



**MÄLARDALEN UNIVERSITY**  
**SWEDEN**

# *Downtime cost and Reduction analysis:*

## *Survey results*

Master Thesis Work, Innovative Production, IDT  
KPP231

**Mohamad Tabikh**

**Commissioned by:** Mälardalen University

**Supervisor:** Dr. Antti Salonen

**Examiner:** Dr. Antti Salonen

# Abstract

*The purpose of this paper is to present a sample of how Swedish manufacturing companies deal with equipment downtime cost, and further how they analyze its reduction. The study was performed by conducting a web-based survey within Swedish firms that have at least 200 employees. The main results obtained from the investigation show that the estimated downtime cost constitute about 23.9 % from the total manufacturing cost ratio, and 13.3 % from planned production time. Additionally, the hourly cost of downtime, whether planned or unplanned, is relatively high.*

*However, there is a shortage of systematic models that capable to trace the individual cost imposed by downtime events. This lack was shown apparently whilst 83 % of surveyed companies they do not have any complete model adapted for quantifying their downtime costs. Moreover, only few companies develop their cost accounting methods such as, activity-based costing (ABC) and resource consumption accounting (RCA) to assimilate and reveal the real costs that associated with planned and unplanned stoppages. Still, the general pattern of downtime cost calculation allocated to direct labor and lost capacity cost.*

*On the other hand, the attempts of decreasing downtime events and thus costs were based on schedule maintenance tactics that supported by overall equipment effectiveness (OEE) tool, as an indicator for affirming improvements. Nonetheless, the analysis indicates the need for optimized maintenance tactics by incorporating reliability-centered maintenance (RCM) and total productive maintenance (TPM) into companies' maintenance systems. The maintenance role of reducing downtime impacts not highly recognized. Furthermore, the same analysis shows the requirement for better results of performance measurement systems is by implementing total equipment effectiveness performance tool (TEEP). The advantage of such tool is to provide the impact index of planned stoppages in equipment utilization factor.*

*Finally, the lack of fully integrated models for assessing the downtime costs and frameworks for distinguishing the difference between planned and unplanned stoppages are the main reasons behind the continuation of cost in ascending form. Due to that, the improvements will emphasize on areas with less cost saving opportunities. As a result, this will affect the production efficiency and effectiveness which in return has its influence on costs and thereby profits margin.*

**Keywords:** Downtime cost, planned stoppage, Maintenance optimization, Performance measurement systems, Swedish manufacturing companies

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# Table of Contents

<b>1. Introduction</b> .....	8
1.1 Background .....	8
1.2 Problem discussion .....	9
1.3 The objective and Research questions .....	10
1.4 Delimitations and limitations .....	11
1.5 Summary of the chapter .....	12
<b>2. Methodology</b> .....	13
2.1 Research philosophy .....	13
2.1.1 Research philosophy of this study .....	14
2.2 Research approach .....	15
2.2.1 Research approach of this study .....	16
2.3 Research methods .....	16
2.3.1 Research method of this study .....	17
2.4 Research strategy .....	18
2.4.1 Internet based survey .....	18
2.4.2 Research strategy of this study .....	19
2.5 Data collection tool - Questionnaire .....	19
2.5.1 Questionnaire design of this study .....	20
2.6 Data Analysis.....	23
2.6.1 Data analysis of this study.....	24
2.7 Research credibility.....	25
2.7.1 Reliability .....	25
2.7.2 Validity.....	25
2.7.3 Credibility of this study .....	26
2.8 Summary of the chapter .....	27
<b>3. Theoretical framework</b> .....	28
3.1 Cost accounting methods .....	28
3.1.1 Traditional cost accounting .....	28
3.1.2 Life Cycle Costing .....	29
3.1.3 Resource Consumption Accounting .....	31
3.1.4 Activity Based Costing .....	33

3.2 Performance measurement systems.....	35
3.2.1 Overall equipment effectiveness .....	35
3.2.2 Total equipment effectiveness performance .....	37
3.3 Maintenance concept and interventions .....	38
3.3.1 Maintenance definition and perspective change .....	38
3.3.2 Maintenance strategies, policies and tactics .....	39
3.4 Downtime identification, causes and effects .....	42
3.5 Determination of cost categories .....	46
3.6 Summary of the chapter .....	49
<b>4. Results .....</b>	<b>50</b>
<b>5. Analysis and Discussion .....</b>	<b>58</b>
<b>6. Conclusions and Suggestions .....</b>	<b>68</b>
<b>7. References.....</b>	<b>70</b>
<b>8. Appendices .....</b>	<b>74</b>
8.1 Appendix (A), The Swedish version of questionnaire template.....	74

# List of Figures and Tables

## Figures

- Figure 1.** The difference between inductive and deductive process ..... 16
- Figure 2.** The respondents’ number and their positions ..... 21
- Figure 3.** Respondents’ type of industry ..... 22
- Figure 4.** The structure of forecasting model for calculating LCC..... 30
- Figure 5.** Traditional costing and activity- based costing..... 34
- Figure 6.** OEE and the perspectives of performance integrated in the tool..... 36
- Figure 7.** Conceptual process of maintenance impact on firms’ profits..... 39
- Figure 8.** The sequential steps of RCM analysis ..... 42
- Figure 9.** The generic factors and processes that related to Downtime event ..... 44
- Figure 10.** The effect of downtime duration on process activities ..... 47
- Figure 11.** The cost categories that associated with downtime in manufacturing ..... 48
- Figure 12.** The methods used by firms for assessing downtime cost ..... 64
- Figure 13.** Differences of decreasing downtime costs through maintenance tactics..... 66

## Tables

- Table 1.** The comparison between positivism and interpretivism ..... 14
- Table 2.** The different types of scales of data and their descriptions ..... 24
- Table 3.** Maintenance strategies, policies and characteristics ..... 40

# List of Abbreviations

**LCC:** Life Cycle Costing

**RCA:** Resource Consumption Accounting

**ABC:** Activity Based Costing

**OEE:** Overall Equipment Effectiveness

**TEEP:** Total Equipment Effectiveness Performance

**RM:** Reactive Maintenance

**PM:** Preventive Maintenance

**CBM:** Condition Based Maintenance

**RCM:** Reliability Based Maintenance

**TPM:** Total Productive Maintenance

**FMECA:** Failure Mode, Effects, and Criticality Analysis

**TQM:** Total Quality Management

# Chapter 1

## 1. Introduction

---

*The opening chapter mainly displays the motivation factors behind the thesis topic and the intention of approaching such a subject. Further, the introduction context enclosed by different constituent elements namely background, problem discussion, objective, research questions, delimitations, limitations, and finally a chapter summary. The report structure consists of eight chapters, and at the end of the first three chapters brief summary will be provided. The purpose is to facilitate the process of idea flow and content coherence; especially the first three chapters addresses the theoretical background of this study. Consequently, the overall goal of this chapter is to furnish the reader with a general understanding about the proposed topic.*

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### 1.1 Background

In today's competitive manufacturing market, production efficiency and effectiveness are among top business priorities. Thus, production equipment becoming the central focus of interest as it is the backbone of the manufacturing process and key performance indicator of productivity. The requirements of outstanding performance force companies to substantially consider reducing their machines downtime frequency and its consequential costs [1].

Equipment downtime occurs due to planned or unplanned stops. However, the unplanned stops caused by failures and disturbances occurrence are the most common unexpected factors that have the non-trivial influence on the overall productivity. Also, this interrelation between downtime events and productivity lies in gist of economic connotation, in which cost and profit variables are inversely proportional by means of decreasing downtime cost and thereby increasing production profit [1]. To this end, in order to decrease the downtime cost, suitable and developed costing methods are needed to calculate and trace every single cost disbursed during the stoppage juncture. All activities and resources that have depleted whilst retrieving the production equipment function should be allocated based on their real costs. The primary role of costing method is to highlight areas with high-cost savings, and of which

managers proceed to implement improvements. For instance, one explicit trade-off is between costing methods and maintenance applications. Productive maintenance strives for minimizing downtime events and hence cost. On the other hand, proper costing method can be of much beneficial to maintenance managers through assessing the efficiency of the adopted maintenance policy. Moreover, it allows the use of series mathematical modelling and simulation as an input to optimizing maintenance strategy, in particular, the preventive maintenance strategy [2].

Thereupon, a real case study is very urgent in approaching this topic in a logical manner. According to that, Swedish manufacturing industry was chosen for this issue as it has perceived vast technological progress within production facilities. Moreover, the infrastructure of such development was based on the installation of robotic systems. Nevertheless, these sophisticated and complex systems exposed to frequent stoppages wherein are some of these stoppages has a significant impact on production outage and so lost profit [3].

The case of malfunctioning equipment and its restoration is very costly and requires many resources and budget expenses. For those mentioned reasons, Swedish manufacturing industry is considered a good option to investigate especially the issues that related to downtime cost and reduction analysis.

## 1.2 Problem discussion

According to Lincoln [4], the downtime costing methods that have been used by manufacturing companies they are often static in nature and inappropriate of measuring the dynamic nature of production lines. These methods lack the ability of identifying the hidden cost categories and instead emphasized on the direct cost that levied itself. Additionally, the traditional paradigms of costing downtime did not accurately traced the consequential costs of changing system behavior in accordance to random downtime events. The downtime cost bundled with other costs in an overhead bucket, where managers cannot have a clear vision about the individual cost of downtime and thus conduct practical decisions in line of improvements.

On the light of this, the research has been previously estimated that 80% of industrial facilities were unable to quantify the cost of downtime. Furthermore, many companies underestimating the total cost by a factor of 200-300% [5]. However, the research did not mention any remarkable work about the real cost of planned stoppages and how it contributes to downtime total cost [6].

Under those circumstances, the common attempts toward decreasing downtime events and further costs were restricted to applied maintenance, in which consider the crucial pivot in assuring the availability of production equipment. Nevertheless, the difficulty of selecting the optimal maintenance policy or by practicing the inefficient maintenance tactic, not only will fail to reduce downtime incidents but rather will lead to added-costs [7]. In return to Swedish industries, the role of maintenance is not exceedingly recognized. There is a need to invest more in productive maintenance, which is considered by the majority as a necessary expense [8].

### 1.3 The objective and Research questions

The overall aim of this work is to investigate on downtime costs in Swedish manufacturing companies, and how they are analyzing its reduction. Specifically, this work will discuss issues related to the subject such as, cost categories and drivers that attributable to downtime events whether planned or unplanned. The firms' used methods for assessing the cost of downtime, and what are their holistic vision about the cost difference between planned and unplanned stoppages. Finally, the accredited maintenance applications so as to reduce the downtime events and thus costs.

*Therefore, a set of research questions formed for achieving the work objective and those questions are:*

- 1. What are the main cost categories and drivers associated with planned and unplanned stops can be identified?**
- 2. Which methods are used in industry for assessing the cost of downtime?**

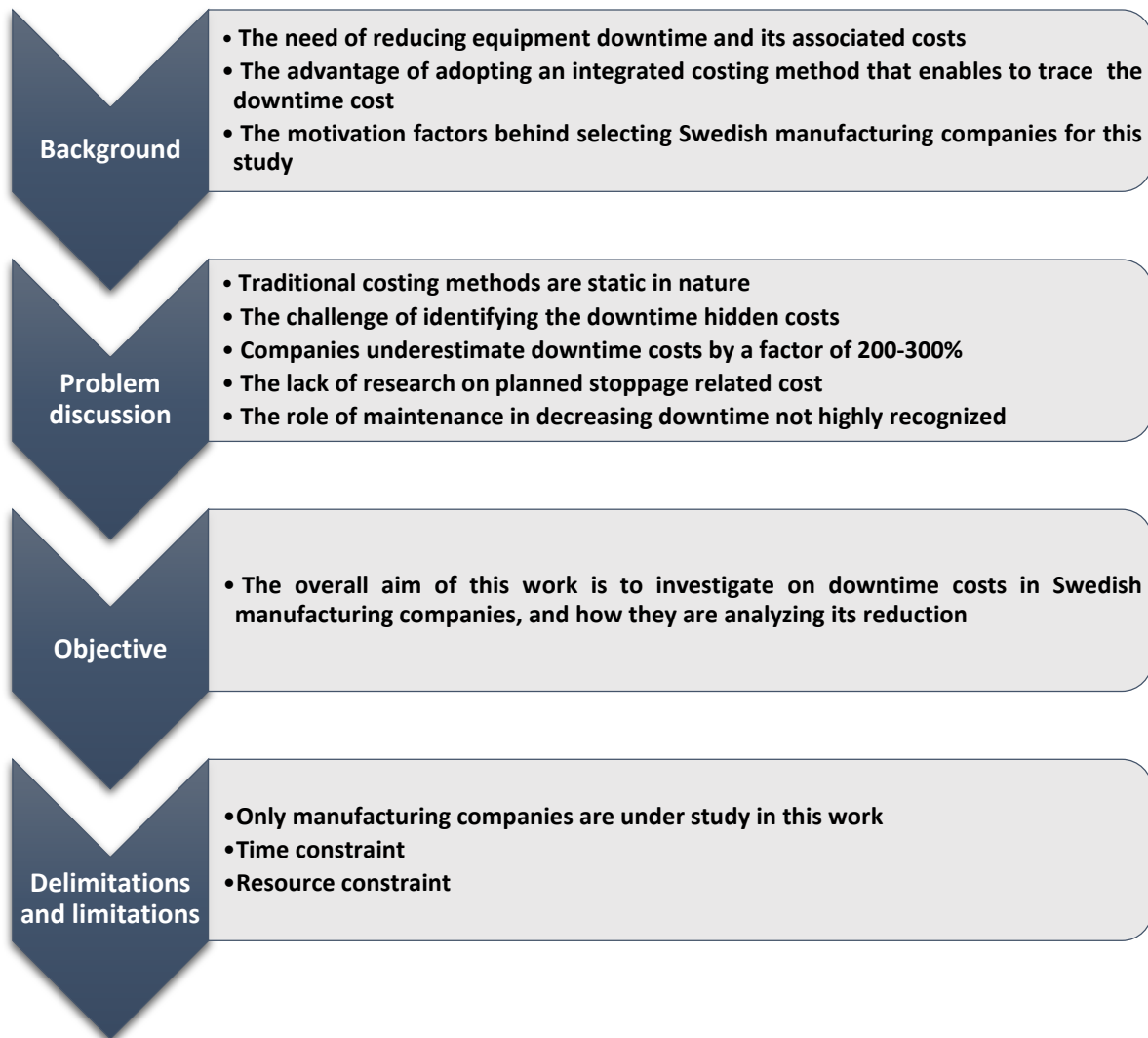
- 3. What is the industry's view of the cost difference between planned and unplanned stops in production?**
- 4. What is the maintenance strategy that applied for reducing downtime events and thereby costs?**
- 5. Is there any performance measurement system adopted for evaluating the improvement of production equipment?**

#### **1.4 Delimitations and limitations**

The work delimitations can be divided into following points: (1) the field of selected population that required to conduct this survey was mainly chosen from the manufacturing companies with high capital investments. According to that, the equipment downtime has a significant impact on cost and productivity. (2) IT companies and service providers were excluded from this work. (3) The improvement procedures of decreasing downtime cost were only associated with maintenance practices, regardless other methods that could be efficient and applicable.

On the other side, the limitations were classified as uncontrolled factors whilst performing this study. The first factor was the time constraint; this work built on a survey study and required more time to assimilate much responses and analysis. The second factor was the scarce resources and literature of costing downtime in manufacturing environment, especially the works that correlated to planned stoppage costs.

## 1.5 Summary of the chapter



# Chapter 2

## 2. Methodology

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*In this chapter, a description of how study was conducted is presented. Moreover, a comprehensive discussion about adopted research method and its strategy is also provided.*

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### 2.1 Research philosophy

The philosophical attitude of qualifying any research work mainly based on arguing the methodology that have been adopted for a particular investigation. The decision of selecting one method rather than another will be assessed individually by researcher's vision, ontologically and epistemologically, that often related to the research questions in hand [9]. The research paradigms referred to conservative philosophical schools, which known as positivism and interpretivism. Both schools have their impacts of constituting the significant evolve of controversial science [10].

*Positivism* is considered the co-founder of epistemological movement, especially in connection to social science. The pioneers of this philosophy introduced the argumentative that social world exists externally to researcher, and can be measured directly through observation. This statement implicit properties of which researcher must be restricted. Subjectivity, not any more accepted. Instead, objectivity is the new trend that enables scientific research on a logical basis. In addition, the independence of analysis is neither affected nor affects by the subject of the research [10].

The achievement of state-of-art research in accordance to positivism require clear mechanism and structured method. This methodology facilitates the process of collecting observations and further quantifying them statistically [10]. In contrast, *interpretivism* approached the interrelation between people and their environment. The debate core here contradicts the essence of positivism custom, *see table 1*. Interpretivism beliefs are based on merging axiomatically both entities, the researcher and social world in one mold. The researcher and

his/her social world cannot be separated. For this reason, the criteria of embracing interpretivism values in research work demanding the methods to emphasize on people. For example, the data collection procedure, usually, preferable with qualitative over quantitative data. In this context, the investigator should make interviews to figure-out people behavior in a particular phenomenon [11].

