Business Driven Maintenance Strategy Development with Performance Indicators

(A Case Study at GETINGE Disinfection AB)

A Master’s Thesis Submitted for the
Total Quality Maintenance (Systemekonomi) Program

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<td><strong>Abstract:</strong></td>
<td>The overall target of the maintenance management system is to improve the role of a maintenance organization in positively impacting <em>production capacity, products quality, safety</em> and also <em>overall production cost</em>. In the course of ensuring the above mentioned benefits, the maintenance system should be designed under an umbrella of appropriate strategy that is developed in line with the company’s major business objectives. The thesis work is focused on developing a model that assist the design of a maintenance strategy which is linked with the company’s major business objectives. And for this the balanced score card approach is utilized. Then the model’s application is tested in a case company with the general procedures described below. The business requirements by the customers, which are translated to business objectives of the case company, were used as starting points. Then the production performance indicators were checked for their effectiveness in addressing the business objectives of the company. After this, a maintenance strategy with approaches to address the business objectives of the company, which are expressed by the production performance indicators, was developed with potential maintenance performance indicators. The result showed that the different elements incorporated in the model developed are appropriate in linking the maintenance activities with the company’s business objectives as can be observed from the analysis made on the case company.</td>
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Matias Taye
May, 2009
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i. Definition of Terminologies

In the course of working on the project, the different terminologies and concepts presented are used for the meanings that are described below. Such clarification of these terminologies is needed as they are sometimes used interchangeably and depicting other meanings creating understanding gaps.

**Business Objectives** are “goals that an organization sets for itself which are used as foundations up on which the strategic and operational policies are based up on” (Ultimate Business Dictionary).

**Maintenance Objectives** are defined on the EN 13306:2001 as “targets assigned and accepted for the maintenance activities. These targets may include: availability, cost reduction, product quality, environment preservation and safety.”

**Maintenance philosophy** is defined on the British standards (BS 3811: 1993) as: “A system of principles for the organization and execution of the maintenance.”

**Maintenance strategy** is defined on the European Standards (EN 13306:2001) as “Management method used in order to achieve the maintenance objectives.”

**Maintenance policy** is defined in the British Standards (BS 3811: 1993) as: “A description of the interrelationship between the maintenance echelons, the indenture levels and the levels of maintenance to be applied for the maintenance of an item.”

**Maintenance echelon** is “a position in an organization where specified levels of maintenance are to be carried out on an item.” the British standards (BS 3811: 1993)

**Indenture level** is “a level of subdivision of an item from the point of view of a maintenance action” as defined on the British standards (BS 3811: 1993)

**Level of maintenance** as defined on the British standards (BS 3811: 1993) “is the set of maintenance actions to be carried out at specified indenture level.”
1 Introduction

This Section briefly introduces what the study is all about using different sections. First a background to the topic studied is presented covering why this study is important. Then the problem is discussed briefly followed by problem presentation so as to lead to the problem formulation. Then the purpose and relevance of the study is presented showing the theoretical and practical implications of the study.

1.1 Background

The varying demands of the market in the form of product or service variety, quality and volume are demanding industries to think of ways to address them and maintain their market share. In addition, the availability of many service providers with different capacities makes the competition fierce (Chan et al., 2009 and Campos, 2009). So an overall adjustment on the performance of industries by incorporating appropriate strategies is a fundamental requirement (Chan et al. 2009). But, the current practice shows that 60% of resources in companies are not linked to definite agreed strategies (Parmenter 2007). In addition, Al-Najjar et al. (2003) argues that maintaining the resources that are in place is equally, if not more, important as to implementing new technologies and systems so as to make sure that the systems are available, reliable, safe, economically optimal and friendly to the environment.

Maintenance, as one of the support functions to a system, addresses the above mentioned targets with its direct and indirect effect in making systems function within limits that ensure all encompassing optimal operations (Komonen, 2002; Duffuaa et al., 2002). Duffuaa et al. (2002) also add that maintenance contributes to strategic company goals in ways like: reducing cost, minimizing equipment down time, improving quality and providing reliable and safe equipments.

1.2 Problem discussion

Customer requirements in the form of product quality, delivery time and price influence the shape of the production processes (Chan et al. 2009). In the process of achieving the above, the production process is expected to be cost effective and safe as pointed out in Kelly (1997). The maintenance function would then be responsible to make sure that the production system is available, reliable and safe with optimum resource utilization (Al-Najjar, et al. 2004).

The impact of maintenance for company’s overall goal is vague (Al-Najjar 2007). This unclear perception towards the maintenance function then results in different consequences including: technical, financial, safety and organizational flaws (Vineyard et al. 2000). In addition, the ineffectiveness in the linkage of maintenance with company goals and strategies also contributes to the wider perception towards maintenance only as a cost centre by the management bodies (Al-Najjar 2007). And this prohibits good management attentions towards it that manifest in different aspects like resource lacking, bad work environment and lower personnel motivation, which add to the sub standard functioning of the maintenance function. This intern adds to the misperception by the management, completing the vicious circle of misunderstandings towards maintenance (Komonen, 2002; Sherwin, 2000).

So, the identification and application of appropriate (in alignment with the business goals of a company) maintenance strategy with potential performance indicators would minimize the above mentioned flaws and make the contribution of the maintenance function visible (Vineyard et al. 2000). Ronan McIvor (2009) also suggests that one way to strengthen competitive advantages in the market and still maintain the market share is by focusing on key
areas that are in line with the company’s strong sides. And, shaping the maintenance function to assist this effort is one important strategic consideration.

