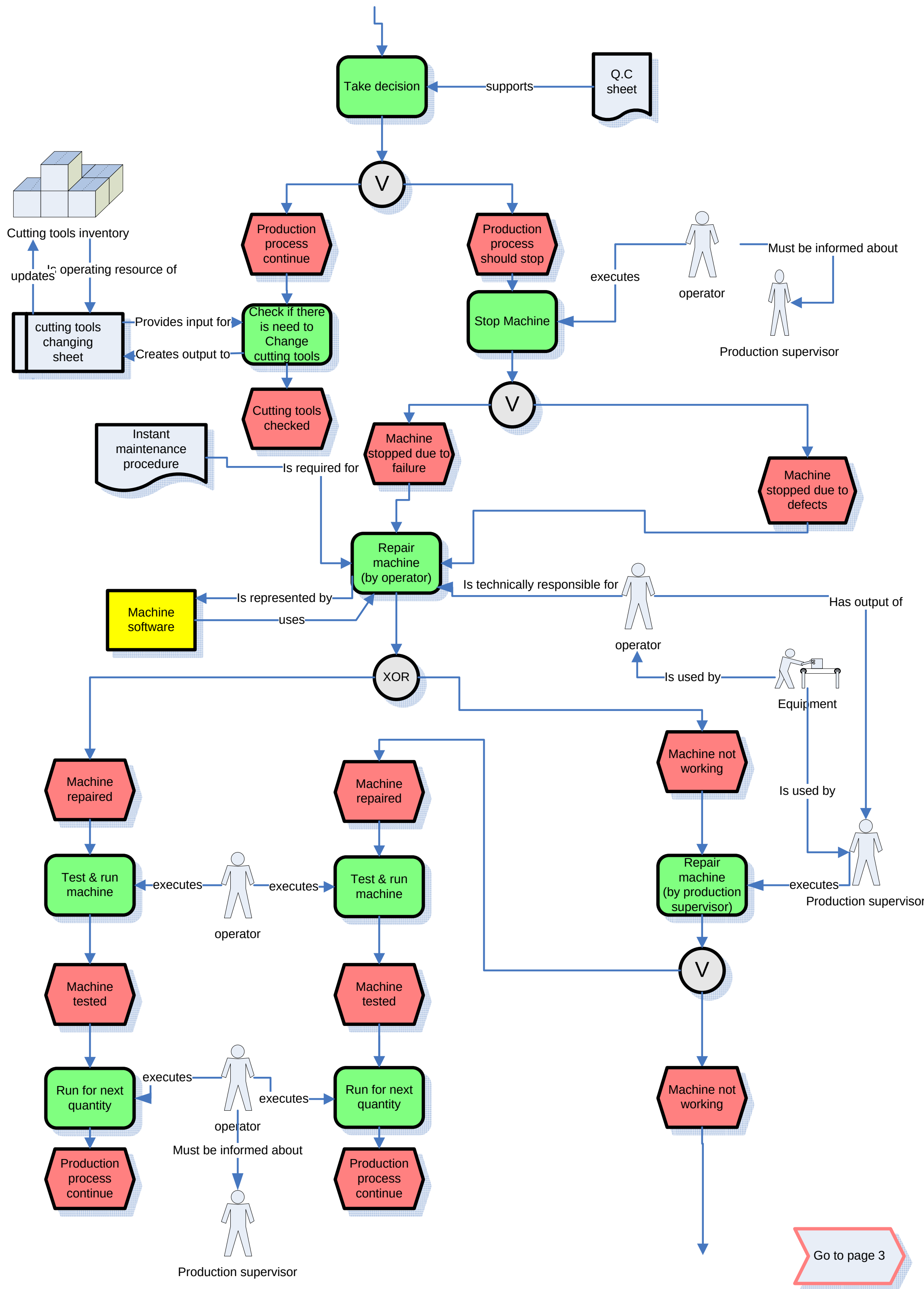
Work planning			
Priority criteria - priority criteria established and not-documented - priority criteria addresses appropriate factors - priority criteria applied consistently to al work - work performance recorded by priority and reviewed		7 7 0 0 0	28
Work classification - classification definitions established and documented - processing procedures are tailored to each class of work - workforce distribution targets for each class of work - work performance recorded by class of work and reviewed	Small company and maintenance staff are only two members	7 7 0 0 0	28
Alternatives and improvement (A/I) work approval - A/I work is not identified separately from maintenance and repair work - All A/I work processed by work control - A/I fund source - A/I work programmed		0 0 0 0 0	20
Work order preparation - Work order issued, general description, no estimate - Work order includes detail description with estimate hours and costs - Work order planned by job phase - Material lists prepared		10 10 0 0 0	40
Budget requirement for Maintenance &Repair	It is responsibility of production department		
Backlog deferred maintenance & repair			
Budget execution plan			
Backlog of funded work			
Total		24	116