**Table 1. The comparison between positivism and interpretivism**

	Positivism	Interpretivism
Reality	Objective, External	Subjective, Internal
Type	Survey, Experimental, Quantitative	Phenomenology, Qualitative
Purpose	Generalize, control	Interpret, Understand

Source: Merriam [12]

**2.1.1 Research philosophy of this study**

The philosophical discourse on the subject of this study has been taken to a large extent the positivism manner, as a base for approaching downtime costing issues in Swedish manufacturing companies. Moreover, this study claims the objectivity through investigating topic problem, i.e., information, data, and all types of obtained results were presented as given without any biased subjective influence. According to positivism, any problem must be into considerations of numerical assessment and can be realized throughout customized

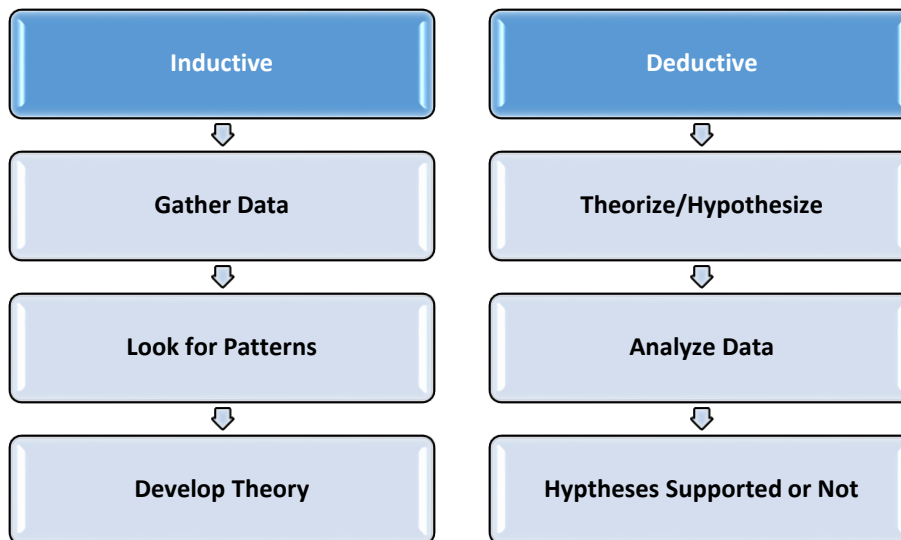
measurement tool. Therefore, this study utilized web-based survey as a tool for collecting data and further creating a database for content analysis. The enumerated analytic techniques such as, descriptive statistic was adopted to discern the central tendency of population. Furthermore, this type of analysis enables to generalize results and spotlights interrelated factors.

Nevertheless, the distinction between positivism and interpretivism and in relation to best research philosophy is quite difficult. They have interchangeable characteristics in which any separate selection may lead to impairment of research quality. In my opinion, they are somehow linked in one way or another but at different levels and their causality based on the nature of matter that under study. Consequently, this relative relationship between those two concepts will be pointed-out during the display of upcoming chapters, for instance while firms calculate their downtime costs. They exclude the cost of planned stoppages as routine that entrenched to mindset and organizational cultural aspects.

## 2.2 Research approach

One of the essential crucial elements in research is to specify which method is being applied. There are two well-known approaches dedicated to research namely, inductive and deductive. In the *inductive approach*, the researcher strives for collecting the data that considered relevant to the topic of interest. Then, the next step starts with analyzing these data in purpose of finding patterns, and afterward developing a theory that could interpret such patterns. Hence, if research trending towards the inductive paradigm the driven factors might be attached to set of observations, and indeed must transit from particular experiences to more general set of propositions about those experiences [13].

In a paradox with inductive concepts, *deductive approach* enforces researcher to start with existing theories and then attempting to tests its inferences with data, *see figure 1*. In general meaning, deductive characteristics constrained the work procedure to be into scientific investigation category as labelled by positivism. The investigator must review what others have done in the field, and that in ease of drawing hypotheses that emerges from studied materials [14].



**Figure 1. The difference between inductive and deductive process**

Source: Blackstone [14]

### 2.2.1 Research approach of this study

The scientific approach of this study is deductive in nature, and that because the project idea created after wide review of existing theories. Those reviews are the literatures that associated with downtime cost in production systems. For instance, the proposed methods and models to quantify the downtime cost, the difference between planned and unplanned stops, identification of cost drivers, and the maintenance strategies to increase reliability and thereby minimize downtime cost. The study primarily included articles published in prestigious scientific journals, conference proceedings, books, theses and any other relevant reports that may considered important and fulfill the level of scientific research standards.

Afterthought, the step was to formulate research inquiries - in the form of research questions - from what have been reviewed and then begins with collecting and analyzing the obtained data in order to answer the research questions. Finally, the compiled results and conclusions will either confirm or reject the proposed research hypothesis.

### 2.3 Research methods

The best-chosen method for gathering data have been disputed between qualitative and quantitative audiences. In general principle, any selected method either quantitative or

qualitative based will be considered appropriate as long as it guides the anticipated research. Hence, the nature of given research determines the method that needed to accomplish better results [15].

*Qualitative* method explores attitudes, behavior and personal vision through interviews or focus groups. It attempts to obtain opinions from specified participants in which few people take part in the research. In a paradox, *quantitative* method generates statistics through use of survey accompanied by the assistance of questionnaires. This type of methods reaches many participants, and the contact is much quicker than it is in qualitative [15].

The main differences between qualitative and quantitative research methods explained into following points:

- Quantitative data collection is more close-ended in comparison with qualitative data collection that based on more open-ended
- Quantitative data analysis used the statistical theories as background; Qualitative data analysis count on text or image analysis.
- Quantitative reporting has a set structure, as it grounded on mathematical elaboration; Qualitative data reporting is more flexible and may contain additional conscientiousness [16].

### 2.3.1 Research method of this study

The study of downtime cost analysis in Swedish manufacturing companies required large size of active participants in order to achieve good results. Therefore, a quantitative method based on survey was adopted and considered effective over qualitative because the target is to assimilate many responses in limited duration. Moreover, the acquired data might be easier to standardize in numeric form for later comparison than data obtained through qualitative methods.

The choice was not easy though, because topic like downtime cost evaluation it might contain more investigations about human and machine interactions. In other meaning, the qualitative analysis could magnify the problem from different angles. However, the proposed survey was

included semi-structured questionnaires in which allows participants to present their opinions to some extent.

## 2.4 Research strategy

Research strategy defined as the way that relied on logic and set of procedures with the aim of answering research questions in particular. There are many listed strategies used by research work such as, survey, experiment, case study, grounded theory and so on [17]. In spite of the variety of available strategies, this work feasibly implement the survey strategy as a tool for answering research questions. Thus, the following parts introduces only elements that shaped such strategy and omitted others for its unsuitability to this study.

### 2.4.1 Internet-based survey

Survey defined as a measurement process through asking questions, and that in the aim of collecting information from selected group of interest to be representative of a larger population. In fact, this procedure known as a sample survey and its importance allows to generalize results even though not the whole population being tested. There are two types of surveys, questionnaire and interview. The questionnaires mainly handed-out through different ways, electronically, by asking online questions and by sending private emails or throughout physical distribution by post. On the other hand, the interview associated with face-to-face meetings or via phone [18].

According to Cohen et al. [19], internet-based survey is becoming commonplace in many branches of science because of its accessibility of features over other methods. Some of those features can be summarized as following listed points:

- Automated data entry
- Lower costs
- Wider distribution
- Faster turnaround times [20]

#### 2.4.2 Research strategy of this study

The success of this work required an accurate sample from large existing population. Although, the time and expenditure factors also a paramount concern whilst planning any survey. For this reason, internet-based survey was considered a right choice to get fast responses with high rate participants, in addition to the advantages that arise for both surveyor and contributor by flexible data entry. This method has its positive impacts on the planned budget as well, since there is no much work done manually and no paper work included through distributing questionnaires. In the light of this benefits, the environmental facets have been likewise influenced in a safe manner.

#### 2.5 Data collection tool - Questionnaire

One of the techniques that commonly used in collecting data is well-defined. This technique namely, questionnaire, it composed of customized and set of standardized questions in which aim for gaining new knowledge from a given subject. There are different types of questions incurred questionnaire layout such as closed-ended, open-ended and combination of both questionnaires. Closed-ended questionnaires, usually, more suitable for quantitative research than other types because it's easier to generate statistics and perform analysis. Open-ended questionnaires have better consistency with qualitative research than quantitative, but still researcher could quantify the answers during the analysis stage. As well as, this questionnaire offers respondents the freedom to express their opinion without any restriction [15].

Additionally, the mixed-questionnaires have been more applied recently whereas many researchers tend to use such approach of closed and open questions at the same template. Furthermore, this questionnaires might enclose a series of closed questions, with boxes to tick or scales to rank and even an open questions for getting more detailed responses at the same time [15].

The planning and design stage of the questionnaire required a set of sequenced steps in order to perform a convincing scientific questionnaire as stated by Cohen et al. [19]. Firstly, the researcher needs to start with deciding the objectives of the questionnaire and then specifies the population in which the sample will extract from. Next, the investigator must generate concepts to be addressed and data required for meeting purposes of the study. After that, the

decision of varieties of measurements and questions should be evaluated in order to confirm if its test the research questions/ hypothesis. Then, the subsequent steps start with writing questionnaire items and piloting questionnaire, to end with the final version of reliable and valid questionnaire.

### 2.5.1 Questionnaire design of this study

*The plan and design process of questionnaire that dedicated to this study passed through three stages: the objective of the questionnaire; population and participants; and finally the procedure*

#### **1. The objectives of questionnaire**

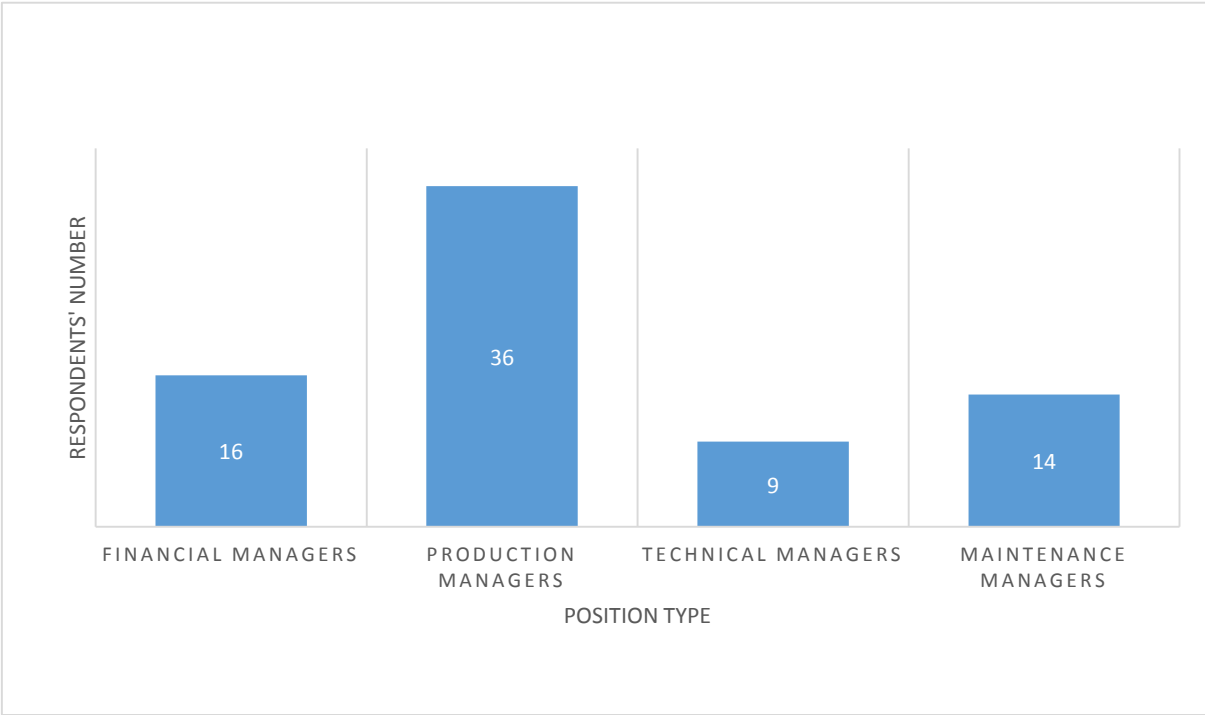
The aim of the questionnaire that centered this study is to collect information and data about how Swedish manufacturing companies evaluate their downtime costs and its reduction. Then, the subsequent stage is to analyze obtained results and recommend improvements of conditions pertaining to matter at hand. In like manner, the questionnaire should meet the research objective directly and neglect all questions that do not support the overall target. The research questions should be answered by questionnaire, and that in order to generalize results from specified population and by this means affirming the reliability and validity of the tool.

#### **2. Population and Participants**

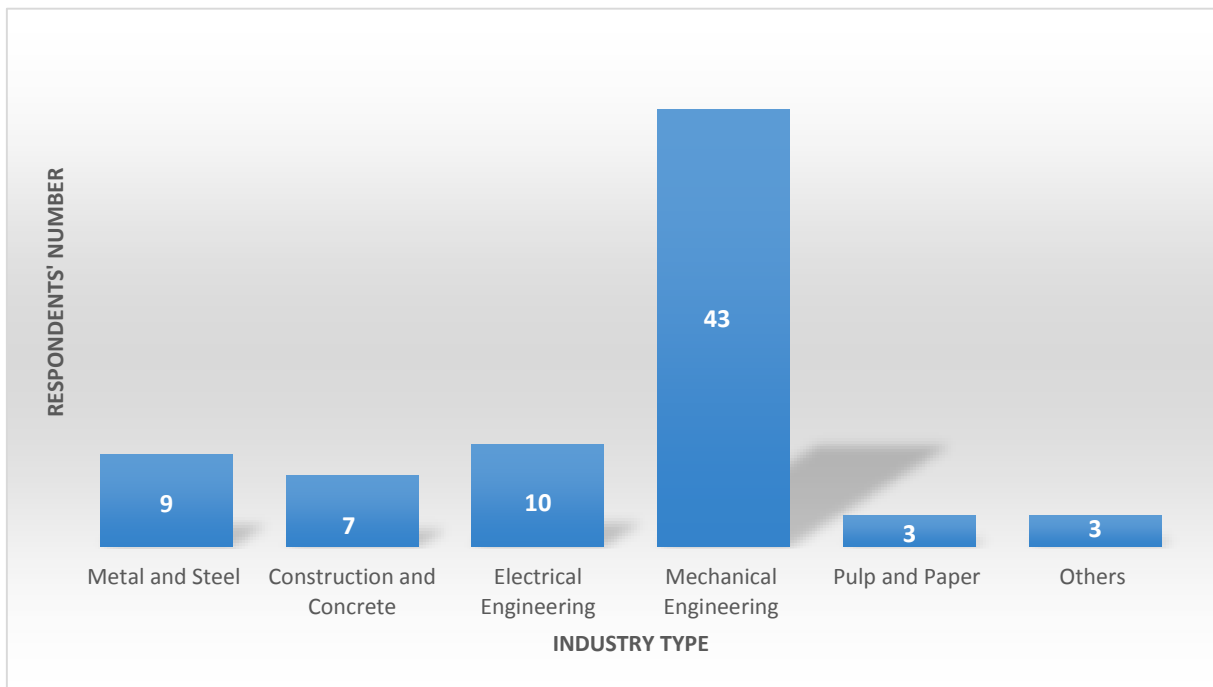
Once the questionnaire objectives identified clearly, then the next important step was by specifying the population and participants that needed for conducting the empirical study. The decision was to find manufacturing companies that have intensive production lines in which downtime events has a significant impact on their productivity level and costs. Furthermore, the participants must be appropriate for answering the questionnaire and have a broad cognizance about the subject related issues. Therefore, a list of 647 email addresses of financial, production, technical, and maintenance managers have been acquired from the official database company. The company known as “parguide-Bisnode” and has a database that including detailed information about all active companies, worksites, and organizations in Sweden. Those addresses present 647 firms wherein they have at least 200 employees.

The survey starts by sending-out email for every member of the selected population, for instance, 647 emails have been sent-out. Each email was included the research topic, purpose, and a link to questionnaire website in addition to expected time needed to answer the questions, i.e., around 10 minutes. However, 189 email addresses were removed for various reasons such as invalid addresses or the probable participants are not in their positions anymore. Thus, the total population of this study was restricted to 458 employees from different manufacturing industries, and the number of respondents was 75, which represents the overall response rate by 16.3 %.

The respondents were 21.3 % financial managers, 48 % production managers, 12 % technical managers, and 18.7 % maintenance managers, *see figure 2*. Moreover, the respondents were distributed among the following industries: 58 % of the respondents were in mechanical engineering, 13 % electrical engineering, 12 % metal and steel, 9 % construction and concrete, 4 % pulp and paper, and 4 % other types of industries, *see figure 3*.



**Figure 2. The respondents' number and their positions**



**Figure 3. Respondents' type of industry**

### 3. Procedure

The questionnaire used in this study consist of three main parts: general, downtime cost analysis part and supplementary questions. The number of main questions was 13 additionally to sub-questions. The questionnaire designed according to the standard of constructing relevant, short and understandable questions. At the same consistency, the structured questions were allowing respondents to pick an answer from a set of listed possibilities. As well as, open-ended option was necessary to be adopted in sake of enabling respondents to elucidate their answers as intended.

The questionnaire passed through different stages of procedures such as drafting, pre-testing, finalizing and production. The first stage includes the drafting process of objective questions in which attempts to cover all the pertinent aspects of chosen subject. Hence, the questions content and wording have been checked by academic expert to assure that questions contained the educational, technical, organizational and financial aspects. Furthermore, the first draft was written in English and then translated to Swedish. This procedure happened because the targeted group for survey were located in Sweden, and for more responses and better results the decision has been made based on this matter. However, the altered version,

*see appendix A*, has also been corrected by academic expert to guarantee the content understandability.

The next stage was to pre-tests the constructed questions if they are easy to understand and can be answered directly, thereof the questionnaire was introduced to different industrial practitioners and the results were encouraging. After that, the final stage was by finalizing and producing the questionnaires, one questionnaire was sent to each participant by email and so forth. This process occurred on the first level of distributing questionnaires and then after a while the first and second reminder using emails correspondingly performed.

## 2.6 Data Analysis

Quantitative data analysis is a vigorous research form, originating from the positivism source. It is often linked to large-scale studies such as, surveys. It can also employ in smaller scale studies, i.e., action research, case studies, experiments, and correlational research. Statistical formulas ground the numerical analysis, and usually, the analysis processed through software tools. These tools simplify the complex computations. However, the scales of data must be clearly identified before the data analysis launched, *see table 2* [19].

There are two main well-known techniques in analyzing the data's, descriptive and inferential statistical methods. The descriptive statistics are denoted by mode, mean, median, range, variance, standard deviation, standard error, skewness, kurtosis, etc. On the other hand, inferential statistics consists of Hypothesis testing, correlations, factor analysis, regression, etc. With this classification in mind, a systematic process of selecting the technique whilst conducting data analysis considered a critical step for better results and thereby drawing rational conclusions [19].