1.3 **Presentation of problem**

The inefficiency of establishing proper linkages between the maintenance function and company’s business objectives deprives companies from achieving more from the maintenance function in supporting overall company goals (Murthy et al. 2002). And the major aspect of a maintenance system that can serve as a platform for this link is the maintenance strategy that is implemented with visible links to business objectives (Vineyard et al. 2000). And the inability to apply appropriate performance indicators in alignment with the company’s business objectives (goals) also minimizes the visibility and also the measurability of the impact of the maintenance function on company’s overall performance (Kari Komonen, 2002).

1.4 **Problem formulation**

How can business objectives be translated in a maintenance strategy and key performance indicators for improved maintenance contribution to company’s business strategies?

1.5 **Purpose**

The thesis work will be focused on how to develop a business driven maintenance strategy *(in accordance with an agreed scope)* by suggesting a model to be utilized as a guideline to link the business objectives with the maintenance function. The work would also incorporate selection of appropriate key performance indicators (KPI’s) to standardize and measure maintenance performances, on their effectiveness in addressing the business goals they are linked to.

1.6 **Relevance**

One of the theoretical implications of the work is that the procedures of addressing the study problem can show how business goals can be translated to technical parameters that are tractable at the operational level, which is a suggested important approach in (Pramod et al. 2007). In addition, the successful depiction of the link of maintenance actions with company’s business objectives (goals) would also possibly address the old perception toward maintenance only as a cost center with no visible impact on company’s business goals (Komonen, 2002; Sherwin, 2000).

As mentioned above, the task to be covered with this project would provide a general procedure in developing a maintenance strategy in alignment with a company’s dominating business drivers. And it would also incorporate appropriate performance indicators that enable monitoring of maintenance performance, which affect the company’s business goals visibly. This then has a practical implication, as most resources (60%) in companies are not linked to the company’s strategies as pointed out earlier by Parmenter (2007).
1.7 Delimitations

In the course of working on this project work, there are some delimitations within which the scope of the work is constricted. These delimitations are:

✓ The case study is done in an overall context showing the linkage between business objectives and maintenance strategy. This limited the development of particular maintenance policies and standard operating procedures. The possible reason for this can be the broad nature of the topic and the limited time allotted for the work.

✓ The presence of different company strategic planning and executions at the case company limited the access to enlarged number and variety of respondents.

1.8 Time frame

The work planning of this project work is composed of three parts. These are: pre-task, on-the-task and documentation. The different sub components of these major categories and the time frame designed to perform these tasks are presented on the next Gantt chart.
Table 1.1. Gantt chart for project work

<table>
<thead>
<tr>
<th>Overall Project Tasks</th>
<th>Weeks</th>
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<td>Project Topic Discussions</td>
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<td>Maintenance Strategy and policy derivations</td>
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<td>Tasks Finalization</td>
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</table>
2 Research Methodology

This section of the report presents the potential researching methods and describes which research method has been utilized for the study. It also describes the different tactics used to increase the dependability of the research method used.

2.1 Research approaches chosen and why these approaches?

Case study is one of the different research conducting methods in different fields including technical and business areas even though there have been some notable arguments on its reliability. Other researching methods include: experimentations, surveys and analysis of archival information as pointed out in Yin (2003).

Yin 2003 further explains that the type of research methods to choose depends on factors like: “the research question posed, the extent of control the researcher has and the degree of focus on contemporary than historic events.” So, if the research question is inclined to answering “Why” and “How” questions and intends to clarify a blurred correlation, the application of case studies is preferable (Yin 2003). The other important factor is the level of control of the researcher over the studied situation. If a researcher has limited privilege to control the studied setting and that the factors affecting the study concerned have unclear cross boarder nature, he/she has two options of addressing the research question. These ways are direct observations and interviews with involved persons. So, for study situations with these characteristics, case study would then be the best option. As a result, since the nature of this study and the case setting chosen have properties of the above mentioned research characteristics, case study is the chosen method of research for this study.

But, there are still arguments on the flaws of a case study as a research option. The two major arguments are that the results of a case study are probable to incline in the direction of the author and that a case study is difficult to generalize from. The applicable remedies for these are: designing the study questions with lesser biasness and generalize the outcomes of case studies to align with existing scientific theory, so as to enable the study align with one form of generalization called “analytic generalization” (Yin 2003, ).

The four testing parameters to minimize the percentage of occurrence of the above discussed possible flaws from a case study are: “construct validity, internal validity, external validity and reliability” (Yin, 2003; Burns, 2000).

2.1.1 Construct Validity

Is a parameter that is useful in measuring how well a measuring parameter measures the theoretical concept presented [16]. This factor is affected as a result of the researcher’s failure to develop sufficient set of measuring parameters that address the studied issue in full extent (Yin, 2003; Burns, 2000). This point has become important as case studies are blamed for using subjective judgements as the primary data collection way. So, proper indicator parameter selections and appropriate data collections side by side with the subjective judgements can eliminate the mentioned problem as pointed out by Yin (2003); Burns (2000).
2.1.2 Internal validity

“Is the rigor with which the study was conducted” as pointed out in [16]. The other definition presented for this parameter of research is “the extent to which the designers of a study have taken into account alternative explanations for any causal relationships they explore” [16]. This is an aspect of a research that can be affected by flaws within the study itself with reasons such as: not controlling some of the major variables (a design problem), or problems with the research instrument (a data collection problem). In addition, the different findings of the research are said to be internally invalid if the data interpreted by the researcher do not clearly align with the justified arguments. The following are some of the factors which affect the internal validity of a research (Lynn Henrichsen et al. 1997; Burns, 2000).

- Subject variability
- Size of subject population
- Time given for the data collection or experimental treatment
- History
- Maturation
- Instrument/task sensitivity

2.1.3 External validity

This parameter measures the extent to which the research result can generalize the findings to a larger group or other contexts. If a research lacks external validity, this shows that the findings cannot be applied to contexts other than the one in which the research is carried out (Lynn Henrichsen et al. 1997; Burns, 2000).