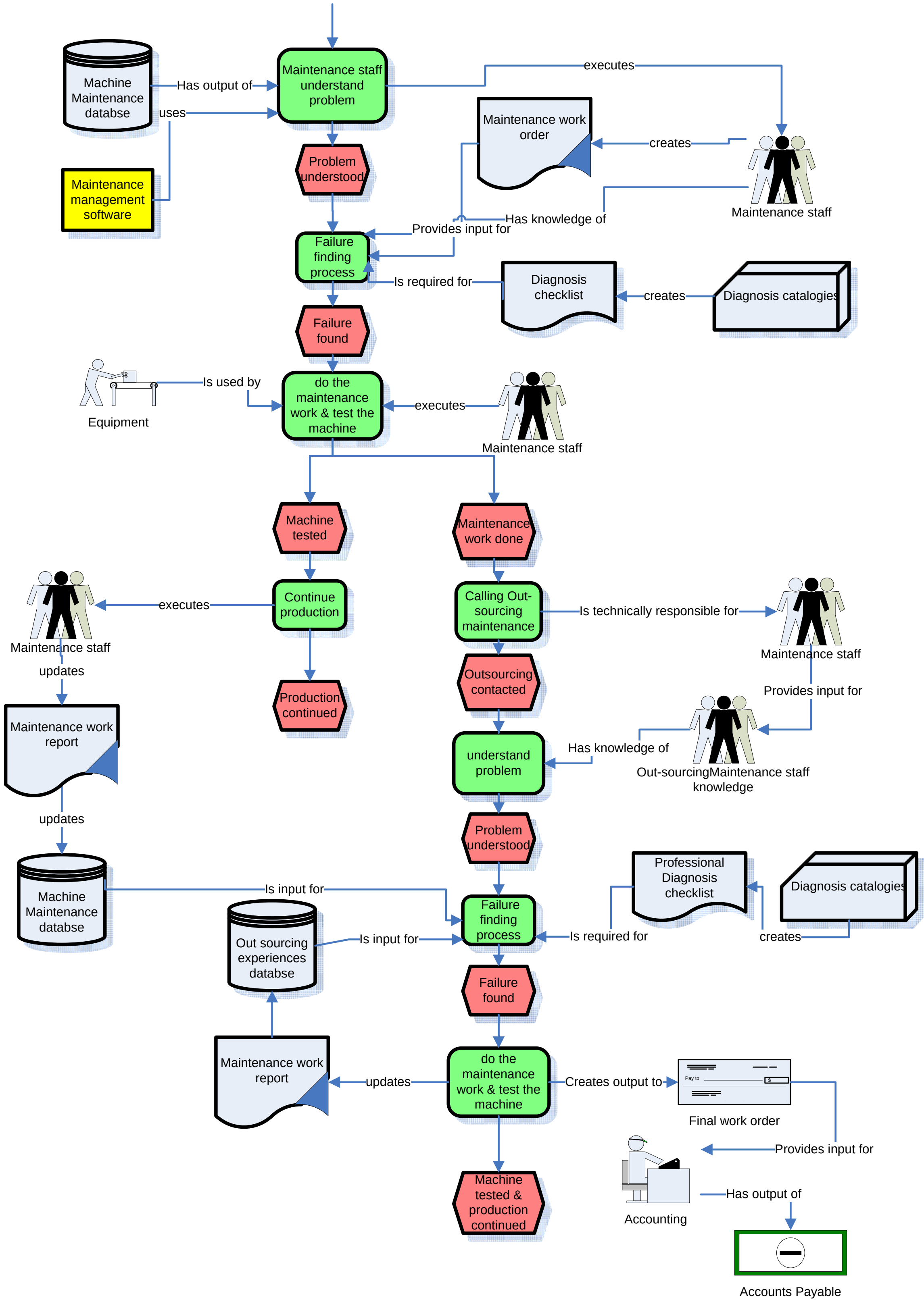
Work accomplishment			
Shop scheduling and planning procedures - Formal functions not established - scheduling functions established - formal schedule procedures and planning accomplished weekly - scheduling performance within ± 10% - shop planning support provided		8 8 0 0 0 0	32
Craft and material availability - work order assigned without hour or material plan - shop force distribution planned each work - work order scheduled only when craft hours are available - work order scheduled only when materials available - principal materials procured and reserved		0 0 0 0 0 0	24
Training program - minimum interest indicated - some training accomplished on unstructured basis - training plan established and budgeted - training plans based on needs assessment reviews - active apprentice program		12 6 6 0 0	24
Supervisory operation - percent supervisory time on direct supervision is adequate - effective supervisory training program - supervisory responsibilities firmly established - supervisors actively support workers' programs; training, safety, etc.		7 7 0 0 0	28
total		27	108