**Table 2. The different types of scales of data and their descriptions**

SCALES OF DATA	DESCRIPTION
NOMINAL	Denotes categories
ORDINAL	Classify and introduces an order into the data
INTERVAL	Introduces a metric
RATIO	Embraces the classification, order, metric and a true zero.

Source: Cohen et al. [19]

### 2.6.1 Data analysis of this study

After the data had collected, the main results and findings obtained through processing these data by descriptive statistical techniques. During the analysis phase, each question was analyzed separately and treated as mutually exclusive variable. The arithmetic averages and standards deviation in addition to other elements within descriptive statistics were mainly considered in the analysis of central tendency. In a precise, arithmetic average were treated as weighted average score on Likert-scale and ranged from 1 to 5. The equation used for arithmetic average denoted as:  $\mu =$

$$\frac{1}{n} * \sum_{i=1}^n x_i$$

And standard deviation equal to

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$$

*These symbols express as:  $n/N$  = number of participants,  $X_i$  = number of participants given score out of five on Likert-scale [21].*

## 2.7 Research credibility

*The aim of any research is to be trustworthiness or in scientific term, credible. The research credibility can be classified into two parts: reliability and validity*

### 2.7.1 Reliability

Reliability is the extent to which achieved results are consistent over time and can reproduce under a similar methodology; thus, the approach is considered reliable. The vitality of this definition instigating researchers to create stable measurements in which can sustain same results when the procedures are repeated [22].

Even though, still there is an alive argument about research reliability especially in a survey studies. The test-retest questionnaire may sensitize the respondents to the subject matter, and therefore affect the responses given. So, the state of an attitudes change may lead to differences in answers provided in which have been identified by surveyor as extraneous variables [22].

### 2.7.2 Validity

Validity determines whether the research measures what was intended to measure. In other words, does the study tool was collected the appropriate data that needed for answering the research questions [23]. Moreover, the validity in quantitative research was described as “construct validity”, the cornerstone of validation. The construct is the initial question, concept or hypothesis that regulates which data is to be gathered and in which way [22].

There are different types of validity:

- I. *Internal validity*: it shows how dependent and independent variables logically connected
- II. *External validity*: this kind linked to which the results can be generalized, and the conclusions may be projected in other settings.

- III. *Statistical validity*: is a mathematical measure used and considered relevant enough to evaluate the cause and effect between variables.
- IV. *Construct validity*: this type of validity associated with the optimum selection of theories that considered applicable in line of the research subject. It legitimates the relationship between studied variables, for instance, if the theories that used cover all aspects of the study [23].

Insofar of these definitions and taxonomies, the general term of reliability and validity divided into two strands: firstly, the reliability frame constrained by whether the obtained result is replicable. Secondly, in return to validity, one can say the content is valid as long as the means of measurement are correct and if they are actually assessing what they are anticipated to measure [23].

### 2.7.3 Credibility of this study

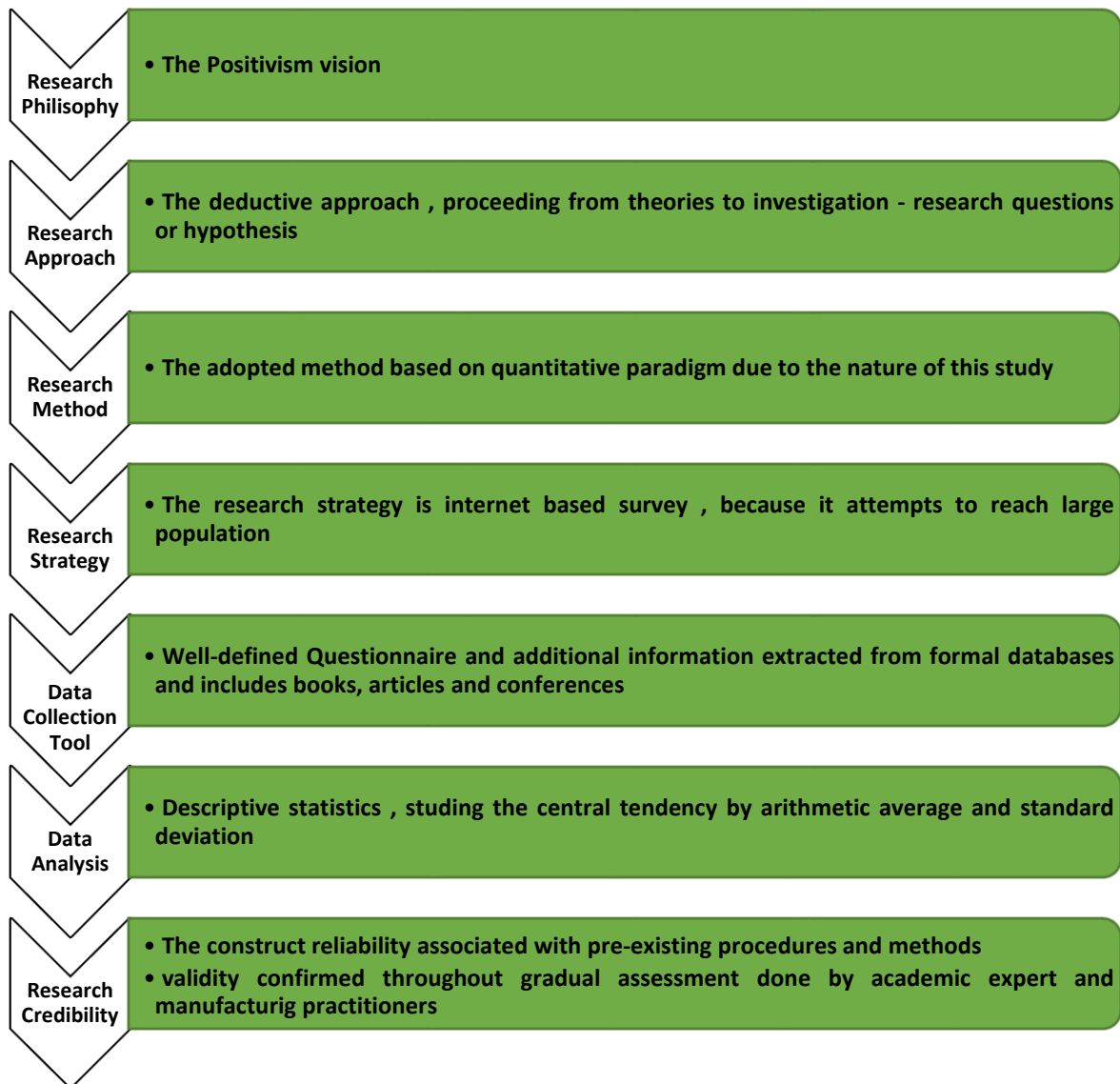
This report claims that it has followed the scientific foundations in every stage of investigating the downtime cost analysis in Swedish manufacturing companies. Accordingly, the methods used; data collection tool; analysis; presented results as well as theories that attributed to its content was based on purely scientific approach.

*Thereof, we can declare the reliability and validity of this work through list of following points:*

- The work consists of pre-existing theories, methods and procedures as cited in many scientific references such as books, conferences, and journals. Therefore, if any new investigator conducts same study mostly will attains similar results.
- The questionnaire used in this study was designed with structured questions for instance, mixed questions (open and close) in which the responded has the freedom to introduce his/her opinions as intended. This structure improves the construct validity and reliability of the instrument.
- The questionnaire was based on appropriate theories and literature and was pre-tested by academic expert and manufacturing practitioners in order to ensure that all concepts are clear and relevant.

- A check of every question to assure the adequacy of measuring all needed aspects and subject areas within the proposed study. This procedure will increase the reliability of the questionnaire and so forth construct validity.

## 2.8 Summary of the chapter



# Chapter 3

## 3. Theoretical framework

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*This chapter will present the concepts and theories that have been deployed in questionnaire. Furthermore, a holistic literature review incurred into this section in purpose of enriching the knowledge about the mentioned field.*

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### 3.1 Cost accounting methods

#### 3.1.1 Traditional cost accounting

There are many cost accounting methods exist in manufacturing industries. The evolution of those costing methods is not entirely compatible with the development that intervene production systems. The introduction of lean manufacturing strategies obliges companies to launch a new costing structure, in which can fulfill the requirements of agile production lines. This technological advancement, beside the cultivated automation, made Swedish manufacturing companies aware of the importance of developing their costing methods, as it was monitored at ascending level. Further to that, and in return to the traditional costing accounting methods, Swedish firms were stemmed its accounting method originally from a model that firstly presented by Frenckner and Samuelson, [24].

The model viewpoint was meant to ascribe the manufacturing costs by the absorption factor of the unit produced. In other words, absorption costing or full absorption method is considered a way for distributing all costs generated to every finished product. Moreover, the mentioned model determined a set of cost items whilst analysis takes place. Those items can be distributed into direct labor, direct material, indirect material, administration, sales, and manufacturing overhead costs. The presented model was in the era of mass production. Therefore, the manufacturing overhead costs as maintenance, energy, design department, etc. was apportioned according to direct labor, direct material, labor hours, and machine hours [25].

### 3.1.2 Life cycle costing (LCC)

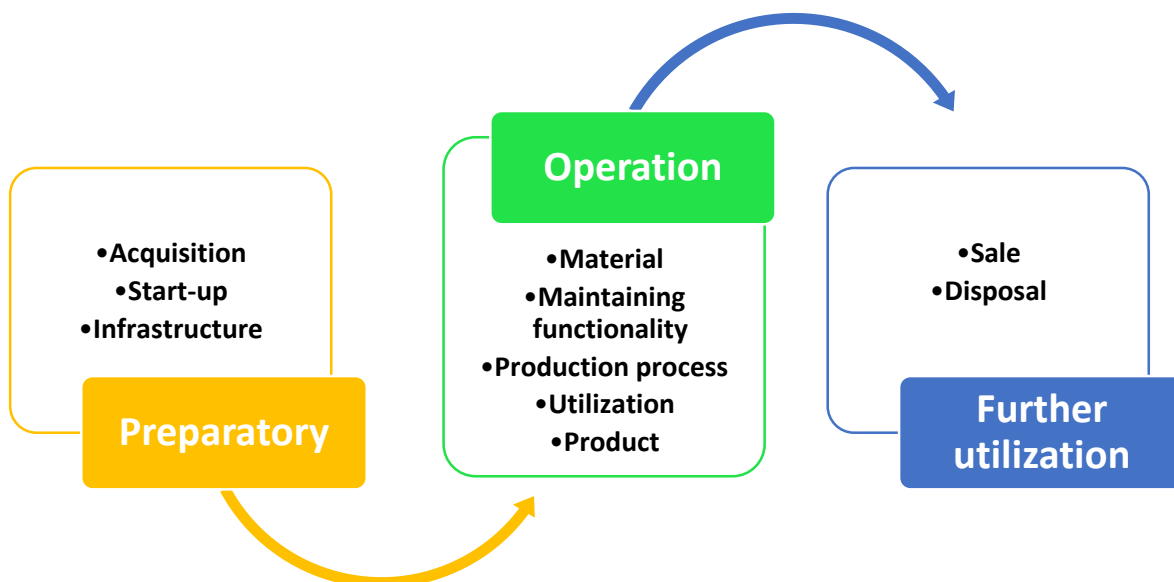
LCC is a method that pursues to optimize the cost of physical assets over their valuable lives, through identifying and quantifying all the incorporated costs tangled in that life, and that by using the present value technique. The general procedure for LCC analysis defined in first position the cost elements of interest, or all the cash flows that happened during the lifespan of the asset. The process of LCC of an asset, usually, includes all the expenditures that attached to it, and in particular the conversion stage from acquisition until disposal at the end of functioning life. The second step of the procedure is to delineate the cost structure, the structure mainly consists of those costs that can be grouped together so as to identify the potential trade-offs and thereby achieving optimum LCC. Moreover, the cost collections divided into three modules of engineering and development; production and implementation; and operation. Similarly, other cost categories distributed into utilization, ownership and administration. Even more, there is proposed cost categorization as engineering, distribution, manufacturing, service costs, sales costs and renovation [26].

Despite such diversion of defining cost structures, the aim in the end is the detailed costs of each component will depend upon an individual item under consideration. The vital point is that the structure must be designed in a way allows analyst to perform indispensable LCC analysis, and trade-offs to adequate the project objectives. The third step of the LCC general approach is to estimate the cost relationship, and that expressed mathematically in which describes the cost of the item as a function of one or more independent variables. Finally, the last stage of LCC procedure is by establishing the method of LCC formulation by finding a proper methodology to appraise asset's LCC [26]. Hence, a systematic methodology was provided by given eight steps as following:

1. Operating profile that labels the periodic cycle of equipment or the proportion of time the equipment will be operating, mainly covers the modes of startup, operating and closure.
2. Utilization factors specify in what way equipment will be running within each mode of the mentioned operating profile.
3. Identification of all cost elements

4. Determine the critical cost parameters, for instance, the factors that control the degree of the costs earned during the life of equipment. Such factors as energy usage rate, period of repairs, time between overhauls, time between failures and time period for scheduled maintenance.
5. All costs are first deliberated at current rates.
6. Escalate the current calculated costs at assumed inflation rates
7. Discount costs to the base period; the money has a time value and the cash flows arising in different period should be discounted back to the base period to certify comparability.
8. Sum discounted cash flow to establish the net present value; this will enable the LCC of the asset to be established [26].

The structured model that delivered by VDMA and SEMI [27] for calculating LCC of an asset during a period of consideration is a comprehensive list of items that affects the cost of the machine along its lifespan. The many cost items were gathered into three phases and each phase including different cost pools and parameters as shown in *figure 4*.



**Figure 4. The structure of forecasting model for calculating LCC**

Source: VDMA and SEMI [27]

### 3.1.3 Resource consumption accounting (RCA)

RCA defined as an emerging management accounting method that composites the benefits of managerial accounting's highlighting on resources with those of the activities and processes vision. Furthermore, RCA takes advantages of an enterprise resource planning system's ability to track, sustain, and cluster the most detailed information and to successfully assimilate the operational and financial information. The main principles of RCA are the enable factors that determine the costs attributable to certain resource pools. Though, the construct mechanisms of RCA models preconditioned from managers to have a full understanding about all resource interrelationships. The resource pool conception focuses on assemblage the different costs of homogenous resources in a specific area of restraint. This mechanism known as the cost center in which contained one or more resource pools for instance, the resource pool may be a particular machine and the operator that connected directly to it [28].

White [29] claims that RCA main concepts can be seen as resource flows and pools, in which the resource flows from resource pools to products. The resource pool in this context is carrying a cost in addition to specific inputs needed to produce an output, and might this output support another cost pool rather than becoming product or service. Thus, the flows should be modeled properly because one of the important objectives of RCA is to provide causality information so the decision-makers can make the right judgments. Here, the cause and effect principle ensure the relationship between resource pools can hold both fixed and proportional costs. However, this relied on the nature of the costs that can be altered between resource pools [28].

The example of such disparities can be electricity, i.e., the electricity arrived at the company as a proportional cost but in some resource pools it becomes a fixed cost. As the cost that devoted to heating and lightened the manufacturing facility. Furthermore, RCA-cost allocation method deals only with the resources costs that have been used to products, and neglecting the imposed costs that related to non-added value. Another issue is the unused and idle capacity costs; RCA approach attributes those costs to people or department in charge and that in purpose of not affecting the product cost. The causality between resources and resource drivers are very essential to determine. Otherwise, the costs accuracy would not be

allocated appropriately to products. However, if the costs in one cost pool did not impact the other cost pool or product then no needed to be included in the cost model [30].

When RCA cost sheet conducted for analysis target, there are several features to be illustrated:

- I. Primary and secondary costs
- II. cost driver type if it is resource or process
- III. Origin of the cost (provider)
- IV. Fixed and proportional quantities and costs

Primary costs are the costs that originate in a particular resource pool such as direct labor. On the other hand, secondary costs initiate in support of manufacturing resource pools that are related to the consuming object. The secondary costs can be maintenance, utilities, space, etc. Afterward, the type of cost driver consumed is based on the nature of its output. For instance, the cost driver for secondary cost of space is a resource type because the output is measured as square feet. However, the cost driver for the secondary cost of human resources is a process type because the output of this resource is an activity. The provider of the input is where the cost constructed, this could be the production department or any other support department. An example of that is the plant maintenance as secondary costs, the driver type is a resource because the output is maintenance labor hours. Therefore, in this case the provider is plant engineering and maintenance [30].