Here are seven important factors that affect the external validity of a research.

- Population characteristics (subjects)
- Interaction of subject selection and research
- Descriptive explicitness of the independent variables
- The effect of the research environment
- Researcher or experimenter effects
- Data collection methodology
- The effect of time

2.1.4 Reliability

This measures the consistency in results of a measuring instrument, including the tendency of a measurement to produce the same results when it measures some entity or attribute twice, which is believed not to have changed in the interval between the measurements (Grinnell M. et al., 1990; Burns, 2000)

The different tactics that a researcher can follow and address the above mentioned research parameters so as to come up with a balanced research result are summarized in the following table as suggested by Yin (2003).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case Study Tactic</th>
<th>Phase of research in which tactic occurs</th>
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<tbody>
<tr>
<td></td>
<td>✓ Use multiple sources of evidence</td>
<td>Data collection</td>
</tr>
<tr>
<td></td>
<td>✓ Establish chains of evidence</td>
<td>Data collection</td>
</tr>
<tr>
<td></td>
<td>✓ Have key informants review draft</td>
<td>Composition</td>
</tr>
<tr>
<td>Construct Validity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>✓ Do pattern matching</td>
<td>Data analysis</td>
</tr>
<tr>
<td></td>
<td>✓ Do explanation building</td>
<td>Data analysis</td>
</tr>
<tr>
<td></td>
<td>✓ Address rival explanations</td>
<td>Data analysis</td>
</tr>
<tr>
<td></td>
<td>✓ Use logic models</td>
<td>Data analysis</td>
</tr>
<tr>
<td>Internal Validity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use theory</td>
<td>Research design</td>
</tr>
<tr>
<td>External Validity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability</td>
<td>Use case study protocol (standards) to minimize variability</td>
<td>Data collection</td>
</tr>
</tbody>
</table>

The major back up for the dependability on the data collected is the practical experience of the respondents in the topic of interest for more than ten years. And during these years, the respondents had the exposure to work in maintenance and performance improvement areas in other companies too. So this can be one port for the responses from them to have multiple sourced natures even if it was focused on the case company chosen. The other tactic to make sure that the data are from multiple sources, respondents were chosen from different parts and levels of the organization ranging from operators up to company strategic team members.

In addition, in the process of collecting data, the necessity of the data, the data analysing tools and the expected results of the implemented tools were briefed to the respondents primarily. Then, questions were sent to respondents some days before the meetings so that they can contemplate on them before the actual meetings. And in the meetings, the questions were elaborated so as to minimize ambiguities. Then, the results of the data analysis were discussed again with respondents for confirmations of responses in some situations.

The general research flow is as depicted below containing the major activities. Then the detail activities performed are described under the major tasks.
Fig. 2.1. Overall task activities

The pre-task activities and their components are described below.

- Topic Discussion: Relevance Checking, Title Selection, Potential Case Implementation.
- Delimiting Task: Limiting the scope, Identifying deliverables.
- Planning: Task schedule planning, Study tools selection, Company time planning and information access planning.

The on-the-task activities and the activities/resources within them are:

- Theoretical background: Books, company slides, company regulatory documents, international standards, related research papers and web sources.
- Data Collection: discussions, interviews, questioners, plant observation and company documents.
- Analysis Tools: Analytic Hierarchy Process (AHP) and House of Quality (HOQ).

The last part is the documents preparation part which includes the two expected deliverables i.e. a master’s thesis document and a draft maintenance policy document. In the process of conducting the research, the central element that functioned in coordinating and directing all the activities for a fruitful result was the supervision, which can be divided into supervision by company responsible and supervision by the tutor.
3 Theory

In this chapter, literature reviews from different sources mentioned in the research methodology chapter above are presented. It covers the definition of the key terminologies, concepts and previous researches that are in alignment with the topic of study. In addition, foundational theories and different considerations that are thought to back the analysis that follows are also discussed.

3.1 Maintenance Contribution to Company Business Strategies

Customer requirements in the form of product quality, delivery time and price influence the shape of the production process so that it can perfectly address them. In the process of achieving the above, the production process is expected to be cost effective and safe as pointed out in Kelly (1997). The maintenance function would then be responsible to make sure that the production system is available, reliable and safe with optimum resource utilization (Al-Najjar, et al. 2004).

Duffuaa et al. (2002) also points out that the consideration of the maintenance function as one of the business units is demanded for proper planning of the maintenance actions and resources. This attention then calls for an implementation of quality improvement systems in the maintenance systems so as to enable it contribute in measurable ways towards the business goals. The objective of any maintenance organization as described by Kelly (1997) is that it matches the available maintenance resources to cope with the maintenance work load enabling it to be handled in an economical way, which is directly or indirectly linked to the company’s overall business goals.

Murthy et al.(2002) presents that a strategic maintenance management has two major targets to address. One is to acknowledge that maintenance is a central activity to businesses and the other is that it needs to be managed using quantitative business models that can be technically translated and interpreted to give maintenance related interpretations. It further explains that strategic maintenance management can also go deep into developing and using quantitative models that enable to predict the impact of different actions (including business induced actions) on equipment states so as to shape the maintenance actions accordingly, in alignment with the strategic needs. Murthy et al.(2002) makes use of the following representation to show the link between business objectives and maintenance strategies.

[Diagram representation]

14
Any maintenance objective, that is designed to impact the business in the above mentioned way, is then expected to be broken down to equipments and parts level in accordance with the criticality of the systems and the subsystems as shown above. This would then enable the development of maintenance life plan that lead to schedules and standard operating procedures.

3.2 **Key Performance Indicators (KPI’s)**

The performance of a sub system within a system must be measured against agreed goals so that the performance of the encompassing bigger system can be checked. Likewise, the performance of maintenance should also be measured in a way that can show the impact of the function (maintenance in this case) on the company’s overall goals (Kari Komonen, 2002). Performance measurements would also make it easier for top management to visualize the impact of the maintenance function on the company’s business; as such performance measures also incorporate business related performance of the function (Sherwin, 2000).