Appraisal			
Computerized maintenance management system - no structured system - basic system established with monthly reports - reports specifically designed for each user level - system includes facility and equipment history records - reports utilized extensively at all user levels		24 0 8 8 8 0	32
Performance measurement - no effective measure of performance established - estimated and actual hours/cost reported each work order - performance data summarized and reported against targets - engineered performance standards used as basis for work order estimates - methods improvement studies conducted during past two years		0 0 0 0 0 0	24
Productivity measurements - not studied/measured during past two years - productivity study accomplished during past two years - productivity study include valid work sampling - work sampling measured work categories & compared with established targets - study results generated an improvement action plan		6 0 6 0 0 0	24
Equipment history records - not established - records established for each piece of equipment - records contain adequate and current data - data summarized and structured for review and evaluation - analyzed periodically as routine practice		6 0 6 0 0 0	24
total		36	104

Appendix 5.2, manufacturing process flowchart




Take decision
supports
Q.C sheet
V
Production process continue
Production process should stop
Cutting tools inventory
updates
Is operating resource of
cutting tools changing sheet
Provides input for
Creates output to
Check if there is need to Change cutting tools
Cutting tools checked
executes
operator
Must be informed about
Stop Machine
Production supervisor
V
Instant maintenance procedure
Is required for
Machine stopped due to failure
Machine stopped due to defects
Repair machine (by operator)
Machine software
Is represented by
uses
Is technically responsible for
operator
Has output of
XOR
Is used by
Equipment
Machine not working
Is used by
Machine repaired
Machine repaired
Test & run machine
executes
operator
executes
Test & run machine
Repair machine (by production supervisor)
executes
Production supervisor
V
Machine tested
Machine tested
Run for next quantity
executes
operator
executes
Run for next quantity
Machine not working
Must be informed about
Production process continue
Production process continue
Production supervisor
Go to page 3


Machine Maintenance databse
Has output of
uses
Maintenance management software
Maintenance staff understand problem
executes
Maintenance work order
creates
Maintenance staff
Problem understood
Has knowledge of
Provides input for
Failure finding process
Is required for
Diagnosis checklist
creates
Diagnosis catalogies
Failure found
Is used by
Equipment
do the maintenance work & test the machine
executes
Maintenance staff
Machine tested
Maintenance work done
Maintenance staff
executes
Continue production
Calling Out-sourcing maintenance
Is technically responsible for
Maintenance staff
updates
Production continued
Outsourcing contacted
Provides input for
Maintenance work report
Has knowledge of
understand problem
Out-sourcingMaintenance staff knowledge
updates
Problem understood
Professional Diagnosis checklist
Diagnosis catalogies
Machine Maintenance databse
Is input for
Out sourcing experiences databse
Is input for
Failure finding process
Is required for
creates
Failure found
Maintenance work report
updates
do the maintenance work & test the machine
Creates output to
Final work order
Provides input for
Accounting
Has output of
Machine tested & production continued
Accounts Payable