The last step is to derive the fixed and proportional cost; RCA is based on quantity structure in which means that all consumption interactions are specified on the basis of quantities. Nevertheless, the monetary value follows these quantities regardless the cost that involved in defining the consumption relationship [28]. The way used to define how total fixed and proportional cost constituted from a consuming object are determined under RCA as following:

**PR-** the proportional budget rate for a resource provided by the support department

**FR-** the fixed budget rate for a resource provided by the support department

**PQC-** the proportional quantity of a resource expended by the receiving sample object

**FQC**- the fixed quantity of a resource used by the receiving sample object

The formulation for determining proportional and fixed costs are expressed into two equations:

$$\textit{Proportional cost assigned} = \text{PQC} * \text{PR}$$

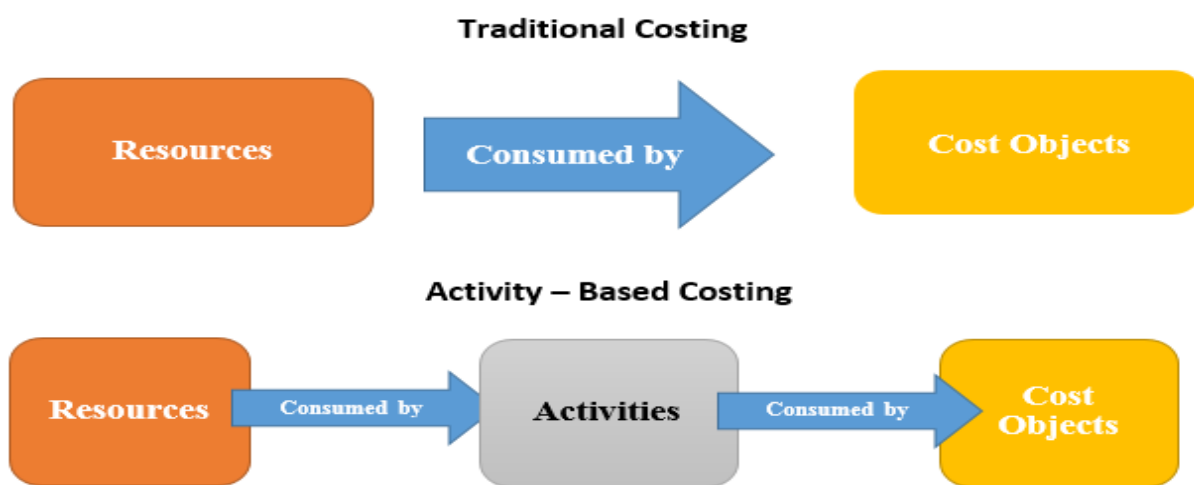
$$\textit{Fixed cost assigned} = (\text{FQC} * \text{FR}) + (\text{FQC} * \text{PR}) + (\text{PQC} * \text{FR}) \text{ [28]}$$

#### 3.1.4 Activity-based costing (ABC)

ABC is a cost allocation method mainly pioneered in the area of management accounting. This method has been successfully conducted in manufacturing plants for improving the strategic vision of decisions-making, in addition to enhancing the business cost control and customer profitability. One of ABC role is to supplies management with appropriate information to comprehend the use of scarce resources in various business activities. It helps management to notice areas of the high cost, identify the elements that stimulus these costs, and develops performance. Furthermore, it allows to measure improvements in the time and cost of the activities performed. This drive forward to better management of resources concerning product costing and customer profitability. In the ABC tactic, resources are traced to activities, and activity are then traced to the targeted object such as products or services based on their intake of the activities [31].

ABC model uses different structural blocks in comparison with traditional costing, *see figure 5*. The traditional costing approach was presented product as a cost object that consumes resources directly. On the contrary, the propose ABC model are adopted the cost objects as a consumer of activities that in turn consume resources. Resources and activities are disbursed in a certain amount, and the rates of consumption are regarded as resource drivers and activity drivers. Resource drivers describe the rate of consumption of each resource when an activity is completed. Activity drivers underlined the rate of consumption of each activity as cost objects are generated. The idea here is that the activity driver defined on per- job basis for every cost object created, and there is a specific degree of activity consumed [4].

For example, the cost driver for the delivery activity is limited by the number of loads. The specialist computes the total number of shipments in a given time duration and traces the delivery activity costs to all the products based on the number of shipments consumed by each product. ABC method trace the true cost of a product either correlated to direct or indirect overhead costs, and then it identifies any non-value added activities. This characteristic is considered a significant advantage, because it illustrates expenses that may be vagueness to an organization [31].



**Figure 5. Traditional costing and activity- based costing**

Source: Lincoln [4]

ABC designed in aiming to provide an accurate cost data and information about the root of the cost, which means ABC make overhead traceable. In many cases, ABC has been used in combination with other process improvement tools to assert progresses initiatives and to track cost improvement. The managers that were familiar with ABC applications they had better condition monitoring of management than non-adopting method. Costs were minimized through the removal of non-value activities, or due to processing enhancement. However, the impressive results of such method and the fact of cost reductions that supported by its sufficiency of calculating the operating cost, still incurred a deficient in the handling of capital

costs. Whilst the depreciation cost is considered in ABC analysis, the interest charges for capital invested in an organization are not been taken seriously [32].

## 3.2 Performance measurement systems

### 3.2.1 Overall equipment effectiveness (OEE)

OEE in general display is described as one of the sufficient performance measurement tool that measures the different types of production losses essentially at equipment level and indicates areas of improvement. This tool provided a quantitative metric of efficient and effectiveness machine performance; it identifies and measure losses in relation to manufacturing factors such as availability, performance and quality rate. The major losses that drained the production efficiency and thereby the effectiveness are classified into three groups: downtime, speed, and quality losses [33].

Downtime losses consist of a breakdown, set-up, and adjustment losses. The breakdown event is categorized as time and quantity losses caused by equipment failure. For instance, this type of events lead to downtime and thus production loss. On the same ground, set-up and adjustment losses occur due to production is changing over from requirement of one item to another. This problem can happen in the situation of mixed products as the set-ups between different products. The second class of losses are the speed losses, this type of losses divided into idling and minor stoppage and reduced speed losses [34].

The idling and minor stoppage losses occur when production is sporadic by transient malfunction, and this can be a result for instance, the dirty photocells. Although, this type of stoppages can overcome quickly but in case of frequent occurrence much capacity is lost. Reduced speed loss is referred to the variance of equipment design speed (theoretical) and actual operating speed. An example of that is the improper materials used in which leads to longer processing times and speed loss [34].

The last category of production disturbances and losses is the quality losses, it includes quality defects and rework in addition to reduced yield during start-ups. The defects and rework are the losses that affect the quality because of malfunctioning production equipment such as, the

material that get stuck and damaged while processing. Reduced yield losses are the losses that occur from machine start-up to steadiness phase of machine operations. This kind of reduced yield might be attributable to inadequate preparation before starting up machine and especially after long-time stops caused by failure [34].

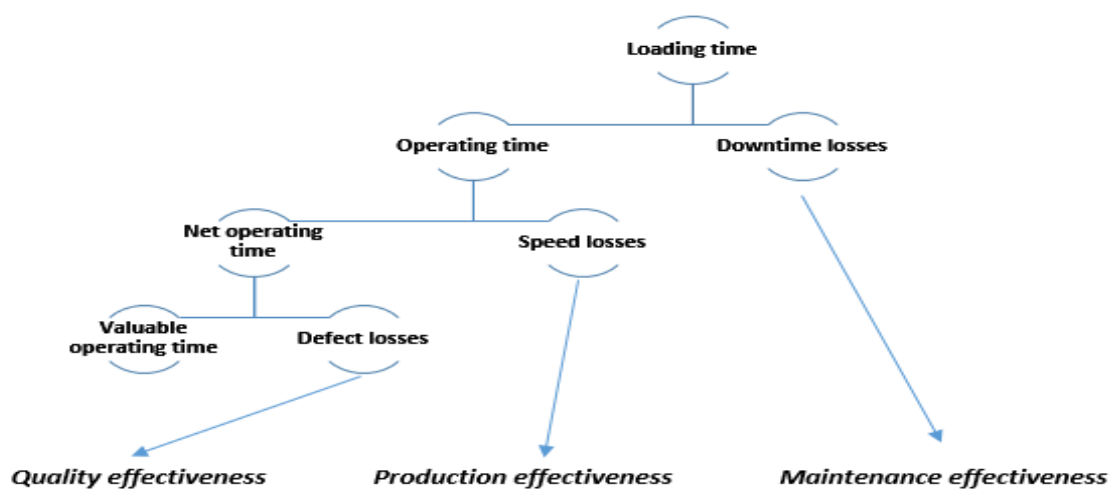
According to Muchiri and Pintelon [34], all those mentioned losses are measured by OEE, and that specified in OEE equation:

$$\text{OEE} = \text{A} * \text{P} * \text{Q}.$$

Where:

- **Availability rate (A)** = Operating time (h) / Loading time (h) \* 100
- **Performance efficiency (P)** = Theoretical cycle time (h) \* Actual output (units) / Operating time (h)
- **Quality rate (Q)** = Total production – Defect amount / Total production (units) \* 100

The strength of an OEE tool is in its appearances of integrating different aspects of manufacturing into one single measurement and the contribution of indicating the efficiency of those aspects. The perspectives that emerged are maintenance effectiveness, production efficiency, and quality efficiency as can be seen in *figure 6*. An example of those perspectives is maintenance effectiveness in which evaluated by OEE to affirm that the maintenance policy adopted to reduce failure, and set-up times are the optimal strategy [34].



**Figure 6. OEE and the perspectives of performance integrated in the tool**

Source: Muchiri and Pintelon [34]

Based on OEE results, there are many advantages can be extracted from such a measurement. Firstly, it allows managers to evaluate the initial performance of a manufacturing plant and through same manner compare it with future OEE values. This feature is quantifying the level of improvement made. Secondly, an OEE calculated value for one manufacturing line can be used to assess the line performance across the whole company and thus spotlights any inefficient line performance. Thirdly, if the machine process works separately without any reliance to another machine, OEE tool has the capabilities to measure the individual machine and thereby provide the performance status. Which in turn designates the areas of improvements [35].

### 3.2.2 Total equipment effectiveness performance (TEEP)

TEEP is a measurement tool similar to OEE, but it deals with equipment output in reference to the total calendar time available rather than the loading time that used in OEE calculations. So, TEEP is adopted to evaluate how well the production machine (assets) are deployed in relative to the total calendar time. This way specify opportunities that might stand among current operations and world- class levels [36]. However, the performance efficiency and quality efficiency metrics are alike in correlated to both tools; the main difference is the inclusion by the availability efficiency metric [37].

Zandieh et al. [38] underlined this difference as TEEP tool has added a capability over OEE realization. This added-value happened through the measurement of equipment utilization such as, planned downtime in the total planned time horizon. Moreover, the importance of showing clearly the maintenance contribution to bottom line productivity of the plant, TEEP elements provide an obvious distinction between planned and unplanned downtime. With the help of TEEP, both parameters can be measured. Still, one main flaw of TEEP analysis is such tool limited to equipment-level productivity. Nevertheless, it is applicable to processing industries or a flow shop where the production streamline approached as a single entity [34].

In the sake of clarification, an example given by Chand and Shirvani [39] is a good example explained how TEEP can be calculated. Firstly, the equipment utilization is calculated based on the following formula: **(Total running time- planned downtime)\*100 / Total running time**

According to the same example, the total running time was equal to 30,000 minutes (125 hr. /week \* 4 weeks \* 60) and planned downtime is equal to 1,035 minutes. This calculation excludes the set-up and adjustments time. Thus, the equipment utilization after calculation is equal to 96% (0.96). The second component of the tool is to find the actual availability that expressed into the following formula: **(Loading time – set-up time – Downtime)\*100 / Loading time**

The loading time (running time – planned downtime) is equal to 28,965 minutes; the set-up and adjustments time in addition to downtime were summing up to 4,881 minutes. In which leading to the actual availability of 84 % (0.84). The performance efficiency is the third element in calculating TEEP, and the formula is: **(Average cycle time\* number of good units made) \*100 / operating time**

The average cycle time is considered to be 0.71 minute / unit; number of good units made are 25,718; the operating time is equal to 24,155 minutes. Thus, the performance efficiency gives 76 % (0.76) of its capacity. The last piece of calculating TEEP is to evaluate the rate of quality, the formula is: **(Number of good units made- Rejects) \*100 / number of good units made**

The number of good units made is equal to 25,718, and the number of scrap and rework units are 797. In relied on given formula the rate of quality can be extracted, the value is 97% (0.97). Finally, the TEEP can be calculated according to this formula:

$$\text{TEEP} = \text{Utilization} * \text{availability} * \text{performance} * \text{rate of quality} * 100$$

In consistent with this example,  $\text{TEEP} = 0.96 * 0.84 * 0.76 * 0.97 * 100 = 59 \%$

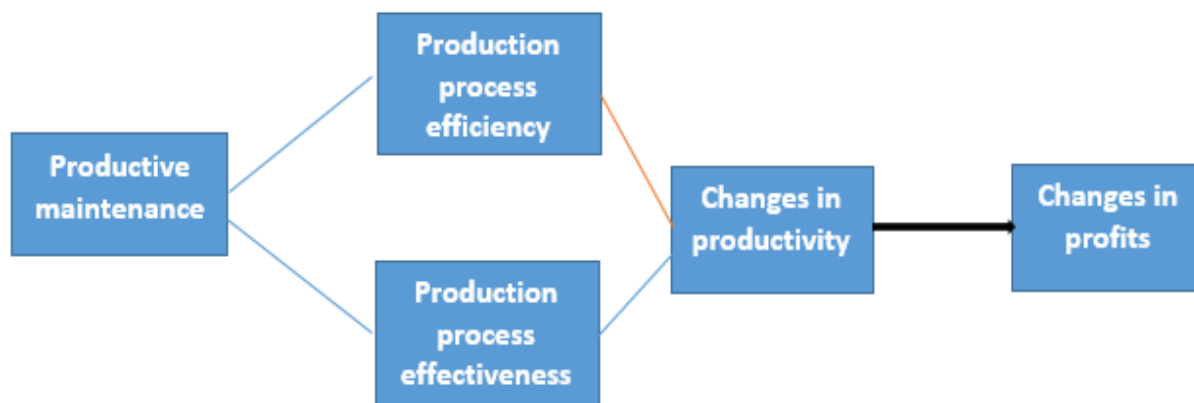
### 3.3 Maintenance concept and interventions

#### 3.3.1 Maintenance definition and perspective change

Maintenance is defined as the arrangement of all technical and managerial actions intended to preserve the item and restore it to the state in which it can perform its required function. Maintenance conventionally treated as a necessary evil, but the concept evolved recently and

diverted into profit generating function. The essence of this function is that the maintenance has become a cornerstone for a manufacturing organization to sustain its competitiveness [40].

The implementation of effective maintenance policy will impact in increasing the utilization of manufacturing systems. This output because the proper maintenance leads to enlarging quantity produced with good quality due to the effect that released on process efficiency and effectiveness. i.e., whilst decreasing downtime events, short stoppages, bad quality, etc. Consequently, the economic paybacks of maintenance strategies can be characterized by increasing the profit margin as a result of decreasing the manufacturing costs as shown in *figure 7*, [41].



**Figure 7. Conceptual process of maintenance impact on firms' profits**

Source: Alsyouf [41]

### 3.3.2 Maintenance strategies, policies and tactics

There are two crucial strategies for maintenance activities. One is reactive maintenance (RM), which attempts to decline the severity of equipment failure once they occur; the form of overhaul or replacement work is only performed when machinery has failed. In other meaning, this type of strategy restricted by a reaction to a failure occurrences. The other one is preventive maintenance (PM) that strive to reduce the probability of failure after maintenance has been applied in a certain period. It carried out at pre-determined intervals and inconsistent with pre-described criteria as intended to eliminate the degradation of an item functions. Those strategies can be realized and adapted through discrete set of policies. In the case of a

reactive strategy the corrective and prospective policies are the factors that constitute its content. On the other hand, the preventive strategy associated by pre-determined, predictive and proactive policies, *see table 4* [42].

**Table 3. Maintenance strategies, policies and characteristics**

Strategies	Policies	Characteristics
Reactive maintenance	Corrective	<ul style="list-style-type: none"> <li>- Run- to-failure</li> <li>- Restore defective items to a specified condition</li> <li>- Repair and replacement of broken parts</li> </ul>
	Prospective	<ul style="list-style-type: none"> <li>- Opportunistic maintenance</li> <li>- Maintaining other components which not failed yet</li> </ul>
Preventive maintenance	Pre-determined	<ul style="list-style-type: none"> <li>- Schedule maintenance</li> <li>- Tasks are performed at a set time intervals</li> <li>- Entails inspection, repair, replacement, etc.</li> </ul>
	Predictive	<ul style="list-style-type: none"> <li>- Measurements that detect the onset of system degradation mechanism</li> <li>- Determines the current asset condition to predict the best time for maintenance applied</li> </ul>
	Proactive	<ul style="list-style-type: none"> <li>- The diversion into acting rather reacting</li> <li>- Ensuring machine reliability according to state-of-art</li> <li>- Failure root causes analysis</li> </ul>

Source: Khazraei and Deuse [42]

On the whole, the implementation of those strategies in successful mode required forming and employed the right tactics. Some tactics are well commonly used in manufacturing industries, and they are characterized by enabling the preventive maintenance strategy. The tactics are condition-based maintenance, reliability-centered maintenance, and the total productive

maintenance. The former tactic linked to predictive policy, and the latter tactics are restricted by proactive policy [42].

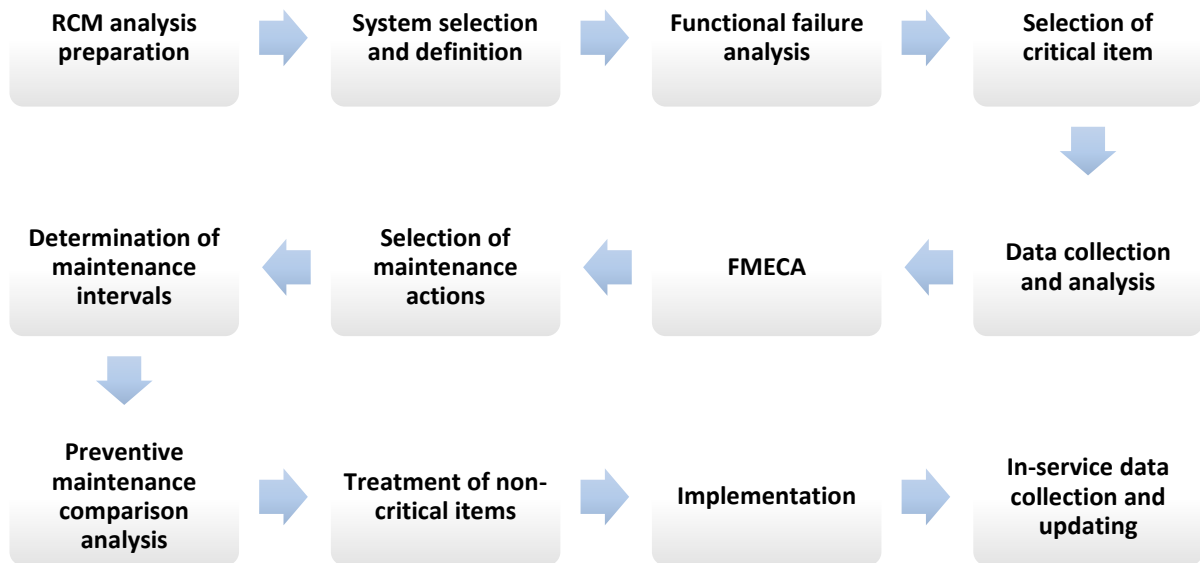
**Condition-based maintenance (CBM):** CBM focuses on the current condition of the system or other components that derived as subsystems. The main role is to mitigate downtime at the optimal time; it infers that a system capacity is exploited as much as it can perform its expected performance degree. The incurred procedure of replaced or repaired item must be performed before it goes below certain performance measures. As an outcome, CBM provides the ability for the system to remain operating as long as it is acting within predefined performance limits [43].