SS-EN 15341:2007 presents that KPI’s can be used for one of the following purposes.

- Measure status;
- Compare (internal and external benchmarks);
- Diagnose;
- Identify objectives and define targets to be reached;
- Plan improvement actions and
- Continuously measure changes over time.

*Fig. 3.1.Key elements of strategic maintenance management (Murthy et al., 2002)*
Sherwin (2000) points out that, in the case of maintenance, any maintenance action taken (not taken) can substantially affect a system as maintenance flaws have the nature of affecting a system for a prolonged duration. Ingwald (2009) also adds that maintenance ineffectiveness also has the nature of multi-directional impacts touching different functions like facilities, technologies, planning, control and human resource. So, having proper and timely performance indicators becomes an apparent choice here.

Now a days, the maintenance performance is measured by making use of indicators that are categorized with regard to subject matters like financial, technical and safety as pointed out in Komonen (2002). A holistic performance measurement of maintenance, as pointed out by Sherwin (2000), is recommended; as the conventional maintenance performance measurements were only able to show technical aspects, which have limited capacity for overall strategic decisions. The SS-EN 15341:2007 also supports the above classification of maintenance key performance indicators into three major aspects with little modifications. The three aspects suggested are: economic, technical and organizational. In addition, this classification of the KPI’s is also supplemented by three different levels of organizational functions i.e. top management level, support functions level and maintenance function level, as each parts of an organization have different area and level of interest in performance measurements.

Concerning the final implications of maintenance, Sherwin (2000) presents that, performance indicators in the form of ratios like: maintenance costs over sales or profit are mostly used. But such performance indicators only depict the maintenance function as a cost center, as they do not incorporate the impact of maintenance on economic gains through different forms of savings. Some of the economic savings by maintenance function as pointed out in Ingwald (2009), which need to be considered to see the overall impact of maintenance, are: “reduced down time, increased quality and reduced amount of capital tied in inventory and spare parts.” The above mentioned flaws of the customary maintenance performance indicators lead to biased decisions and wrong perceptions to the positive effect of maintenance on company goals (Komonen, 2002; Sherwin, 2000).

The OEE (Overall Equipment Effectiveness) is one of the many ways that has the ability to incorporate different aspects of the production effectiveness affecting factors, which can enable it to show the impact of maintenance in the overall performance of production. It is presented on Ingwald (2009) that OEE, which is the product of availability, performance and quality rate measures the reliability of a system. It is also additionally explained by the same author that this performance measurement incorporates losses associated with down time, lessening of operating speed and quality, which are the major losses encountered in manufacturing firms. But, there is also an argument that OEE can’t be used as a sole measurement of maintenance effectiveness as it doesn’t incorporate economic informants (Ingwald ,2009) and the application of other indicators along side OEE can account for this disability.

Availability is defined as “the proportion of total time that an item of equipment is capable of performing its specified functions, normally expressed as a percentage. It can be calculated by dividing the equipment available hours by the total number of hours in any given period.” [29]

Reliability is defined in [29] as “the capability of an asset to continue to perform its intended functions.” The same author presents that this system reliability measure is measured mostly by the mean time between failures. And mean time between failures is described as “the total equipment uptime in a given time period, divided by the number of failures in that period.”
3.3 Computerized Maintenance Management System (CMMS)

A computerised maintenance management system (CMMS) as defined in Bagadia(2006) “is a computer software program designed to assist in the planning, management and, administrative functions required for effective maintenance.” The function of a CMMS is presented by the same author as for “generating, planning, and reporting of work orders; development of traceable history; and recording of parts transaction.” As can be seen on the different roles of a CMMS system, it is a tool that can be used for interactive and enhanced communication for better utilization of the different maintenance resources in different aspects, which is the main goal of a maintenance management as pointed out by Kelly (1997).

3.4 Balanced Score Cards (BSC)

As pointed out in Mills et al.(2009), the balanced score card, a method developed by Robert Kaplan and David Norton of Harvard Business School, is “a method for developing strategic objectives through the measure of key financial, structural and process factors linked to organizational performance critical to its success.” The same author argues that BSC enables the identification of a direction to go in, communication of the direction to the stakeholders and direct resources towards the agreed direction. And it is also pointed out that 60% of resources in a company are not linked to a strategy, which necessitates the utilization of a holistic approach so as to channel resources for the benefits of a company, which can be handled well with a balanced score cards approach (Parmenter 2007).

The four aspects of a BSC are financial, customer, internal and learning (Education) (Mills et al.2009). It is further explained in Parmenter (2007) that the financial aspect emphasizes on the utilization of assets in ways that optimize the working capital of the company; where as, the internal aspect covers the on time delivery, optimization of internal processes and effectiveness of communication between the different parts of the system. Parmenter (2007) presents that the customer and the learning aspect focuses on ways to maximize the best utilization of the customer segments and the professional expertise at hand. The different general steps of applying a BSC and channel company resources to a chosen company goal are:

a) Assess the company’s missions and visions in alignment with the intended target.
b) Build strategic objectives based on the particular vision identified in the last step.
c) Map out linkages between the inputs to the strategic objectives and
d) Develop implementation strategies and performance measures

The MQFD would also have been one other approach that can be optional to the BSC approach. But, the freedom provided by BSC in assessing other organizational factors other than the technical floor is one criterion for it to be chosen as a study model. In addition MQFD’s specific requirements for TPM inputs and other detail production process parameters also direct the choice towards BSC (Pramod et al. 2007). And this much detailed information may not also be available in for this study from the studied case production setting because of young system integration moves and also the limited time allotted for this study.
3.5 Models implemented for the study

3.5.1 The House of Quality (HOQ)

The QFD (Quality Function Deployment) is a tool for quality improvement implementation and management that is powerful in changing customers’ expectations into technical languages that are achievable (Pramod et al. 2007). It then enables quality to be built into processes so as to come up with the desired quality level on the final products or services as pointed out in Duffa et al. (2002).