Appendix 5.3, measurements collection sheets

	Operator	Time (min)		Machine 1			Machine 2		
1	Starting up machine Small discussion with the previous operator	5	13:30	Start up machine	5	13:30	Start up machine	5	13:30
2	Material loading check Fast-Check for all cutting tools, Review the production sheet (for machine 1)	5	13:35						
3	Program Running (for machine 1)	1	13:40						
4	Material loading check Fast-Check for all cutting tools, Review the production sheet (for machine 2)	5	13:41	Machine working	5	13:41			
5	Program Running (for machine 2)	1	13:46			13:46			
6	Quality check for first sample (for machine 1)	5	13:47				Machine working	5	13:47
7	Program running for next quantity (20 units) (for machine 1)	1	13:52						
8	Quality check for first sample (for machine 2)	5	13:53	Machine working	20	13:53			
9	Program running for next quantity (20 units) (for machine 2)	2	13:58			14:13			

10	Within this time ,the operator take sample of produced unit for quality check	5	14:00				Machine working	20	14:00
11	Machine 1 stop Cleaning machining module,	2	14:13						14:20
12	According to the quality check (step 10) The operator make (if needed) adjustments Then program running again for next 20 units		14:15	Machine working	22	14:15			
13	Machine 2 stop Cleaning machining module, (sometimes there difficulties in cleaning and pike up the produced units so it take more time)	3	14:20			14:37			
14	According to the quality check (step 10) The operator make (if needed) adjustments Then program running again for next 20 units		14:23				Machine working	22	14:23
15	Within this time ,the operator take sample of produced unit for quality check	5							
16	Machine 1 stop Cleaning machining module + cutting tools check	5	14:37						14:45
17	According to the quality check (step 15) The operator make (if needed) adjustments Then program running again for next 20 units		14:42	Machine working	23	14:42			
18	Machine 2 stop Cleaning machining module,	4	14:45			15:05			
19	According to the quality check (step 15) The operator make (if needed) adjustments Due to some error in dimensions, operator change two cutting tools	5	14:50						
20	program running again for next 20 units		14:50				Machine working	20	14:50

21	Within this time ,the operator take sample of produced unit for quality check	5							15:10
22	Machine 1 stop Cleaning machining module	3	15:05				Alarm for Sudden Stoppage		15:02
23	According to the quality check (step 21) The operator make (if needed) adjustments Then program running again for next 20 units	1	15:08	Machine working	20	15:08			
24	Operator go to the machine 2 Read machine failure massage Cleaning, & Controlling machining module	6	15:09			15:28			
25	Re-running of program for 5 units and Control the machine 2 if working proper way	5	15:15				Machine working	5	15:15
26	Machine 2 stop, Quality Check for those 5 units	5	15:20						15:20
27	program running again for next 20 units (for machine 2)		15:25					20	15:25
28	Machine 1 stop, Quality check Cleaning	6	15:28	Daley in machine 1, for quality check, due to the stoppage of machine 2 the operator can not make the check within production period					15:45
29	program running again for next 20 units		15:34		20	15:34			
30	Within this time ,the operator take sample of produced unit for quality check	5				15:54			
31	Operator find error in dimensions (for products of machine 2), so operator stop the machine 2 - discussion with production supervision	17	15:40				Quality stoppage		15:40

	- Cleaning, & Controlling machining module - change cutting tools, program adjustment								
32	Machine 1 stop,		15:54	Delay due to the operator working within machine 2					
33	Quality check Cleaning (for machine 1)	7	15:57	Daley in machine 1, for quality check, due to the stoppage of machine 2 the operator can not make the check within production period					
34	program running again for next 20 units (for machine 1)		16:04	Machine working	20	16:04			
35	Operator change one of the cutting tools in the machine 2 which it is responsible the dimension error	6	16:04			16:24			
36	Re-running of program for 5 units and Control the machine 2 if working proper way	5	16:10				Machine working	5	16:10
37	Quality check Cleaning (for machine 2) Discussion with production supervisor about the results	10	16:10						16:15
38	program running again for next 20 units (for machine 2) Within this time ,the operator take sample of produced unit for quality check	6	16:20				Machine working	20	16:20
39	Machine 1 stop,		16:24	Delay due to the operator is in the quality dept. for quality check					16:40
40	Cleaning (for machine 1)	3	16:26						