Furthermore, Mobley [44] extends the role of CBM into the determination process while problem exists in the equipment, how severe the problem and how long the equipment can perform before breakdown. Condition-monitoring techniques developed for CBM and these techniques classified in accordance to the type of symptoms that they are designed to detect. The classification is the dynamic effects in which vibration analysis techniques adopted for tracking the noise levels. In addition to particles released; chemical released; physical effects such as wear and fracture; temperature rise in the equipment; electrical effects such as conductivity and resistance [45].

**Reliability-centered maintenance (RCM):** RCM defined as a resource optimization method that is conducted in ease of developing and refine maintenance programs. This tool empowers maintenance managers to direct their maintenance efforts and expenditures only on the critical functions of a piece of equipment that demanding reliable operations. The goal of RCM is to generate maintenance standards or routine that keep the critical system functions in the most cost-effective mode [46]. RCM goal can be achieved through a sequence of activities or steps as shown *in figure 8*.

**Total productive maintenance (TPM):** TPM, it is a lean manufacturing strategy that strive for enhancing the machine efficiency and effectiveness as possible, through optimizing all types of maintenance activities [48]. This maintenance tactic is mainly inherent on focuses that combine process and people in one framework [42]. The overall aims of TPM are to:

- Achieve zero losses in downtime events
- Construct integrated system capable of maximizing the process efficiency
- Encompass all departments including production, maintenance, administration, etc.
- Involve all employees from top managers to operators and clerical staff
- Enable small group activities [49]



**Figure 8. The sequential steps of RCM analysis**

Source: Rausand [47]

### 3.4 Downtime identification, causes and effects

The business view about the system availability indicates to the duration of process uptime along the entire supply chain. The higher the availability, the most increased system throughput and so return on assets and investment. On the contrary, the term downtime is potently denoted to period when the system is unavailable due to planned or unplanned stoppages. The unplanned stoppages mainly referred to equipment failures or process disruption. On the other hand, scheduled stops regarded to predetermine procedures of activities that undertaken as calculated duration for which the machine has to be stopped. For example, the planned maintenance, setups, adjustments, inspections, shutdowns, training, breaks, cleaning, standby state [34], in addition to software and hardware upgrade / update.

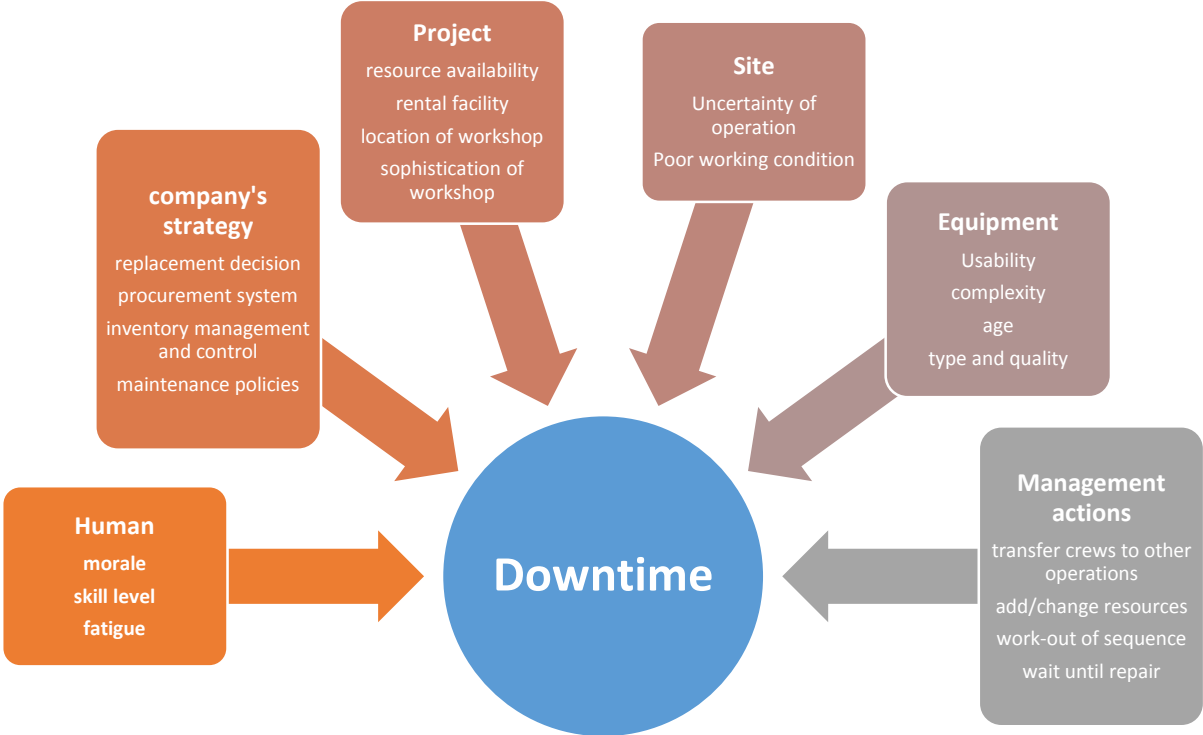
As a result, the downtime events carrying noteworthy costs in which companies attempts to reduce by adopting efficient costing methods that facilitate the improvement process and thereby realizing output in terms of money [50].

Nepal and Park [1] claim that equipment breakdown as the most common unforeseen factor that have an intense effect on equipment productivity and organization overall performance. Moreover, the authors recorded various causes in correlated to plant and equipment downtime as shown *in figure 9*. These factors are the site-related factors that include the poor working conditions, location of the site, and uncertainties during equipment operation. Other important factor comprise the equipment-related issues, for example, its age, usability, type, quality, the complexity, and sophistication of the mechanical and hydraulic system of a piece of equipment. Furthermore, the project-related factors have a great impact on equipment downtime for instance, the spare parts and resources availability. As well as, other factors like the human aspects in which the skill of operators and motivations mainly affects the performance and direct cost of machine downtime. Notwithstanding, the discrepancy between the site management actions and the company's adopted policies may occur due to scheduled maintenance performed into a specific machine while the site manager assign the maintenance crews to other operations.

According to Onawoga and Akinyemi [51], the causes of equipment breakdown assigned by design deficiencies, inappropriate maintenance, inefficient processing, material defects, excessive demands, etc. The authors grouped the sources of failure in four taxonomies and symbolized as 4Ms: man; methods, materials, and machine. The materials categorized by its quality and compatibility with machine nature for instance, if the purchased material is the right material. The human factor due to lack of training and experience may impose errors during operations. Finally, the machine required efficient methods to process in a steady manner and required the avoidance of utilization beyond the design criteria.

In more details, the report that introduced by Sachs [52] shows the major failure contributor of mechanical equipment is attributed to different primary failure mechanisms. These failure mechanisms are distributed into following proportions: fatigue (44%); corrosion (18%); overload (15%); corrosion fatigue (13%); and wear-out (10 %). During the same study, the fundamental cause that stated as enabler to these failure mechanisms consisted of

maintenance errors that score the high rank in comparison with other causes categories. For instance, the operational errors, original installation errors, manufacturing errors, design errors and situation blindness.



**Figure 9. The generic factors and processes that related to Downtime event**

Source: Nepal and Park [1]

Downtime events are dynamic in nature and though consequences. Especially, the downtime that subordinates its occurrences to unplanned stops such as, machine breakdown that lasts for extended periods and this machine considered critical in which any inherent failure leads to total production halt. Therefore, the impact of such events are very severe because it dissipates the efficiency of the production process, and so create a type of casual loop. For instance, once the machine became unavailable the first perceptible effect is the resource idleness - operators and equipment- and thus the project progress (orders fulfillment) slowdown plus the increasing pressure on work schedule. In the magnitude to this repercussion, the managers might become distracted from proper control of the situation and

turn to hasty maintenance. This interference tends to produce low quality of maintenance, which then again lead to downtime event and so forth, in other meaning, creating the vicious reinforcing loop [1].

Another important issue is the cost perspective of downtime, as the frequency of each mentioned factor there is an accumulated cost accompanied with. While Downtime occurred, it leads to reduced recovery of costs of capacity compared to an ideal production volume. Example of capacity cost might be a facility, machinery, utilities, and administration or any other indirect functions related cost. The case here is when machine is down the costs of capacity are still incurred even though there is no product produced. This will brings the cost pressure and under such conditions there are less attention to maintenance work, in which in return the low quality of maintenance increase the probability of downtime events [53].

Occasionally, the frequent downtime can interrupt the original sequence of work. This disruption may happen in several ways such as, changing the work sequence by introducing new methods and procedures or by diverting the influenced resources through downtime duration to other site operations. The concern is by diverting the human resources to other sites may encounter the experience level issues in which required a plenty of learning time inconsistent with projected methods. Additionally, the state of congestion site beside the feelings of declined level of experience affects the crew morale and thereby exposed system to stoppage. The decision that taken by managers for system recovery through downtime event is not easy though, sometimes they decide to execute the temporary maintenance strategy to release the schedule pressure by reducing the period of downtime. The problem arises again through the idleness of resources during the repair duration. On the other hand, the option of using the overtime and placing pressure on staff to increase the work completion rate is not an ideal solution. The overtime can facilitate the progress of production by increasing working hours but at the same time may cause fatigue in workers and as a result Downtime occurs [1].

The literature is not explicit regarding whether downtimes measurements should include planned stops alongside unplanned stops. Moreover, often the analysis of downtime can be tempting to measure such events in terms of total downtime cost and to neglect the variability of their frequency and duration [54]. This shortfall is the bottom line to differ between

planned and unplanned downtimes, so the frequency of Downtime event and its duration is considered a factor in which characterize the downtime type. Commonly, the period that referred to unplanned events are expressed as time-to-repair and time-between-failure, and this period is dynamic compared to the stationary state of planned stops [55].

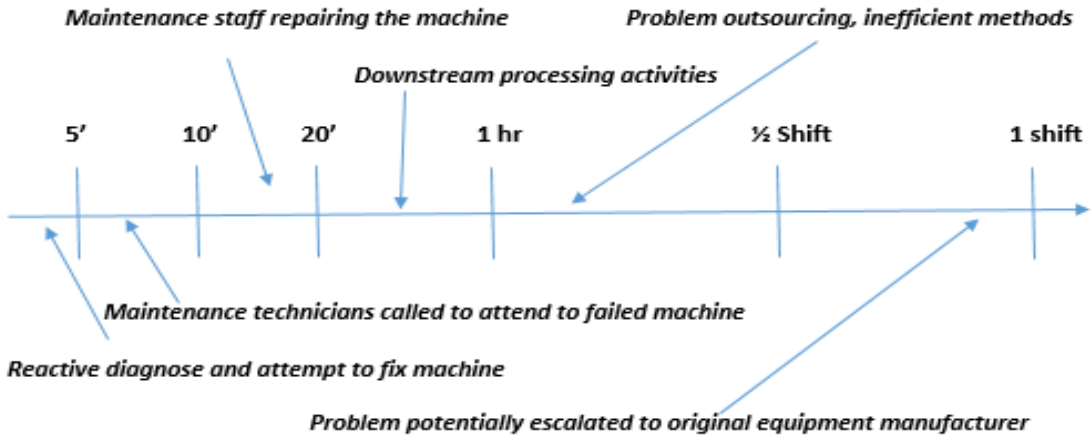
On the other hand, planned event related stops are relatively short such as the time spent on inspection and preventive maintenance. In fact, there is still a research debate about seeing this time as a loss and that based on the effect that planned stops released into normal production time [33]. However, the quantification of the impact whether it corresponds to planned or unplanned events are necessary for ease to facilitate the detection of the real cost associated with both events. In the light of this statement, the internal and external impact of planned downtimes are more managed than unplanned downtimes because of its readiness and less exhaustive resources. In addition to the cost categories that are apparent, and their calculation is straightforward for instance, the direct cost of labors and materials. In a paradox, unplanned downtime enclosed by many cost categories that might not be obvious as the overhead costs, and its measurement required more accurate cost estimation. Consequently, the analysis boundaries based on these inquiries must differentiate between the impact resonance that issued by planned and unplanned stops. The distinguished in order to precisely evaluate the cost associated with both events and compiled it as the total downtime cost [55].

### 3.5 Determination of cost categories

Before revealing the cost categories that imposed whilst a downtime occurs, it is very imperative to describe how the process activities get influenced by the length of downtime duration. The scenario is about a complex processing machine that considered critical among a serial production line and this equipment experienced sudden stoppage. The first reactive activity that attempting to restore the production equipment is by the production team, they try to diagnose and fix the machine immediately. However, if the direct operators incapable of recuperates the machine into its functioning state the maintenance staff called to attend to failed equipment and further endeavor to fix the machine. Hence, the machine become a bottleneck in which has a great impact on downstream processing activities. In more dramatic case, the problem escalated to outsourcing in parallel with adopting alternative methods to replace the system outage. As long as the downtime extended, there is a possibility to send

the equipment to the original manufacturer. The consequence of this time consumption indeed will increase the customers' dissatisfaction in the level of service [6].

The traditional costing methods have piled downtime costs in one overhead bucket and disregard the quantification and tracking the costs individually. As shown in *figure 10*, in every stage of the downtime period there is an involvement of new activities in purpose of recovering the system and each activity accompanied with cost. In other meaning, the rate of cost accumulation is proportional to the participated activities. Therefore, the traditional costing methods are considered inaccurate because the calculation of downtime cost was based on a conventional approach in which emphasized on tangible rather intangible costs. Every activity occupied has its indirect support and costs incorporated. At a first glance, the direct cost appears clearly but the hidden costs required more analysis of categories that drives cost. This type of analysis will empower analysts to obtain realistic value of downtime consequential costs. The aim is to launch improvements and through tracking each activity with its individual costs the improvement process becoming more accurate and effective [56].



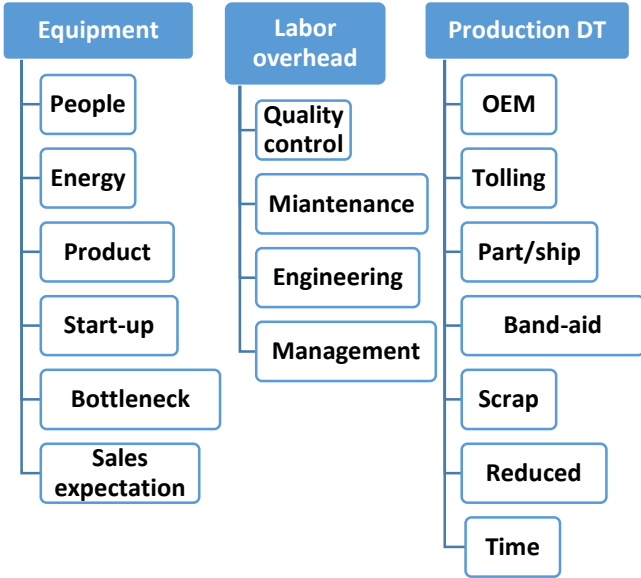
**Figure 10. The effect of downtime duration on process activities**

Source: James [56]

Hitherto, the difficulty of tracking downtime cost was closely related to the complexity of the cost metrics that convoluted in manufacturing. So, instead of searching for what make-up the manufacturing costs the trend was to lay-off workers, cut inventory, and implement lean

methodologies such as, TPM, PM, and TQM. Those practices are considered effective if their assessment was counted in the true downtime cost as a key performance indicator used to justify changes [57].

There are many factors affected by equipment downtime, and each one contributes financial loss in that particular event. These factors carrying an intensive cost and mainly classified into three categories or groups, see figure 11: equipment, labor overhead, and production downtime in addition to the vast array of sub-categories. The equipment group consists of people, energy, product, start-up, bottleneck and sales expectation costs. On the other hand, labor category includes management, engineering, maintenance, quality control and indirect operator’s costs. Finally, the production downtime category contains the elements namely, the time, original equipment manufacturer (OEM), tooling, scrap, Band-Aid, part/ship, and reduced costs [58].