QFD makes use of ‘the house of quality’ tool for the analysis of potential inputs and interpret them to technical goals (Pramod et al. 2007). The major benefit of the ‘house of quality’ is that it relates the customer needs and technical requirements including interactive effects of factors (Duffaa 2002). The major parts of a house of quality model (HOQ model) are shown in the following figure.

![Fig.3.2. House of Quality](image-url)
3.5.2 Analytic Hierarchy Process (AHP)

AHP (Analytic Hierarchy Process) is a tree based powerful classifying and choosing tool that bases in pair wise comparisons to arrive at preferred choices. This tool is also powerful in assessing the sensitivity of the potential options as it points out the important factors from the different potential choices leading to priority lists of factors (Pramod et al., 2007; Chin et al., 2002 and Doumpos et al., 2002).

The other advantage of an AHP is that it is able to assess the validity of the assessment with an indicator called Consistency ratio. This ratio shows the consistency of the scales based evaluation of the factors that led to the factors prioritization. It is presented on Pramod et al. (2007) that CR value normally is acceptable if it is below 0.1. But, in cases of greater CR values, it is a normal practice that the decision process using the AHP be revised. Local and global Sensitivities are the important aspects of an AHP process. So, briefing their meaning at this stage is worthy for a better understanding of the presented analysis later. Local sensitivity is the level of importance of a sub factor expressed in percentage of its share within the parent factor at which it is found. Global sensitivity on the other hand is the sensitivity of a sub factor when compared, in the overall sense, with all the sub factors (Pramod et al. 2007).
4 Theory Development Chapter

In this chapter, the general approach used by the author to trace and develop the desired maintenance strategy and key performance indicators is discussed. The different tools utilized for the analysis of the different sections of the work are also presented.

4.1 A Model for Business-driven Maintenance Strategy Development

As described in the theory part, the aim of maintenance management is to optimize maintenance resources so as to make the maintenance function contribute to its best capacity. For the successful accomplishment of the maintenance goals, there should exist predefined maintenance objectives that the maintenance actions can be measured against. And the strategic maintenance management approach suggests that these maintenance objectives should be linked to the business objectives of the company so as to be labelled business-driven.

The model depicted below is developed based on an inspiration from the model by Murthy et al. (2002), which show the different elements of a strategic maintenance management. But, additional components have also been added on to the model by Murthy, and different possible elements of the different model components are also incorporated. These modifications are done on the model so as to make use of the balanced scorecard approach in the process of developing the maintenance strategy. The main aim of utilizing the balanced scorecard approach for this model is that it enables the maintenance strategy development process to be targeted at addressing specific business objectives and that it enables performance measurements in the different aspects of a balanced scorecard approach like: financial, structural (organizational) or process (technical) by making use of appropriate performance indicators.

In the model developed by the author of this paper, the business objectives of the company are linked with the maintenance strategy through different important elements in between. The first linking element is the implementation of appropriate production key performance indicators that can show how well the business objectives are being addressed in the production line. Then, a maintenance strategy would be developed based on satisfying these set parameters. The proper development of the support function strategies, like maintenance strategy, with measurability nature with reference to achieving the production performance targets also enables effective tracing of the impact of activities at lower levels in affecting the starting point i.e. business objectives. It also gives chance to trace any sub-standard performances at the maintenance function and opt for timely improvements, as linkages become clear. Bourne et al. (2002) also recommends the balanced scorecard approach based strategy revision as an appropriate method for it enables the assessment of existing strategies and develop a more effective strategy that aims at addressing customer expectations.

The model developed is made with the intention to assess the impact of the maintenance function only on the production function, whose outcomes directly affect the business objectives of the company. The model is developed in this limited level in accordance with the scope of this study. The different elements of this developed model are described in detail below.
Fig. 4.1. Business driven maintenance strategy development

- **Company Business Requirements:**
  - Regulatory requirements
  - Customer quality needs
  - Cost Efficiency

- **Company Business Objectives**

- **Production Process KPIs**

- **Critical System Components Identification**

- **Maintenance Strategy**

- **Maintenance Policy**

- **Maintenance Life Plan Development**
  - Maintenance approaches and technologies
  - Standard Operating Procedures (SOP's)

- **Maintenance Key Performance Indicators (KPI's)**
4.1.1 Company Business Requirements

This part of the model focuses on identifying the dominating business requirements of the company. This point is taken as a starting spot as the successful identification of the real business requirements that are expressed in the form of business objectives to work to, by aligning the efforts of the different functions of a company for its successful achievement. This approach is recommended by the balanced score card approach of directing resources towards agreed strategic goals.

For this study, an analytic hierarchy process (AHP) is used in comparing the level of importance of the brainstormed business objectives and also to see the priority of the different factors affecting the chosen business objectives. In addition, a house of quality model (HOQ) is also implemented to evaluate the interactive effects of the different factors affecting the different business objectives and the cross factor effects of these factors on different business objectives. The output of this analysis would be factors in the production floor that are influential for the achievement of the chosen company business objectives.

4.1.2 Production Process Key Performance Indicators

After identifying the different influential business objectives and the potentially feasible ways to address them, the next step is to check whether the different functions within the company are functioning in alignment with the business objectives. And the production process is taken as the influential function to consider as it has close link with the maintenance function, which is the point of interest of the study. The outputs of the previous step are utilized as inputs for the analysis of this portion of the model.