41	program running again for next 20 units (for machine 1) Within this time ,the operator take sample of produced unit for quality check for machine 2		16:29	Machine working	20	16:29			
42	Machine 2 stop Cleaning machining module,	3	16:40			16:49			
43	program running again for next 20 units (for machine 2) Within this time ,the operator take sample of produced unit for quality check for machine 1		16:43				Machine working	20	16:43
44	Machine 1 stop Main Cleaning machining module	10	16:49						17:03
45	program running again for next 20 units (for machine 1)		16:59	Machine working	20	16:59			
46	Machine 2 stop, Quality check Cleaning	6	17:03	Daley in machine 2, for quality check, due to the cleaning of machine 1 the operator can not made the check within production period		17:19			
47	program running again for next 20 units (for machine 2) Within this time ,the operator take sample of produced unit for quality check for machine 1		17:09				Machine working	20	17:09
48	Machine 1 stop Cleaning machining module,	6	17:19						17:29
49	program running again for next 20 units (for machine 1) Within this time ,the operator take sample of produced unit for quality check for machine 2		17:25	Machine working	20	17:25			
50	Operator find the same problem again (for products of machine 2), so operator stop the machine 2	10	17:29			17:45	quality stoppage		17:29

	And he try to solve it by - change cutting tools, program adjustment - and testing								
51	Operator ask other operators about the stoppages Other operators try to solve	15	17:39						
52	Machine 1 stop Cleaning machining module,	6	17:45						
53	program running again for next 30 units (for machine 1) because the operator want to have time for the problem of machine 2		17:51	Machine working	30	17:51			
54	The operator try again to solve it by - change cutting tools, program adjustment and testing but it doesn't work	30	17:51			18:21			
55	Machine 1 stop Cleaning machining module,	6	18:21						
56	program running again for next 30 units (for machine 1) because the operator want to have time for the problem of machine 2		18:27		30	18:27			
57	The operator try again to solve it by reading the maintenance manuals, historical machine book and make modification and testing it but it doesn't work	30	18:27			18:57			
58	Machine 1 stop ,but the operator working in the other machine		18:57	Production stop		18:57			
59	The operator take 1 hour rest	60	19:00			20:00			

60	Operator come back and cleaning machine 1 , and program running again for next 30 units (for machine 1) because the operator want to have time for the problem of machine 2	6	20:00	Machine working	30	20:6			
61	The operator try again to solve it by reading the maintenance manuals, historical machine book and make modification and testing it but it doesn't work	10	20:06			20:36			
62	the operator take sample of produced unit for quality check for machine 1	10	20:16						
63	Operator shutdown the machine 2 to the next shift (5:30 next day) until the skilled operator or production supervisor will come	5	20:26						
64	Operator looking when he should change cutting tools for machine 1.	5	20:31						
65	The operator changing the cutting tools	15	20:36						
66	program running again for next 20 units (for machine 1)		20:51	Machine working	20	20:51			
67	Shift changing		21:00			21:11			

Appendix 5.4, Process FMECA

Process	Function	Failure mode	Failure effects	Causes	SEV	OCC	DET	RPN
Draw the product using AutoCAD	To generate the coordination	No information						
Plan the manufacturing process	To generate the process plan	Select non-optimum processes and tools	Increase processing time and time waste	- Worker don't follow the documentation	1	4	1	4
Prepare the manufacturing process using Cam Module	To combine the process plan with the coordination	Select non-optimum processes and tools	Increase processing time and time waste	- No standard documentation for optimal selection	1	4	1	4
Use CNC simulator program	To generate the NC code and test the program and determine the producing time	No information						
Production planning	To plan and schedule the production quantity	schedule difficulties	- extend production time - Increase the production rate	- weak scheduling system - no cooperation with other working systems - stoppages and downtimes	3	6	4	72
Download/simulate the program inside Traub program	Simulate the program to the selected machine	No information						
Installation operations	-Do the set up for the machine	- long time - repeat the job many times	-Time waste	No standard operating procedures	4	6	5	120