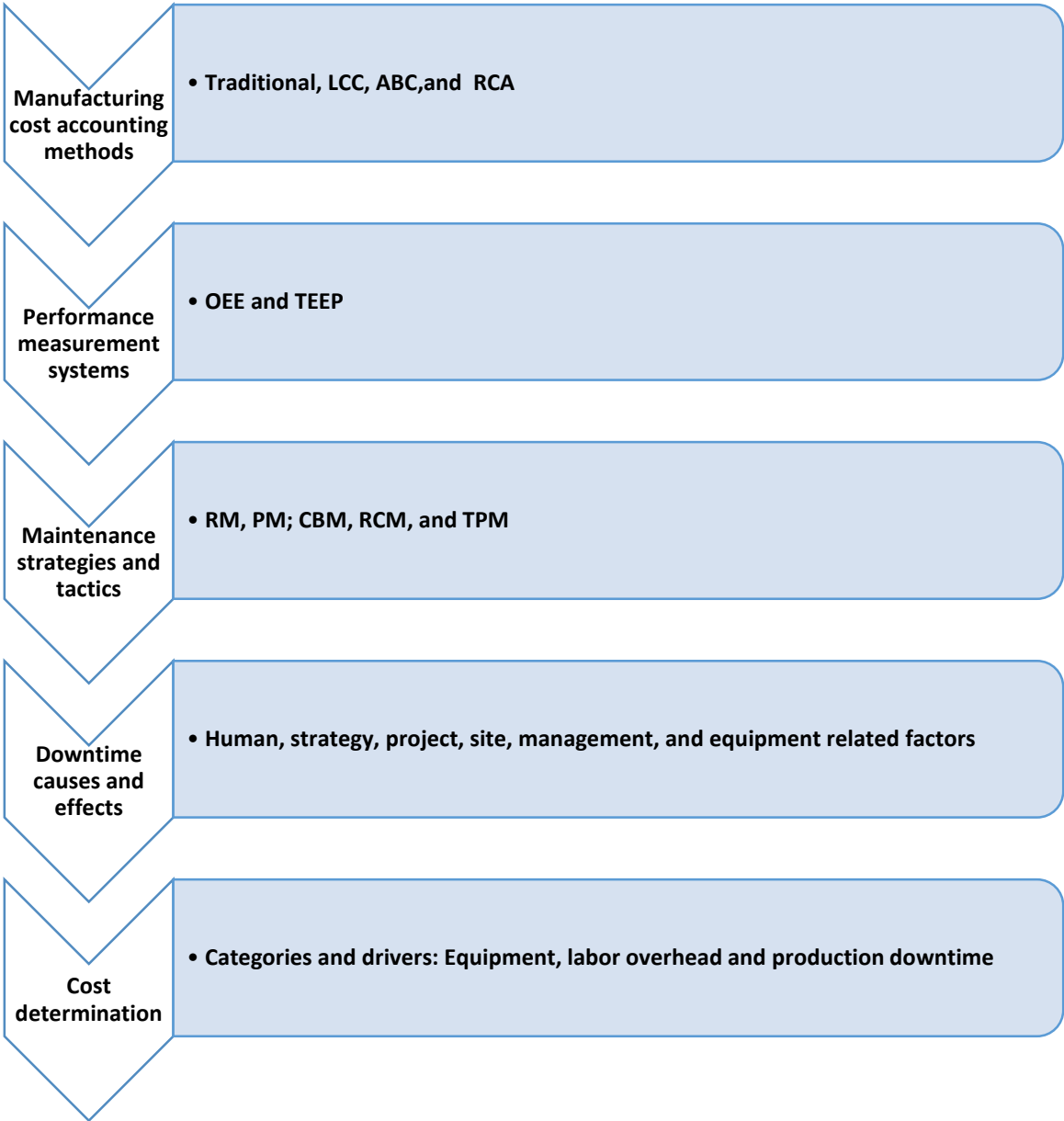
**Figure 11. The cost categories that associated with downtime in manufacturing**

Source: Fitchett and Sondalini [58]

According to James et al. [6], the indirect cost categories that assigned to frequent downtime event can divide into many categories. Those categories are the reduced asset life, lost

opportunity, lost profit, lost demand, additional freight charges, lost capacity, customer dissatisfaction, liabilities and lost or missing information costs.

### 3.6 Summary of the chapter



# Chapter 4

## 4. Results

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*In this chapter, the questionnaire results after being processed by descriptive statistics tools are provided here.*

---

**Question 1.** How do you evaluate the status of knowledge of downtime cost analysis in related to production equipment on a scale of 1 to 5 representing very low to very high respectively?

Number of participants: 75

	1 (1)		2 (2)		3 (3)		4 (4)		5 (5)							
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%						
status	14x	18.67	16x	21.33	22x	29.33	17x	22.67	6x	8.00						
	<table border="1"> <tr> <td>Arithmetic average (<math>\bar{x}</math>)</td> <td>2.80</td> <td>±</td> </tr> <tr> <td>Standard deviation (<math>\pm</math>)</td> <td>1.22</td> <td></td> </tr> </table>										Arithmetic average ( $\bar{x}$ )	2.80	±	Standard deviation ( $\pm$ )	1.22	
Arithmetic average ( $\bar{x}$ )	2.80	±														
Standard deviation ( $\pm$ )	1.22															

**Question 2.** What is the estimated downtime cost ratio from the total manufacturing cost? (In percentage)

Number of participants: 71; Valid answers = 26; invalid answers = 45 (the respondents do not know the answer)

According to the valid answers, the calculated average percentage is: **23.9 %**

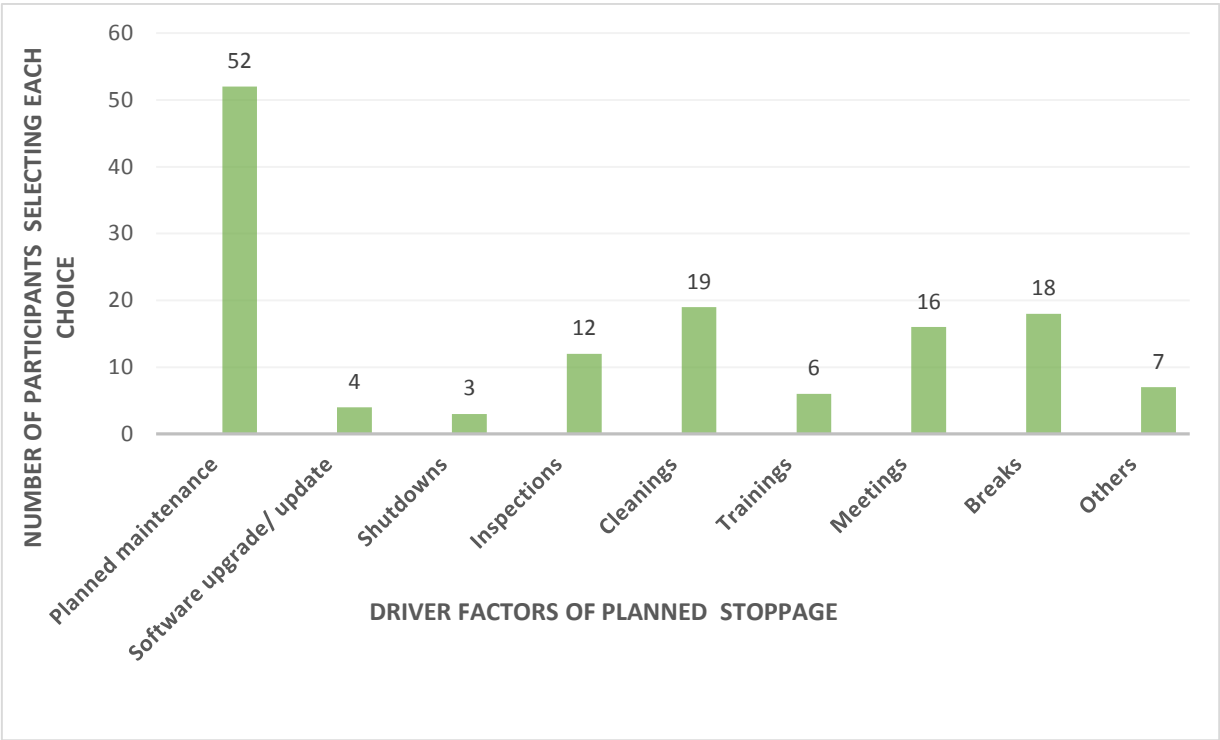
**Question 3.** What is the estimated downtime rate from planned production time? (In percentage)

Number of participants: 72; Valid answers = 47; invalid answers = 25

According to the valid answers, the calculated average percentage is: 13.3 %

**Question 4.** Select the main driver factors of planned stoppage at your company (Choices given below); *note: the participant can select more than one answer*

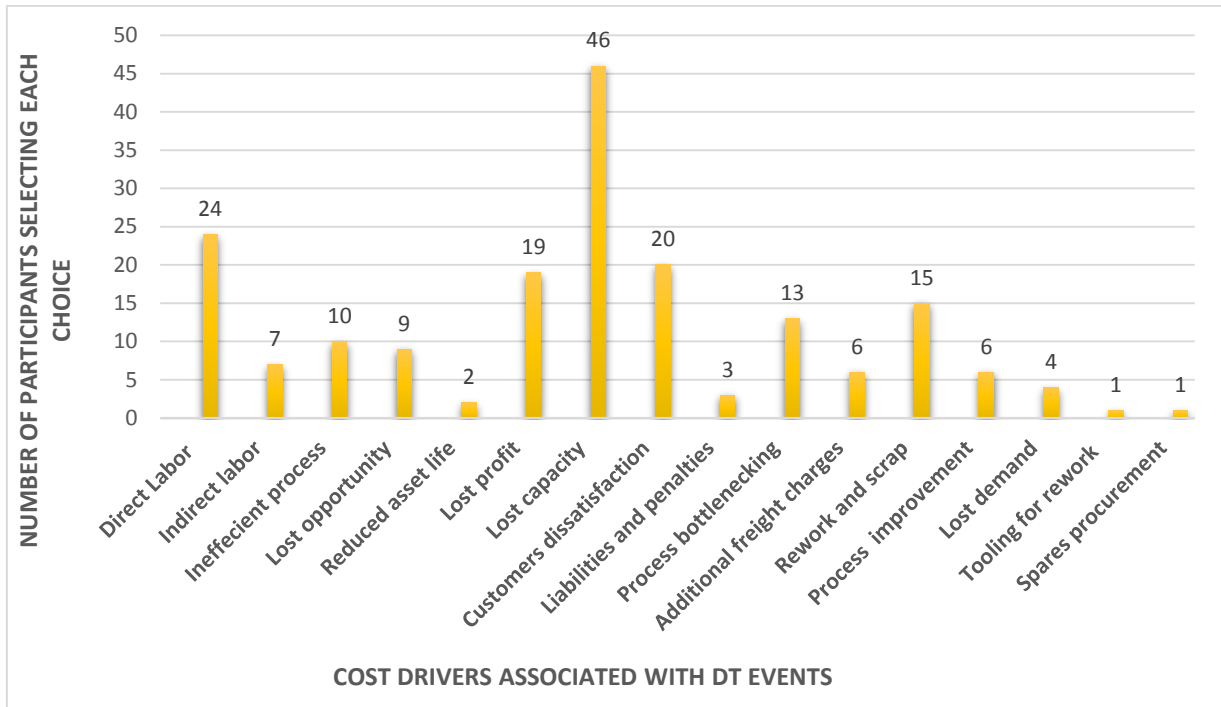
Number of participants: 64



The “others” driver factors that have mentioned by respondents were the diverse disturbances in production processes that last less than two minutes, in addition to the lack of people due to various reasons such as illness. The lack of material, quality, and orders were also been considered as driver factors of planned stoppage.

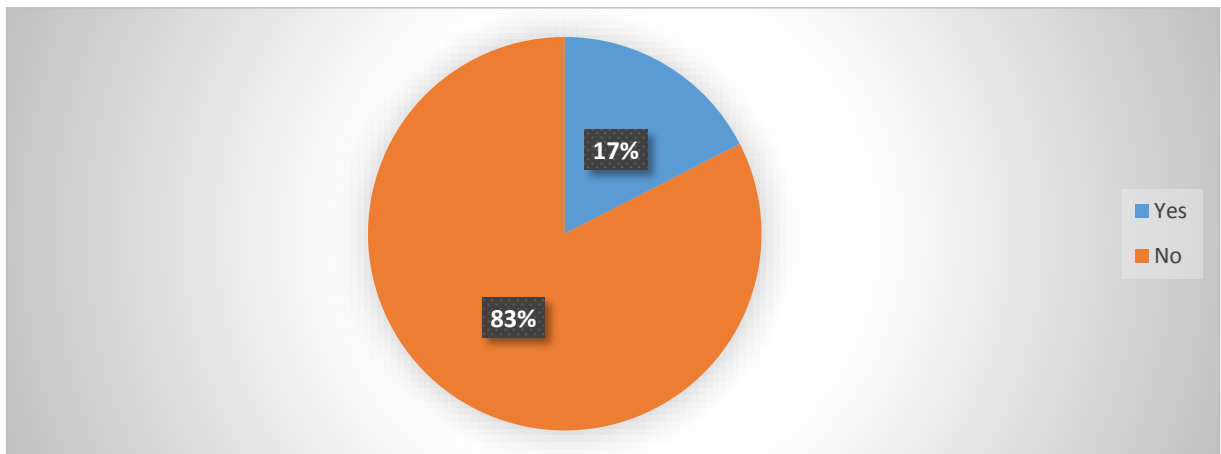
**Question 5.** Which cost categories and drivers that associated with downtime event, whether planned and unplanned stoppage are the company essential concern? (Select one or more answers from the choices below)

Number of participants: 62



**Question 6.** Is there any systematic model used by company for evaluating and quantifying the cost of downtime?

**Number of participants: 63**



**Question 6-A.** If yes, what is the proportion of planned downtime cost from the total downtime cost? (In percentage)

**Number of participants: 11; Valid answers = 8; invalid answers = 3**

**According to the valid answers, the calculated average percentage is: 36.9 %**

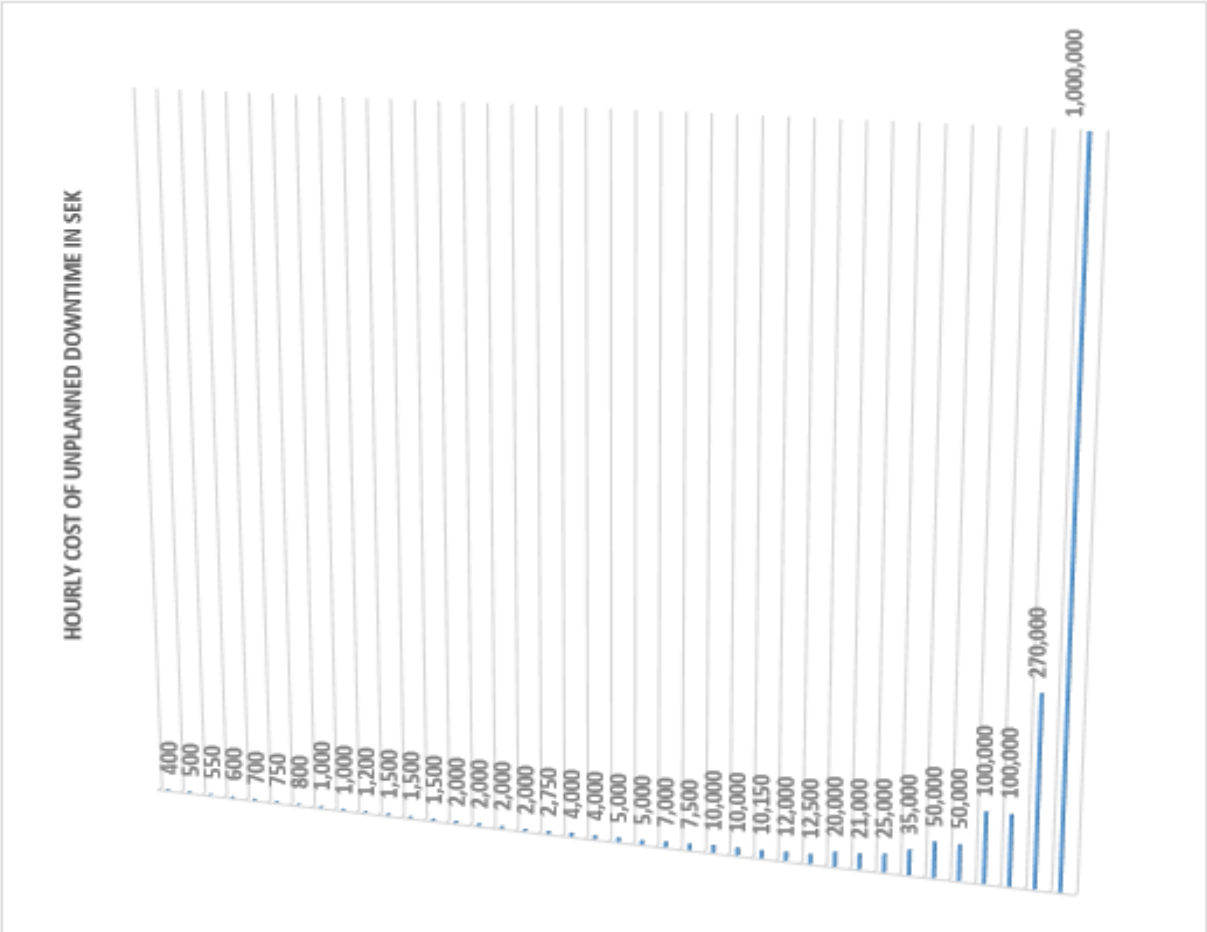
**Question 6-B.** If no, which estimated portion (in percentage) could be given for planned downtime cost in accordance with total downtime cost? *Note: the answer based on company's own experience and subjective assessment*

**Number of participants: 52; Valid answers = 23; invalid answers = 29**

**According to the valid answers, the calculated average percentage is: 33 %**

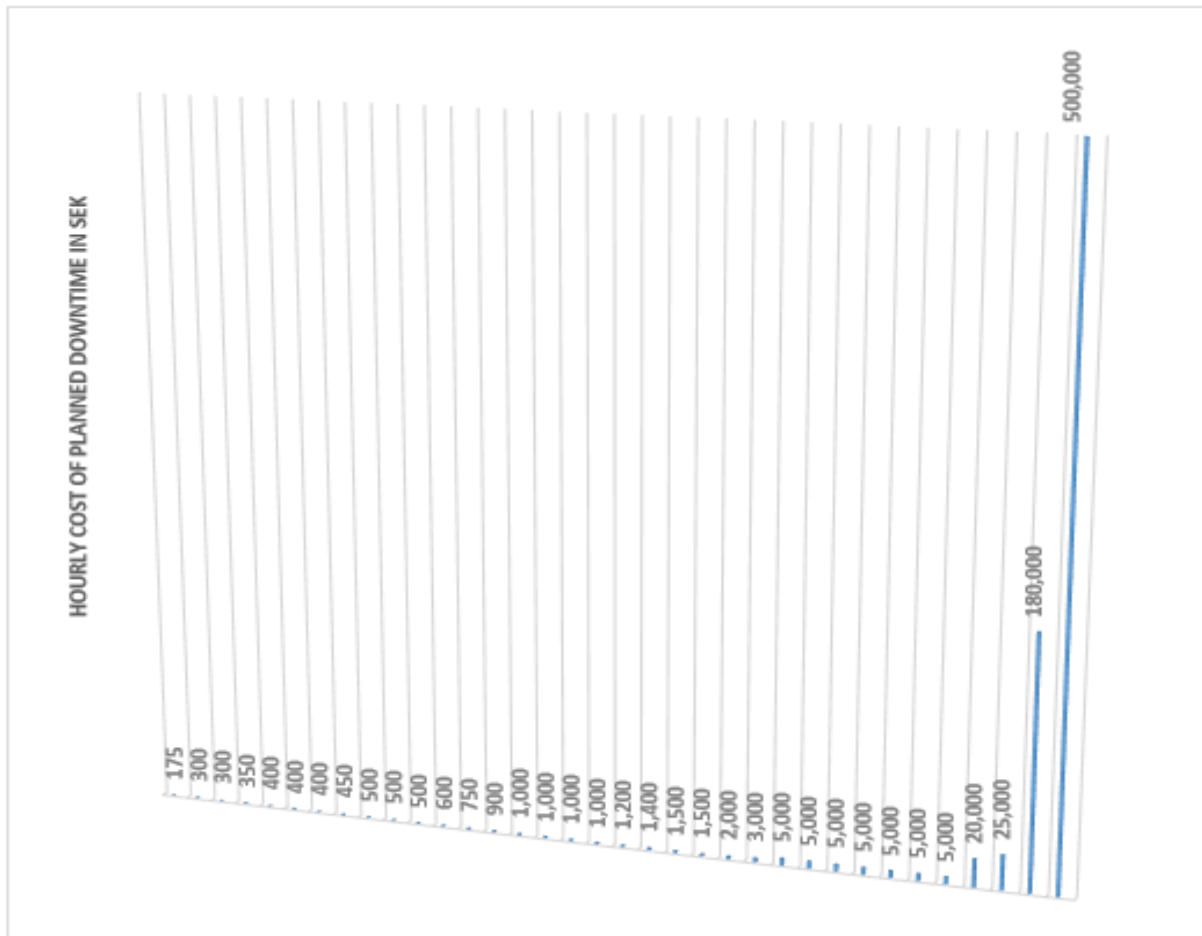
**Question 7.** Approximately, how much one hour of unplanned downtime does costs your company? (In SEK)