The different parts of the production process and the production flow need to be analyzed to study the production performance measurement. For this, the identification of the currently used production planning and process key performance indicators may be the starting point. Then follows checking whether the production performance indicators are appropriate enough to evaluate and give proactive information of the success of the production process in achieving the chosen business objectives of the company. Identification of relevant factors that are affecting production performance can also assist the evaluation process.

The outputs of this step would be identification of production performance indicators and the critical production process elements, which can lead to the development of the maintenance strategy in the next phase of the work that is targeted at the critical system elements which are believed to affect the business objectives.

4.1.3 Maintenance Strategy Development

This is the last phase of the model that focuses on developing a maintenance strategy that is driven by the company business strategies. It is in this part of the model that appropriate maintenance management philosophies are chosen which are effective in addressing the set company goals. The results of the previous stage of the model are the inputs for the successful developments of the maintenance approaches that fit to the production floor with the distinct characteristics.
The maintenance strategy serves as an umbrella of management procedures that enables successful achievement of the set maintenance objectives. The detail interactive planning of the maintenance echelons, the indenture level to address the maintenance tasks and the maintenance level can then be described within a maintenance policy that is under the maintenance strategy. This logical linkage from the maintenance strategy to the maintenance policy can show the link of a maintenance action at the maintenance policy level in addressing the chosen maintenance objective that is directly linked with the company’s business objectives. And it is these linkages that enable the outcome to be called a business driven maintenance strategy.

The major outputs of this phase are a maintenance strategy which addresses the production floor’s needs that are expressed in distinct performance indicators. The strategy also incorporates maintenance plan inputs and outputs with description of some support tasks for an efficient execution of the maintenance plan. The implementation effectiveness of the strategy is dependent on the implemented maintenance approaches, technologies and the standard working procedures.

Last but not least is the application of appropriate performance measurement of the maintenance strategy by making use of performance indicators. These performance indicators are linked to the maintenance strategy as well as the maintenance policy as its nature and extent of measurement differs for the two levels.
5 Empirical findings

In this chapter, the case company and the sections of the case company operations that go in alignment with the scope of the study are discussed. These information are used for the analysis in the next chapter along with the theoretical backgrounds presented in previous chapters.

5.1 Getinge Group Presentation

Getinge Group is one of the leading health equipments and systems provider founded in 1904 in Sweden with a vision to measurably contribute to the health sector. Getinge Group has a total of 10358 employees worldwide and net sales of 1.75 billion Euro as reported in 2007. The major business areas of Getinge Group are: 

- **Extended care (37%)**, **Infection control (26%)** and **Medical systems (37%)**. Getinge group has a market standing of 10th place in Europe and 26th place worldwide in the area of medical device supplier (Espicom, world Medical Market Fact book 2008). The products and services under the group are provided in three brands in alignment with the business lines mentioned above. These are:

  - *ArjoHuntleigh* - specializing in patient handling, hygiene, medical beds, therapeutic surfaces and diagnostics.
  - *GETINGE* - Products and services within this brand include infection control and prevention.
  - *MAQUET* – This brand focuses on surgical workplaces, cardiopulmonary and critical care.

One of the business lines that specialize in infection control was founded in 1904 in Sweden. This line provides complete solutions for effective and efficient cleaning, disinfection and sterilization in the health care and life science sectors.

The infection control line has 12 plants in seven countries now and a total of 2866 employees worldwide. The net sales was registered to be 464 million Euro in the fiscal year 2007. This business line has two products lines, namely, disinfection and Sterilization with market shares of 27% and 25% respectively.

5.2 Getinge Disinfection AB

This company focuses on the manufacturing of disinfection equipments to account for one of the two product lines in infection control. This plant has been founded in 1943 in Växjö and got its current name in 1993. Getinge Disinfection AB has a turnover of 560 million Euro and a total of 230 employees currently.

The company has two types of disinfectors i.e. *flusher and washer types*. In addition to the whole product packages, the company also produces accessories for the equipments supplied to the market. The different product series include Getinge 1345, Getinge 46-Series, Getinge 8666/8668, Getinge Turbo 88 and Kabinett 9100 series differing in capacity and operating principles.
5.3 The Need for this Study at the Case Company

The case company (Getinge Disinfection AB) has a well established presence in the local and global market as pointed out earlier. But even if the company is in a good shape with respect to satisfying the expected business and regulatory requirements, it is also working hard to design the manufacturing process in alignment with the customers’ needs and also minimize operation costs. And the maintenance function is known to contribute to the overall production capacity in the company. But, there hasn’t been a clear picture showing vividly how the maintenance organization can contribute to the company’s overall business strategies. In addition, even if there are operating procedures and performance indicators for the maintenance activities, they are not tested to whether they address the production and the company’s business needs at large. So, the successful completion of this work would possibly assist the company’s effort in these aspects.

5.4 Business Requirements and Business Objectives

The medical equipments business, of which Getinge Disinfection AB is a part of, has more requirements than ordinary manufacturing companies. Medical equipments manufacturing industries are expected to satisfy two types of customers i.e. the product users and the regulatory bodies. The requirements of these varied customers are mainly expressed as quality requirements, which are discussed below. The following figure shows the business requirements at Getinge Disinfection currently.

![Business Requirements Classification at GETINGE Disinfection](image)

In the process of satisfying the above mentioned requirements, the different processes within the company are susceptible to increased cost of operation as pointed out by the quality and production operations departments of the company. So, the quality requirements by the different sets of customers and the internal cost inefficiency are the two business requirements that need to be addressed currently. And the general business objectives that can be worked on to address the above mentioned business requirements can be expressed as: ‘enhancing quality and cost efficiency in the production processes.’ In this paper, the improvement possibilities in the maintenance function to address the mentioned business objective are discussed to account for the scope of this study.
5.5 Regulatory Requirements Preview

Medical equipments are the fundamental parts of medical treatments as they are fundamentally useful in diagnosing, informing and treating different ailments. Since these medical practices are directly concerned with patients, greater emphasis is given to the accuracy of equipments for the intended application. This is done as there is a greater probability that malfunctions of these machines directly confront the lives of patients. The intensity of this care becomes even more intensive in some medical equipments, as they are the last choices for some critical medical cases diagnosis.