Shift changing	Take information from previous operator	Information transfer	Occur stoppages or problems suddenly	Bad inform process Forget some important information	3	4	6	72
Material loading	-To load	-Pneumatic cylinder	-Minor stoppages	Technical problem	1	4	1	4
Material fixture	-Prepare material before machining	-Marking surface finished product -Material waste	-Bad quality -Material waste	- some technical errors in the fixing module - bad material quality -	3	5	2	30
Run CNC program	-To run the operation program	- use the suitable speed and feed rate - Efficiency of program	-Minor stoppages -Material and defect on tools -Waste production time	- errors in the production plan - errors In CNC program	1	1	1	1
Machine controlling	- to control the machine conditions	- machine stoppages	-waste time	- no standard controlling sheet	2	4	1	8
Machining running	-Do several machining operations	-Tools breaks due to problems with non experience operators -Non accurate dimensions -Bad surface finish	-Cost, tool broken -Cost of product rejection -Time waste	- technical problems - wrong tool changing	1	4	1	4
Quality check	-To check diameters, length and dimensions	-The check only for product not process -time waste	-Reject products	- no systematic process is depends on the operator	2	6	1	12
Register problems	To describe any problem happen	- the operator can not describe the problem - the person who solve the problem did not write any thing	- waste time - miss the knowledge development	- no systematic system for problem registration - missing the know-how	5	6	5	150
Take decision	To make decision about machine operations	Difficulties to decision making	- time waste - cost waste	- unclear decision making process - unclear responsible person	4	6	5	120

				- missing some of inputs for the decision				
Cutting tools check	To have same quality level	- time to change - how to change - control the changing process	Bad quality Waste time Repeat the process	Missing deterministic approach for the process No standard operating sheet No control checklist	4	6	2	48
Cleaning machine	-Clean the machine rubbish	-Problem in cleaning method	-Make quality problem for product and process		1	4	1	4
Change T1-finskär huvudspindel, T3,T5	-Change cutting tool	-Frequently tool changes -Experience of the operators	-Time waste	Missing know-how	1	6	1	6
Change T1-asvtick, T2, T3-BORRNING, T4	-Change cutting tool	-Frequently tool changes -Experience of the operators	-Time waste	Missing know-how	1	6	1	6
Final quality control	-Check overall dimension include angel measurements	-Large samples with complications -Late for final QC	-Product rejection	- missing QC schedule	4	5	3	60

Appendix 6.1, Modelling checklist sheet

Processes	Organization	Application system	Databases	Knowledge	Information carriers	Measures	Resources	Products
Shift change	operator	X	production	QC system	QC sheet	X	X	X
Load material	operator	production	Material store	X	Material sheet	X	Raw material	X
Run the machine	operator	X	production	Running procedure	Cutting tool sheet	X	Machine catalogue	X
Controlling machine	operator	X	X	X	X	X	X	X
Make Q.C test	Operator & QC system	X	X	X	QC sheet	X	X	X
Monitor production	Operator & production supervisor	X	X	X	X	X	X	X
Register data	Quality controller	X	quality	X	QC sheet	X	QC system	Quality statistic
Take decision	operator	X	X	X	QC sheet	Quality data	X	X
Stop machine	Operator & production supervisor	X	X	X	X	X	X	X
Cutting tool check	operator	X	X	Changing schedule sheet	X	X	Cutting tool inventory	X
Repair machine (operator)	operator	Machine software	X	experience	X	X	equipment	X
Test & run machine	operator	X	X	X	X	X	X	X
Repair machine (production)	Production supervisor	X	X	experience	X	X	equipment	X
Understand problem	Maintenance workers	Maintenance software	Machine maintenance	experience	X	X	X	X
Fault finding	Maintenance workers	X	X	Experience & checklist	Work order	X	X	X
Repair machine (maintenance)	Maintenance workers	X	X	experience	X	X	equipment	X
Repair machine (out-sourcing)	Out-source workers	Private software	Private database	Special checklist	Work order	X	equipment	X
Production Continue	Operator & production supervisor	X	X	X	X	X	X	Finish goods