**Number of participants: 46; Valid answers = 39; invalid answers = 7**



**Question 8.** Approximately, how much one hour of planned downtime does costs your company? (In SEK)

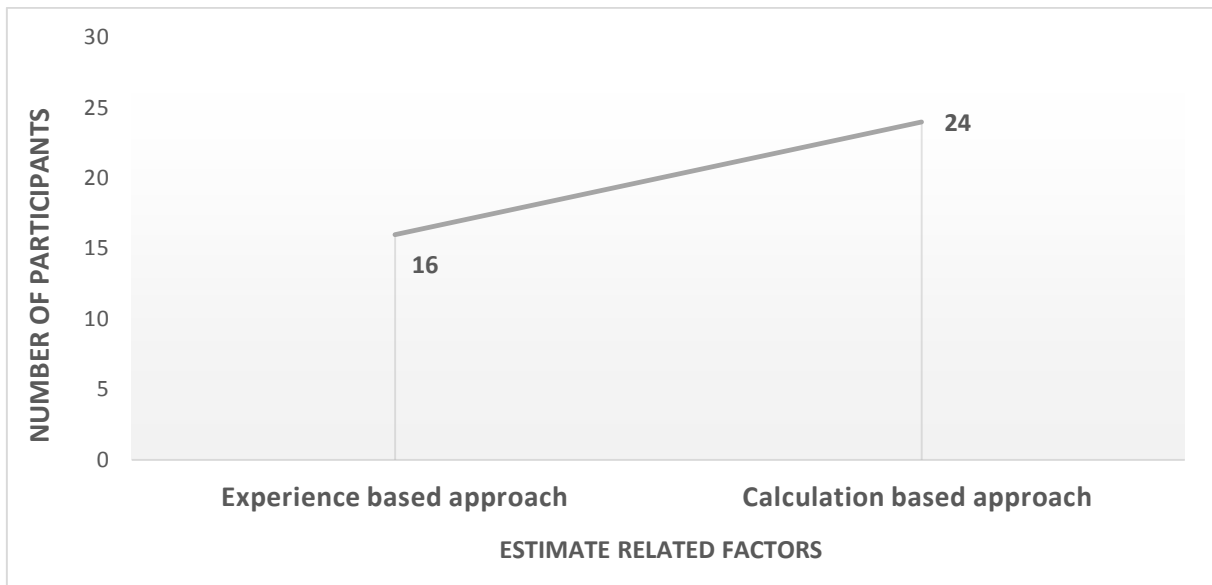
**Number of participants: 46; Valid answers = 35; invalid answers = 11**



**Question 9.** According to question 7 and 8, how these values have been obtained?

**Number of participants: 44; Valid answers = 40; invalid answers = 4**

The given estimates are distributed into two categories (A and B): the first is experience-based approach, and the second is calculation-based approach. The calculation approach of measuring the hourly cost of the downtime event were mainly dedicated to three groups. The direct labor and lost production cost; machine fixed and variable cost; budget expenses, lost income, cost pressure, and standard cost; and some mentioned the calculation of spare parts and overtime costs calculation.



**Question 10.** What is the cost accounting methods that company used for tracing the individual cost of downtime? Select your answer and then determines the status of implementation on a scale of 1 to 5, representing very low to very high respectively? *Note: each participant can select more than one answer*

**The total Number of participants: 48, and the votes distributed as followings:**

Method/ Scale	1		2		3		4		5		Don't know		0	±
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%		
Activity-based costing	18x	45.00	3x	7.50	4x	10.00	1x	2.50	-	-	14x	35.00	3.10	2.27
Life cycle costing	14x	35.90	7x	17.95	2x	5.13	2x	5.13	-	-	14x	35.90	3.23	2.23
Resource consumption accounting	10x	23.26	2x	4.65	8x	18.60	9x	20.93	2x	4.65	12x	27.91	3.63	1.89
Others	1x	3.85	2x	7.69	3x	11.54	2x	7.69	4x	15.38	14x	53.85	4.85	1.57

The “others” set was including the companies estimate of cost computation that centered by experience and using methods of tracking downtime cost. The methods are OEE and unique

cost for each machine, machine cost driver, effectiveness measure from ERP system, and cost deployment.

**Question 11.** Is the company using any measurement tool to ensure the downtime cost improvements?

Number of participants: 51

19 (37.3%): yes

32 (62.7%): no



**Question 11-A.** If yes, select the appropriate choice below and the status of use on a scale of 1 to 5 representing very low to very high respectively. *Note: each participant can select more than one answer*

The total Number of participants: 29, and the votes distributed as followings:

Measurement tool/ Scale	1		2		3		4		5		Don't know		0	±
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%		
Overall equipment effectiveness	3x	11.11	3x	11.11	5x	18.52	5x	18.52	7x	25.93	4x	14.81	3.81	1.59
Total equipment effectiveness performance	9x	42.86	2x	9.52	-	-	2x	9.52	-	-	8x	38.10	3.29	2.35
Others	2x	12.50	-	-	5x	31.25	2x	12.50	1x	6.25	6x	37.50	4.13	1.78

The “others” set was including the companies customized measurements, for instance: time-between failure; time efficiency (operational time/ total time); machine capacity and utilization.

**Question 12.** Which of the following listed policies below is the company main contributor for minimizing the equipment stoppages and thereby decreasing the downtime cost? Select your answer and the status of use on a scale of 1 to 5 representing very low to very high respectively. *Note: each participant can select more than one answer*

The total Number of participants: 49, and the votes distributed as followings:

Policies / Scale	1		2		3		4		5		Don't know		0	±
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%		
Preventive maintenance	1x	2.04	2x	4.08	4x	8.16	17x	34.69	22x	44.90	3x	6.12	4.35	1.01
Corrective maintenance	8x	18.18	13x	29.55	10x	22.73	7x	15.91	3x	6.82	3x	6.82	2.84	1.45
Reliability centered maintenance	11x	28.21	5x	12.82	5x	12.82	1x	2.56	-	-	17x	43.59	3.64	2.22
Condition based maintenance	6x	13.64	7x	15.91	12x	27.27	7x	15.91	1x	2.27	11x	25.00	3.52	1.73
Total productive maintenance	11x	27.50	4x	10.00	7x	17.50	7x	17.50	3x	7.50	8x	20.00	3.28	1.87

**Question 13.** Evaluate the following statement below by rating the given options on a scale 1 to 5 representing totally disagree to totally agree respectively.

*For accurate downtime cost quantification, it is important.....*

The total Number of participants: 50

Options/ Scale	1		2		3		4		5		0	±
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%		
1- that downtime cost analysis includes planned downtime cost	4x	8.51	7x	14.89	9x	19.15	12x	25.53	15x	31.91	3.57	1.31
2- that company mindset adopts a new approach of considering the planned downtime cost	4x	8.16	5x	10.20	8x	16.33	13x	26.53	19x	38.78	3.78	1.30
3- that data sources and data collection are compatible and easily shared between different departments	3x	6.38	8x	17.02	6x	12.77	14x	29.79	16x	34.04	3.68	1.29
4- that cost drivers are obviously allocated	4x	8.51	7x	14.89	9x	19.15	11x	23.40	16x	34.04	3.60	1.33

# Chapter 5

## 5. Analysis and Discussion

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*This section includes the analysis of results after being obtained. The reflections on received answers and numerical figures are deliberated within this part. Furthermore, the discussion of answering the research questions (RQs) are also provided.*

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According to the results, it shows that concerning the knowledge status of concepts, methods, and procedures of costing downtime were recorded the value of (2.8) as a weighted average rate on Likert scale. This result shows that the score is slightly close to moderate item, and it reflects that the companies are not aware of costing downtime. They are not preparing and training groups for evaluating and allocating the true cost of downtime. However, the manufacturing firms were estimated that the downtime cost ratio constituted (23.9 %) of their total manufacturing cost, and (13.3 %) of planned production time. Those figures are relatively high and carrying many incurred implications for instance, the lessening of equipment capacity compared to the theoretical capacity as provided by the original manufacturer, adding the impacts on profits margin [53]. The point here, managers are versed in these mentioned consequences, but they are not taken any serious steps toward quantifying the true cost of downtime and instead they lean into rough estimations.

When the question was to vote for the driver factors that responsible for planned stoppage. The votes apportioned according to highest rated factors as following: schedule maintenance (81.3 %); cleanings (29.7 %); breaks (28.1 %); meetings (25 %). This percentage out of 64 votes dedicated to each factor. The scheduled maintenance considered the main factor of planned stoppage in manufacturing companies, and followed by cleaning activities that are very critical in construction facilities. Nevertheless, the lunch breaks and morning meetings have its influence on productivity even though it ranges between half to one-hour period. On the other hand, lost capacity cost was the main cost category that drive cost due to unplanned stoppage. The other cost categories that rated by participant as essential concern was the direct labor,

customer dissatisfaction and lost profit costs. The votes were distributed to each category of (74.2 %), (38.7 %), (32.3 %) and (30.6 %) respectively. These cost centers were not traced properly, especially the costs related lost opportunity [6]. This result initiated by the lack of systematic model for evaluating and quantifying the accurate cost of downtime as appear clearly in results chapter. For example, (83%) of the surveyed companies they do not have any integrated methods for identifying and tackling such costs.

The estimation of planned and unplanned downtime in cost ratio from the total downtime cost was (36.9 %) and (63.1 %). The average difference in cost was approximated to (68.7 %). These values were provided from the surveyed participants based on their experience and some cost calculations. Their general trend of computing downtime cost relied on fixed and variable associated direct costs such as labors, utilities, and materials used. The financial statements in addition to budgeted cost were the way of measuring the consequential cost of downtime events. Furthermore, the most selected cost accounting methods for calculating the manufacturing cost was the RCA and ABC. The weighted average score of implementation in correlated to each of those methods accounts to (1.5) for ABC and (2.7) for RCA according to Likert-scale. These figures mean that both methods are adopted into firms, but their implementation status ranged from low to moderate item, in which that reflects the weakness of adapting downtime elements inaccurate cost measurements [4]. Moreover, the (35 %) and (27.9 %) of participants whilst choosing either ABC or RCA was not sure about the status of implementation and therefore they check the “Don’t know” choice.

In questioning the performance measurement systems that company utilized for evaluating the improvements as a basis of their downtime cost analysis, was a little unpromising. There are (62.7 %) of surveyed companies they do not have any measurement system to assess their analysis and the results that emanating from it. However, there are (37.3 %) claims the existence of such measurements. OEE was the highest ranked tool picked by participants in which weighted score (3.4) on Likert-scale in accordance with its implementation. The industries tend to high implementation of OEE as a key improvement indicator of their quality, performance and availability [34].

As an essential part of this thesis, the investigation of the maintenance role of decreasing downtime and thereby costs was very necessary. Thus, after collecting the results about this inquiry, PM policy and in particular the scheduled tactic shows the most attracted choice selected by participants. The PM weighted average score of (4.2) on Likert-scale that considered high in comparison with lowest rated tactics (2.6) and (1.8), TPM and RCM respectively. These values reflect that companies are spending a plenty of time in stochastic maintenance and ignoring tactics as TPM and RCM [8].

The participants have been asked about their future vision of better practices of downtime cost quantification, or what are the factors that must include in their daily cost analysis. The answers received according to weighted average score (totally disagree to totally agree) on a scale of 5. The results distributed as followings: (3.78) devoted to the cultural factors and mindsets of considering planned stoppage as a loss. For example, one of the participants comments on that “we don’t see planned stoppage as a loss yet”. Additionally to (3.68) underlined the importance of flexible computerized system such as, a manufacturing execution system that facilitates the compatibility between data sources and collection. Moreover, the information must be eligible for conducting downtime cost analysis and easy to share between different departments. A (3.6) of agree answers stated the need for obvious identification of hidden cost categories, that mainly constitute the large portion of downtime cost. Clear framework and easy procedures must be developed for this target. Finally, (3.57) of slightly agree responses mentioned the need to count in planned stoppages whilst calculating the downtime total cost.

---

***RQ1. What are the main cost categories and drivers associated with planned and unplanned stops can be identified?***

The determination process of the cost centers and its incorporated drivers through random downtime incidents are very reliance on the dynamic of production lines. In manufacturing circumstances, these production lines are often designed to overcome downtime impacts by having buffer systems between stations. The role of buffers strategy is to reimburse the differences in stations cycle time, and for enabling short-term flow of production whilst the critical equipment entering the maintenance state. However, in many cases of downtime

scenarios the buffer level declined to zero or became empty because of the extended period of the downtime event. Hence, this leads to permanent production loss in which regular production schedule cannot replenish such deficiencies, and instead require an overtime or other solutions that, usually, are inefficient and very costly [4].

The number of outages and length of time of inoperative machine are the factors that specifies the cost categories and how the cost drivers accumulated. For instance, in typical downtime situations one of the apparent cost center is the equipment that generated by many activities and resources drivers, but in different rates [56]. Nevertheless, the people cost metrics not only restricted to the number of direct idle operators and their hourly wages, but the indirect affected labors. The production, maintenance, management and administrative labors have the greatest impact on driving equipment cost per downtime events. In addition to the overhead labors that supports the mechanisms of reinstate equipment function [58]. This analysis argued the obtained results from the questionnaire; the Swedish manufacturing companies designate the direct labor costs as an essential concern whilst calculating the equipment downtime cost and disregard the indirect and overhead labors associated cost.

The equipment lost capacity was the main cost driver within reduced production rate category that picked by most Swedish manufacturing companies. This cost measured by the time and quantity loss at machine of interest, the same quantity loss also related to produced defective parts and incurred costs of scrap and rework activities. If the machine is running in its specified speed and capacity, the unit produced will be assigned to a profit center. Moreover, the resources still consumed even though these resources do not added-value to customers. As a result, this will lead to lost profit and in turn customers' dissatisfaction [1].

On the other side, schedule maintenance practices were the potential driver cost of planned stoppage such as, the cost of direct labors involved and material used. Furthermore, the inefficient applications of preventive maintenance as a consequence will affect the production rate negatively and thereby lost production. This lost production has less impact than lost due random or unplanned related stops because it still under controlled limit and within a specified period. The assumption here is planned stoppage will set production line in halt state and machines in setback state, except the targeted machine that entered the maintenance state [4].

As a summary of (RQ1) answer, the cost categories that associated with the planned stop is related to the cost metrics of equipment and production rate. This statement means the obvious cost driver that mentioned in the research and also supported by the questionnaire results was the preventive maintenance and its consequential costs. The loss of production time and quantity while performing preventive maintenance is carried cost and measured by the unit produced. Another noticeable cost drivers are the idle operators, direct maintenance labors, materials and tools. On the other hand, the unexpected stoppage has one more cost category than planned stoppage, which is overhead labor that support the activities needed to restore the machine. Furthermore, the main cost drivers that associated with unplanned stops and drawn from questionnaire and literature are the direct and indirect labor costs; the lost opportunity costs such as equipment lost capacity, demand and lost profit.

***RQ2. Which methods are used in industry for assessing the cost of downtime?***

The methods that are used by industry are essential emphasize on the direct cost of labor during the downtime period. Most of the companies calculate this cost as the number of operators impacted multiplied by the average operator cost per hour and the duration of equipment outage. Lost production and so lost sales revenue have also been incorporated as one of the common measurement used to evaluate the downtime monetary value. The computation of lost revenue were based on the gross sales over the total loading hours multiplied by the number of hours of downtime [59].