There are different kinds of regulatory requirements focusing on the different aspects of medical equipments manufacturing business. These include raw materials, design, manufacturing, packaging, documentation, storage, transportation and installation.

The different regulatory bodies and documents monitoring the medical equipments manufacturing at Getinge Disinfection are listed below.

a) The European standard (EN ISO 15883-1/2/3/4/5)
b) The Medical Device Directive (MDD 93/42/EEC)
c) The Food and Drugs Administration (FDA)
d) Quality Systems Regulation (FDA-QSR)
e) International Electrotrotechnical Commission (IEC 61010-1/2)

Some of the contents of the FDA-QSR that are related to the area of interest of the study are presented so as to highlight the considerations of regulatory documents with respect to manufacturing, production process and maintenance.

Concerning production process control, Sec. 820.70 (a) of [3] presents: “Each manufacturer shall develop, conduct, control and monitor production processes to ensure that a device conforms to its specifications.” And the Sec. 820.70 (b) presents: “Each manufacturer shall establish and maintain procedures for changes to a specification, method, process, or procedure.”

Concerning maintenance, Sec. 820.70 (g) of [3] says: “Each manufacturer shall ensure that all equipment used in the manufacturing process meets specified requirements and is appropriately designed, constructed, placed, and installed to facilitate maintenance, adjustment, cleaning, and use.” It further highlights the maintenance requirements as follows. “Each manufacturer shall establish and maintain schedules for the adjustment, cleaning and other maintenance of equipment to ensure that manufacturing specifications are met” 820.70 (g/1). And 820.70 (g/2) of [3] says: “Each manufacturer shall conduct periodic inspections on accordance with established procedures to ensure adherence to applicable equipment maintenance schedules. The inspections, including the date and individual(s) conducting the inspections, shall be documented.”

The regulatory document also comments on corrective and preventive actions in Sec. 820.100 (a) of [3] as: “Each manufacturer shall establish and maintain procedures for implementing corrective and preventive action.”
5.6 Product users’ Quality Requirements

It is pointed out by the quality and regulatory affairs manager of the company that the following are the influential general customer requests from the products.

   a) Processing Time (PT)
   b) Product Price (PP)
   c) Electricity Consumption (EC) and
   d) Water Consumption (WC)

When we look at the quality defects in the inside of the production process, 60% of defects on the products account for the supplier quality defects and the other 40 percent goes to competence problem.

5.7 Cost Efficiency

The cost efficiency is the internal business requirement of the case company. The discussion with the quality and regulatory affairs manager and the production engineering head of the company revealed that the following are the influential factors affecting cost inefficiency at the production floor. These are:

   i. Personnel Performance
   ii. Production complexity
   iii. Rework
   iv. Work flow in production line
   v. Utilities Cost

5.8 Production Floor Overview

The production floor at the case company has major production systems that are described below.

   i. Rolling and bending section
   ii. Sheet metal fabrication section
   iii. Welding section
   iv. Assembly section and
   v. Testing station

The above described sections of the production floor have different production tightness varying the operational strategies a little bit. For instance, the sheet metal fabrication and the rolling and bending sections, have smaller inventory systems that are used to store backup parts that would be utilized for coming work orders. This approach is chosen for these sections as some of the machines in these production sections are critical with no backup system to replace in case of increased work load or machine failure. But sections like the welding station and the assembly line have no inventory which also has its impact in making them be critical in the sense that their production is linked with direct weekly orders increasing the impact of a machine failure substantially.
The overall production capacity of the production process reaches up to a maximum of 65 assembled products per week which brings the daily work load to up to 13 machines, which requires smooth running of the different machines in the different production sub systems for timely assemblies.

### 5.8.1 Case production line and production process

The main aim of showing one of the sections is needed so that the audience can have an overview of what the production processes in the different sub systems of the plant look with respect to necessary considerations and also see how they function.

The chosen section of the production process for the study to focus on was the welding station. This section is chosen as it is one of the sections with time bounded production demands. The welding center has five work stations. The work flow in these stations and the respective processes in each station are described in the following figure.

![Fig.5.2. Work flow at the welding station](image)

This work center is responsible for the welding of the different parts of the disinfection machine. In station 1 the side walls strengthening bar is pre-welded. Then in station 2, the reinforcement bar is spot welded and made ready for the continuous welding at station 4. In station 3, the roofs are set to place by spot welding and all the assembly is made ready for the continuous welding at the next station. In all of the three welding stations, the works are handled manually and semi-automatic with the help of different movable fixtures. In station 4, the spot welded parts of the disinfection machine are put to a flexible and robotic fixture that facilitates the continuous welding by a robot. Then screws are automatically spot welded on the outside surface of the assembly at station five with the help of the robot. These outside bolts are useful to attach the different parts of the washer in the assembly line. For stations 4 and 5 a single robot is used that is movable on a rail that connects the two stations. Then finally all the welds done are checked at station 6 manually. The person at this station is provided with a check list of parts and weld qualities to check. Then, the final product is signed off by the inspector indicating which operator he is and the date of manufacturing that machine.