Appendix 6.2: stakeholder's requirements

Table (6.11) the derived requirement form analysis techniques

Empirical findings category	Req. No.	Derived requirement(s)	Reference
Production operations description	1	Able to support production scheduling system by Maintenance scheduling system and visa versa.	Table 6.1
	2	Able to Integrate manufacturing operations (installation, set ups)into maintenance management system	
	3	Able to generate standard sheets	
	4	Able to guarantee the right implementation	
	5	Able to solve know-how problems	
	6	Able to distribute the responsibilities	
	7	Able to cooperate production with quality operations	
Maintenance operations description	8	Able to produce a user friendly standard documentations (problem registration)	Table 6.2
	9	able to produce daily schedule of maintenance work	
Quality operations description	10	able to schedules the quality operation within production schedule	Description text
Employee competence	11	able to learn/train the operator	Description text
	12	able to produce daily schedule for operators	
Integration operations	13	able to eliminate the workers communication weaknesses	Description text
Data life cycle and resources	14	able to design practical system for the missing parts such as data preparation, collection and analysis	Table 6.3
Maintenance management auditing	15	able to control the responsibility	Table 6.5
	16	able to control the work order	
	17	able to learn from outsourcing work	
	18	able to measure the maintenance work productivity	
	19	able to updating history records	
Manufacturing process modelling	20	able to define the missing system elements	Table 6.8
	21	able to document the experiences	
	22	able to establish the missing elements	
	23	able to establish the missing relations	
	24	able to smoothing interactions	
	25	able to eliminate overlapping	
Measuring phase	26	able to improve the availability of machines	Table 6.9
	27	able to control the operator activities within two machine	Description text
Process FMECA	28	able to establish problem registration subsystem	Table 6.10
	29	able to establish clear decision making process	
	30	able to establish standard operating sheet	
	31	able to integrate maintenance schedule into production schedule	
	32	able to systemise the information transfer process between workers	

Table (6.12), Originating requirements

Life cycle processes	Req. No.	Stakeholder	Need & Originating Requirements	Reference
Development	33	Operator	It is a complicated activities	Interview
	34	Production manager	I want a reliable system which improve the availability of machines	Interview
	35	Maintenance designer	Able to establish two-way-feedback between maintenance and production	Interview
	36	Quality developer	Ease to reduce the effect of technical problems	Interview
	37	Outsourcing maintenance worker	Able to systematic way for understanding the problems	Interview
	38	Systems engineer	We want define the interfaces between subsystems	Interview
Construction	39	Production manager	The integrated system should be ease to feasible	Interview
	40	Systems engineer	Integrated system should be applicable	Interview
Testing	41	Production manager	Ease to find gaps in order to improve	Interview
Distribution	42	Operator, Production manager and Quality developer	Clear documentation of the system's modifications	Interview
Training	43	Operator, Production manager, Maintenance designer, and Quality developer	Ease to learn the operating system of the integrated system	Interview
Operation	44	Operator	Able to Systemise operator job	Interview
	45	Production manager	Ease to manage the manufacturing operations and other systems interfacing	Interview
	46	Maintenance designer	Increase the cooperation with production	Interview
	47	Quality developer	Should improve the quality control system	Interview
Supporting& maintaining	48	Production manager, Maintenance designer, and Quality developer	Remember the maintaining aspect of the whole integrated system	Interview
Updating	49	Production manager	Able to apply new subsystem or use new technologies	Interview

Appendix 6.3-A Maintenance management systems

maintenance management

- **organizing systems**
  - machine registration system
    - machine instructing system
      - operating instruction system
      - services instructing system
    - designed maintaining plan
      - machine break down structure
        - mechanical systems
        - machine modules
      - machine systems diagrams
        - Pneumatic system
        - electrical systems
        - lubrication system
        - hydraulic system
      - historical practical information system
        - planned stoppages
        - unplanned stoppages
        - modifications
        - services
      - spare parts file
      - updating information system
    - designed maintaining schedule
    - designed maintaining procedure
    - machine reporting system
  - human resources system
  - out sourcing maintenance system
- **identification systems**
  - work request procedure
  - planned maintenance requirements
  - unplanned maintenance requirements
  - work requirements documentation
  - standards
- **work planning systems**
  - priority criteria
  - work classification
  - maintenance capacity system
  - equipment inventory system