On the other hand, there were some methods targeting the fixed and variable cost of machinery operational cost. Here, the argument was that whenever machine breakdown there is an incurred loss capacity cost, and the machine cannot support the producing of items. Many industries suggested the calculation of depreciation, taxes and interest on capital costs as an indicator to measure the downtime cost based on fixed parameters. In addition to the variable costs calculation as, the maintenance and energy consumption costs are also stated. The energy consumption intensities and its related costs were extended to other areas of cost centers. For example, when machine breakdown and in some situations labeled as bottleneck

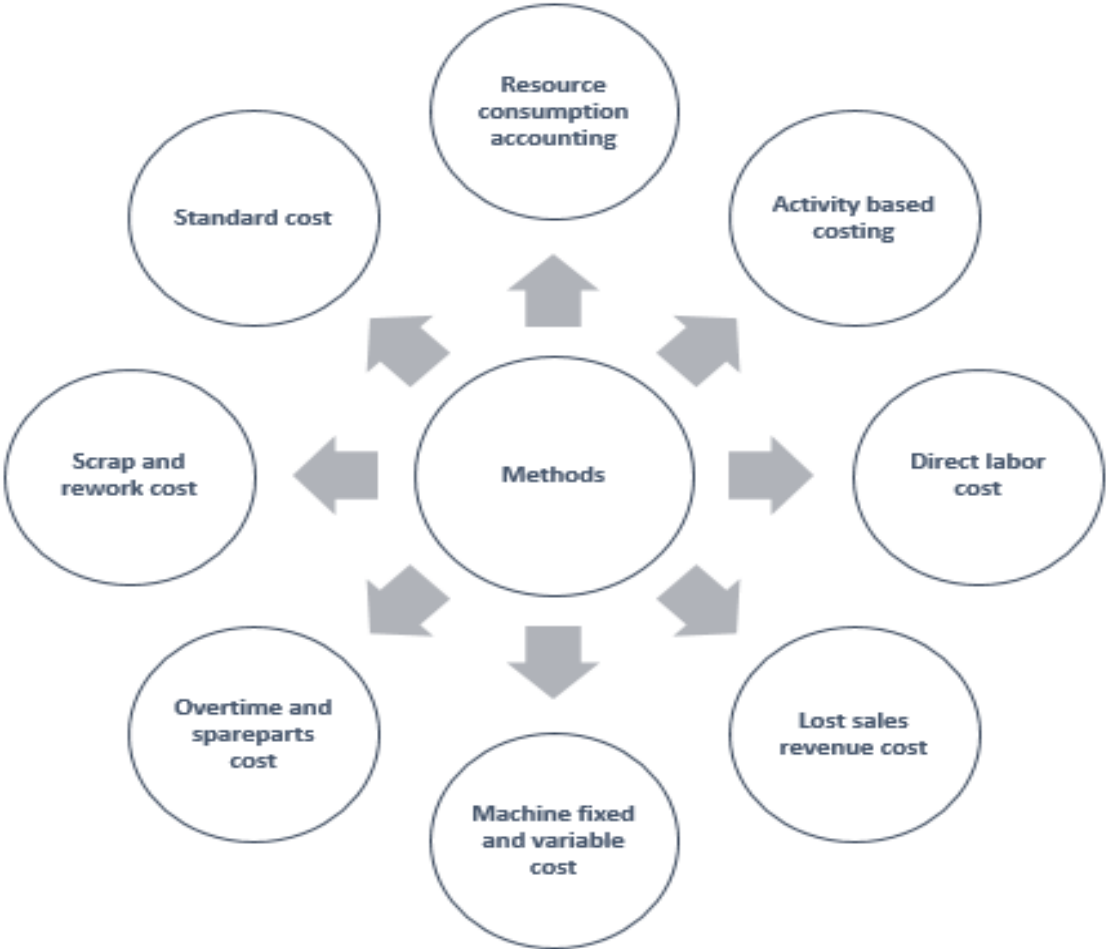
has an effect on downstream process, there are other machines that still consume energy even though they are not processing [60].

Some surveyed companies propose the methods of targeted costs or standard cost whilst assessing the downtime financial determination. This method is willing to restrict downtime expenditure through improving operations. The overall goal was to establish awareness of downtime imposed costs before the stoppage occurs. However, this method shows its efficiency and applicability in correlated to planned stoppage events because of the static nature of stops and the pre-defined procedures. For instance, the cost of maintenance practitioners and the exact raw material amounts. On the contrary, the stochastic nature of unplanned stoppages is more difficult to set a standard costs earlier to incident. In many cases, this type of stoppages expand the standard cost scale because of many cost centers created over the length of the downtime period [61].

The calculation of overtime and spare parts cost was also being considered in industries. In some companies, the downtime event exceeds their normal production time and that demand an overtime work to replenish their lost production. The cost of overtime is relatively higher than the hourly cost of normal working shift, and the calculation must count the fringe benefits percentage as well. The spare parts costs calculation is done especially while maintenance be in charge of repairing the broken equipment. The cost of tooling, components, and parts replacement in addition to purchasing new parts to refill the storage is considered in many Swedish industries for computing the downtime cost [57].

Finally, many surveyed companies adopt methods for cost accounting such as, ABC and RCA. The companies used ABC method to trace every single cost consumed by activities and resources in order to restore the equipment function. For instance, whilst failure occurs, and machine become idle one of the apparent cost center that generate is related to maintenance. This method will identify the activity needed such as in this case, repair activities in which required an absolute amount of resources of labors, materials, energy surges, etc. On the other hand, the RCA method was based on modelling of the resource flow along the entire production line. The resource flows from a resource pool to cost objects. For example, one main distinguish between RCA and ABC is resource pools. In ABC, the activities are the main driven factors of cost analysis and those activities related directly to the broken equipment

(one entity). In a paradox, RCA deals with different resource pools (many entities) that created as a result of critical equipment failure [30]. As a summary, the *figure 12* below represents an overview of the methods that are used in industry for assessing the cost of downtime.



**Figure 12. The main methods used in manufacturing industries for assessing downtime cost**

(Source: Own)

***RQ3. What is the industry’s view of the cost difference between planned and unplanned stops in production?***

Company’s vision about the cost difference between planned and unplanned stops are to large extent subjective. The lack of fully integrated model that clearly distinguish the cost differences among both elements, still the reason behind the rough estimation of these

costs. However, the unplanned stops with its uncertainties earned more attention than planned stops, and that stated by questionnaire participants that appraised unplanned stoppage cost in much higher than planned stoppage cost. Furthermore, some companies still not considering planned stops related cost an impact loss. Their argument was based on the principle that those stops are minor stoppages, and they are not affecting the production processes [50].

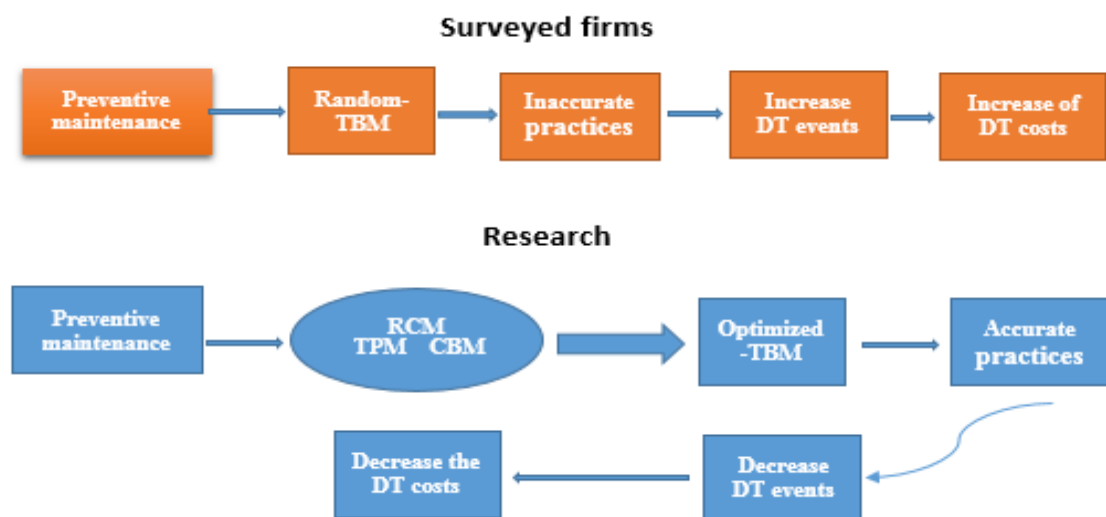
However, the research contradicts that as while preventive maintenance applied to a critically rated equipment in serial production line. The whole production line including all machines, operators, materials, and all types of incurred resources will be setback until the maintenance activity complete. Though, all of those idled resources in addition to lost production time and quantity will be carrying costs. Therefore, the planned stoppage not only contains direct labors cost there are also other areas that will generate added-costs of unused capacity as a result of this event [4].

***RQ4. What is the main maintenance strategy that applied for reducing downtime events and thereby costs?***

According to the questionnaire results, the dominant maintenance strategy applied for reducing downtime events and thereby costs is preventive maintenance strategy. The pre-determined policy such as schedule maintenance was the main policy that Swedish companies rely upon the reduction of downtime events and its associated costs. Similarly, the same results show that TBM especially in corresponding to a fixed schedule of inspections, repair, replacements, etc. are the activities that utilized in purpose of increase equipment reliability and enhancing the availability. The analysis indicates high investment on schedule maintenance but does not show its effectiveness whilst approaching the downtime cost reduction analysis [40]. The cost still at peak, even though preventive maintenance performed!

In the clarification of this statement, the following points will spotlight this gap as observed from the results, see also figure 13:

- I. The surveyed companies were conducting TBM randomly with high implementation degree.
- II. CBM, RCM, and TPM tactics were less adopted to their maintenance system as appeared in results.
- III. The need for optimized schedule maintenance. Therefore, the low implementation of such tactics like CBM, RCM, and TPM will lead to inconsistency between companies applied maintenance and decreasing downtime events and thereby costs [8].



**Figure 13. The differences of decreasing downtime costs by integrated maintenance tactics**

(Source: own)

***RQ5. Is there any performance measurement system adopted for evaluating the improvement of production equipment?***

The majority of surveyed companies were chosen OEE tool, as a whole, the fundamental method for evaluating improvement of production equipment. They use such method to identify the hidden production plant capacity by revealing the six major losses. In addition

to another customized measurements that target the time efficiency such as, the time between failures. However, the measures that restricted to operational time over the total time are partially integrated to provide the real picture of improvements. For example, after maintenance performed this type of measurements will include only the availability factor and exclude the other factors like quality and performance. Furthermore, some companies were focused on measuring the performance rate or the equipment capacity improvement. The number of units produced after machine repaired was the indicator that firms rely on, and that in order to affirm improvements [34].

On the other hand, TEEP tool scores the lowest rated option selected by surveyed companies. This low rated choice happens because of neglecting the total calendar time as a basis for equipment efficiency measurement, and instead using the scheduled production time. The planned stoppages were not considered into their performance measurement system, even though through this study the planned maintenance has shown its remarkable impacts on costs and performance [34]. Moreover, the equipment utilization metric in which TEEP provide is a good supportive function for compensating OEE shortage. Both tools are merged in a role of finding areas of potential cost savings. Although for better practices and world class production, the availability perception from equipment utilization view become more effective as it incorporates planned, and unplanned stoppages bound [58].

## 6. Conclusions and Suggestions

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*This chapter includes the extraction of conclusions out of obtained analysis and results. Additionally to provide recommendations about the future research works that willing to approach this topic.*

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Swedish manufacturing firms are aware of the potential impacts that equipment downtime generates on their product cost and thereby profits. In addition to, the impact that extend to production efficiency and effectiveness. For example, this awareness appears obviously whilst managers evaluate the downtime cost ratio from total manufacturing cost. Moreover, the downtime influence on planned production time, downtime hourly cost, and the need for cultural change and mindsets. These changes aimed to include the planned stoppage cost into their assessment methods, “this type of cost should not be overlooked”.

Even though, the majority of surveyed companies (83 %) do not have any systematic model for assessing and tracking the individual costs that associated with planned and unexpected stoppages. They justify that by the complexity of such models and the length of time and significant costs required for implementation. For instance, the costs that accompanied with training and learned people. On the other hand, only few companies adopt complete models such as, activity-based costing and resource-consumption accounting for measuring downtime costs, but in low rate of integration, according to questionnaire results. Instead, those companies, emphasized on the direct labor and lost capacity cost as the main cost correlated to unplanned stoppage, and schedule maintenance as the main cost driver for planned stoppages.

Consequently, the lack of optimized methods and procedures are the reasons of high downtime hourly cost, whether planned or unplanned related stoppages. These reasons can be listed as following:

1. The absence of accurate methods for revealing the hidden cost categories, and instead dealing only with one or two obvious costs was the reason of consuming improvements in areas with less cost saving opportunities.
2. The adoption of performance measurement system such as, OEE and disregarding other measurements such as, TEEP, the planned stoppage will not be tracked properly. This study shows that planned stoppage has a remarkable cost in which required true assessment of its costs. As a result, the attempt of decreasing this cost will be seen in equipment utilization factor; hence, TEEP has such capabilities over OEE.
3. The high capital investments on randomly applied maintenance considered inefficient to reduce downtime costs but in opposite will added-costs. The TBM tactic that chosen by the majority of surveyed companies needs to be optimized. The optimization mainly starts with adopting and implanting tactics such as RCM, TPM and CBM as supportive functions for enabling TBM in allocating the right practices at right piece of equipment based on criticality degree, Productive maintenance.

Finally, this work aimed to present a sample of how Swedish manufacturing companies approach their downtime costs analysis and its reduction. Therefore, any future work is required to include large scale survey in which more companies involved, and better response rates obtained. The accuracy is very important in such studies, especially when there are a numerical evaluation and further generalizing results. Also, case studies are very necessary to be performed because not many things can be attained through questionnaire. The investigation of downtime cost from different aspects such as, the impact of human factors is indeed at the same level of importance in comparison with other factors.

Additionally, the future research needs to have more works on planned stoppage cost, and that might be supported by developing models for assessing this cost. Moreover, a framework for distinguishing the differential cost between planned and unplanned stoppage are also recommended.

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## 8. Appendices

### 8.1 Appendix (A), The Swedish version of questionnaire template

Stilleståndskostnader-skillnaden mellan planerade och oplanerade stopp 0%

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**Page 1**

A. Allmänna frågor

I. Hur väl känner ni till koncept och modeller för analys av stilleståndskostnader i produktionsutrustning på en skala från 1 till 5 representerar mycket låg till mycket hög respektive?

	1	2	3	4	5	Vet ej
status	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

II. Vad kostar era driftstopp i förhållande till den totala tillverkningskostnaden? (i procent)

0% = Vet ej

Svar  %

III. Vad är den beräknade andelen tid för driftstopp i förhållande till utlagd produktionstid? (i procent)

0% = Vet ej

Svar  %

**Page 2**

B. Driftstopp kostnadsanalys

I. Välj den främsta orsaken till planerade stopp på ditt företag (alternativ nedan)

- Planerat underhåll
- Programvara uppgradering / uppdatering
- Avställningar
- Inspektioner
- Rengöringar
- Träning
- Möten
- Raster
- Annan information

II. Vilka kostnadsdrivare/attribut som förknippas med driftstopp, såväl planerade som oplanerade stopp väger tyngst? (Välj ett eller flera svar från valen nedan)

<input type="checkbox"/> Direkt lön	<input type="checkbox"/> Förlorat Kapacitet	<input type="checkbox"/> Processförbättring
<input type="checkbox"/> Indirekt lön	<input type="checkbox"/> kundernas missnöje	<input type="checkbox"/> Förlorat efterfrågan
<input type="checkbox"/> Ineffektiva processer	<input type="checkbox"/> Vite	<input type="checkbox"/> Verktyg för omarbete
<input type="checkbox"/> Förlorad möjlighet	<input type="checkbox"/> Processflaskhalsar	<input type="checkbox"/> Hyra utrustning
<input type="checkbox"/> Förkortad maskinlivslängd	<input type="checkbox"/> Extra fraktkostnader	<input type="checkbox"/> Reservdelar upphandling
<input type="checkbox"/> Förlorad vinst	<input type="checkbox"/> Oarbete och skrot	
<input type="checkbox"/> Annan information	<input type="text"/>	

III. Finns det någon systematisk modell / metod som används för att utvärdera och kvantifiera kostnaderna för driftstopp?

yes

no

Om ja, hur stor andel av den totala driftstoppkostnader utgörs av planerade driftstopp?

0% = Vet ej

Svar  %

Om nej, vilken beräknade procent skulle kunna ges för planerade driftstoppkostnader i andel av total driftstoppkostnad? Baserat på beräkningar eller erfarenhetsbaserad uppskattning

0% = Vet ej

Svar  %

### Page 3

IV. Ungefär hur mycket kostar en timmes oplanerat driftstopp hos er?

 SEK

V. Ungefär hur mycket kostar en timmes planerat driftstopp hos er?

 SEK

VI. Är dessa kostnader baserade på beräkningsmodeller eller uppskattningar? förklara ditt svar

### Page 4

VII. Vilken modell använder ert företag för beräkning av stilleståndskostnader? Välj ett alternativ och indikera hur väl det används på en skala från 1 till 5 representerar mycket låg till mycket hög respektive.

	1	2	3	4	5	Vet ej
ABC-kalkyl	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
LCC (Life Cycle Costing)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Kalkylering av resursförbrukning	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Annan information	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Om du väljer "Annan information" skriv ditt svar nedan

VIII. Används mätetal för att kvalitetssäkra modellen för stilleståndskostnader?

yes

no

Om ja, välj lämpligt verktyg nedan och deras status för användning på en skala från 1 till 5 representerar mycket låg till mycket hög respektive

	1	2	3	4	5	Vet ej
OEE/TAK (Utrustningens Totala Effektivitet)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
TEEP ( Total Equipment effectiveness performance)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Annan information	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Om du väljer "Annan information" skriv ditt svar nedan

IX. Vilken av följande är den centrala metoden för att minska tiden för oplanerade stopp och därmed minska stilleståndskostnaden? Indikera graden av bidrag till minskningen på en skala från 1 till 5 representerar mycket låg till mycket hög respektive.

	1	2	3	4	5	Vet ej
Förebyggande underhåll	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Avhjälpande underhåll	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reliability Centered Maintenance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Tillståndsbaserat underhåll	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Totalt produktivt underhåll	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Page 5

C. Ytterligare frågor

X. Besvara frågorna genom att kryssa i lämpligt svar som passar ditt företag på en skala 1 till 5 representerar helt annan åsikt att helt överens respektive.

För noggrann kvantifiering av driftstoppkostnader, är det viktigt .....

	1	2	3	4	5
... att driftstoppanalysen inkluderar de planerade driftstoppen	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
... att företaget skiljer på kostnader för planerade och oplanerade stillestånd	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
... att datakällor och datainsamlingen är kompatibla mellan olika avdelningar	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
... att kostnadsdrivare är naturligtvis identifierad	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>