    - training program
    - planning improvement work
    - budget execution plan
- **work scheduling systems**
    - data collection system
        - down time schedule
        - condition monitoring data
        - failure/reliability data
    - data analysis system
        - down time scheduler
        - condition monitoring analyzer
        - replacement optimizer
        - inspection optimizer
    - Total schedule system
- **work accomplishment**
    - craft and material availability
    - training program
    - storeroom operation
- **Unplanned maintenance systems**
    - corrective maintenance
        - failure first description by operator
            - first investigation sheet
        - failure investigation & analysis
            - maintenance investigation sheet
        - finding solution
            - search in historical information
        - execution work
            - work order preparation
            - WIP description
            - WIP schedule and plan
        - testing work
            - testing checklist
        - work reporting
            - final report writing
            - maintenance work measurement
            - recommended future actions
    - opportunity maintenance
        - data collection system
        - data analysis system
        - execution work system
            - work order preparation
            - WIP description
            - WIP schedule and plan
            - maintenance work measurement
- **planned maintenance systems**
    - time based maintenance
        - data collection system
        - data analysis system

- execution work system
  - work order preparation
  - WIP description
  - WIP schedule and plan
  - maintenance work measurement
- use based maintenance
  - data collection system
  - data analysis system
  - execution work system
    - work order preparation
    - WIP description
    - WIP schedule and plan
    - maintenance work measurement
- condition based maintenance
  - techniques
    - simple inspections
      - visual
    - condition checking
      - vibration
      - corrosion monitoring
      - crack
      - lubricant monitoring
      - temperature
    - trend monitoring
  - data collection system
  - data analysis system
  - execution work system
  - maintenance work measurement
- reliability based maintenance
  - data collection system
  - data analysis system
  - execution work system
    - work order preparation
    - WIP description
    - WIP schedule and plan
    - maintenance work measurement

controlling systems

- work control
- material control
- inventory control
- cost control

maintenance continuous improvement systems

- TPM systems
  - installation system

- 5's system
- autonomous maintenance
- Kaizen system
- planned maintenance
- quality maintenance
- educating and training
- office TPM
- safety, ergonomic and environment

- RCM systems
  - plant area selection
  - key functions & productivity goals determining
  - plausible functional failures determining
  - failure modes and effects determining
  - feasible and effective maintenance selection
  - maintenance implementation
  - tactics & program optimization

- **Appraisal systems**
  - CMMS
    - equipment management system
    - work order control system
    - crafts management
    - material supply and control
    - performance reporting
    - maintenance reporting

Appendix 6.3-B Manufacturing management systems

Manufacturing management systems

- **business organizing and support**
  - forecasting
  - long range planning and scheduling
  - material requirements planning
  - invoicing
  - accounting
- **identification systems**
  - CAD system
    - geometric modelling
    - design analysis and optimization
    - design review and evaluation
    - documentation and drafting
    - documentation and drafting
  - CAPP system
    - variant CAPP system
    - generative CAPP system
  - Facility layout system
  - CAM system
    - designed manufacturing system
      - NC/CNC programming
      - cellular manufacturing
      - flexible manufacturing system
    - designed automated material handling systems
    - computer aided test system
    - dies/moulds management
    - tools/fixtures management
- **production planning & scheduling systems**
  - aggregate planning system
  - item forecasting
  - capacity planning
  - inventory planning system
  - master production scheduling
  - MRP/MRPII systems
- **execution system**
  - production and process control

    - material handling
    - manufacturing operations
    - testing
    - inspection

- **Production activity control system**
    - manufacturing order approval & release
    - operations scheduling and loading
    - material staging and issue
    - facilitating CAPP instructions
    - priority control in WIP
    - process control in WIP
        - raw materials
        - transport system
        - stores system
        - assembly system
        - test system
        - finished goods system
    - capacity control in WIP
    - quality control in WIP
    - manufacturing order close
    - process evaluation
    - inventory control system
    - cost control

- **CIM databases system**
    - product data
    - product management data
    - production data
    - operational data
    - resources data

- **production continuous improvement system - kaizen systems**
    - lean & JIT systems (Toyota production systems)
        - kanban system
        - production smoothing system
        - set up shortening system
        - process layout system
        - operations standardization system
        - autonomation system
        - cost accounting for improvement system
    - total quality control
    - total productive maintenance
    - policy deployment
    - suggestion system
    - small group activities