The personnel working in the welding center operate in a way that a welder goes along with the product he is building up to the final stage and start with a new product for the next round. This work method enables the responsibility taking to be higher, increase the awareness of welders about each work station and also lessen ergonomic problems that can result from working in a similar work station. In addition the different welding stations are equipped with automatic mechanisms that allow easy handling of works, minimizing ergonomic problems.
5.8.2 Production Performance Measurements

The work loads for the welding center are specified on a weekly basis based on the weekly production load decided by the production manager who is intern governed by the marketing department. These work loads are discussed between the production leader and the crew at the welding center in the beginning of the week. Then, work flow design and personnel assignment to the different stations is done to align with the needed production scope.

The performance of the production process is measured primarily with how efficiently the weekly load has been addressed. This is done by making use of a daily distributed weekly work load. Then the progress of the welding center is evaluated and corrective actions taken on the daily meetings of 15-20 min. duration. Currently, there is a plan to measure production performance against a weekly work load, utilizing time of production at the different stations and establish a standard time. The other way of measuring production effectiveness is the rework time per product. This parameter is calculated by dividing the total reworking time to the total products produced. Currently the rework time per product is 8min/per product. And at the final stage of the different production processes, there are also quality monitoring using quality checklists.

5.9 Maintenance Organization Overview

- Organizational Structure and Maintenance Resources capacity

The maintenance organization at the case company is responsible for machinery maintenance, building maintenance, fixture maintenance and tools making. The maintenance manager, who is in charge of the function, has responsibilities of planning routine preventive maintenance actions, corrective maintenance work loads and monitoring their implementation to back up the production process. In addition to the mentioned maintenance actions, there are also additional maintenances handled by equipment suppliers.

The maintenance organization has a total of five people with respect to human resource capacity in handling the work loads emanating from the above mentioned categories of responsibilities. These five people have specific specializations in the different responsibility areas that are mentioned and also work in teams to handle work loads requiring common effort. In addition to these five people, the maintenance organization has implemented operator maintenance as one of the work loads of the production personnel, enhancing its capacity in reaching to the different machines for the routine preventive maintenance actions.

The maintenance function is equipped with the necessary tools to handle the maintenance work loads with the necessary technical requirements, as explained by the maintenance manager and the production engineer of the company. The spare parts management for the maintenance works handled by the maintenance department is handled based on machine suppliers’ recommendation of spare stock. But this is possible if there is a contract between the two parties. And these suppliers also take care of spare parts provision for the annual maintenance handled by them. But for the other machines outside of these domains and the maintenance loads handled by the maintenance department, the spare parts management bases on personal judgements that base on past experience of spare availability, lead time of order and the machine criticality. But no systematic approach is used to handle this as explained by the production manager.
• Maintenance at the Production Stations

The minor machine maintenance related problems are handled by the operators themselves. They inspect the problems based on past experience and individual judgement and even replace some parts. The machine problems that are beyond the capability of the operators are handled by the maintenance personnel of the plant after a report by operators to the maintenance section. All the different machines and the fixtures have a yearly maintenance and calibration in accordance to the product quality requirements. In addition to the yearly inspections, there are regular tests like: spot welding test every Mondays, so as to make sure that machine functionalities are according to the standards.

• Maintenance Information Flow

The maintenance work is divided into: operator routine preventive actions, minor corrective maintenance by operators, corrective and preventive maintenance by the maintenance department, and maintenance by equipment suppliers. The maintenance works handled by operators is based on recommendations by machine suppliers. These work loads are an integral part of the daily workloads by operators and is reported by making use of a manual sheet to the maintenance department. But the consistency of the reporting and making use of the reported maintenance actions is not in a satisfactory level according to the respondents communicated.

The maintenance work loads that are beyond the capacity of operators are discussed on the daily morning meeting of the production teams and reported to the maintenance department, in most cases orally. In addition to this meeting, the production and the maintenance function meet every Mondays (20-30min) to discuss the weekly work loads. But maintenance requirement is not that considered in these meetings. These meetings are not also recorded well to enable information utilization for planning, as described by the production engineer.

• Maintenance Planning

The impact of maintenance in affecting work flow becomes apparent in times of peak work loads that normally have a lead time of less than a week to mobilize maintenance activities. Maintenance planning takes much time for the ones that are handled by the maintenance department more than the other two i.e. operator maintenance and supplier maintenance. The reason for this is that operator maintenance is already an integral part of the daily routines for the production people. And supplier maintenance planning is handled in conjunction with them and it is mostly annual.

Currently, management software is being implemented with a maintenance management package in it. This package has features of maintenance actions reporting which can enable the maintenance department to plan based on feedbacks of the already performed maintenance actions. In addition, the maintenance package can enable the evaluation of maintenance performance making use of the different maintenance data input.

• Maintenance Performance measurement

Currently, the maintenance functions performance and its impacts on the other sections of the company are not that much measured. Among the three aspects of the maintenance function performance measurements i.e. financial, technical and organizational, only technical aspects are measured in a limited manner making use of registering down time at some parts of the
production process, which are critical like: sheet metal fabrication machines. These sections of the production are selected from past experience of critical implication on production effectiveness.

- **Computerized Maintenance Management System (CMMS)**

The company has a computerized management system in which maintenance is one integral part. Currently, it is upgrading the system so that it can be more capable in handling data and also have enhanced capacity in handling different functions. The maintenance package part of this system is now being tested for its applicability for the manual maintenance data handling practice that precedes its application. Some of the information that would be input to the system by maintenance performing personnel are:

  ✓ Run time  
  ✓ Maintenance duration  
  ✓ Maintenance responsible person  
  ✓ Levels of maintenance condition indicators, etc
6 Analysis

In this chapter the important aspects of the study question are used to analyze the research focus. For this, the current situation of the case company is used as a background setting. And the different information in the theory chapters and the empirical findings are used for to analyze the current situation.

As pointed out in the empirical findings above, the two major business driving elements that are given due attentions currently are quality requirements and cost efficiency. And the quality requirements can emanate from two sources i.e. product user customers and the regulatory bodies.

The following paragraphs explain the analysis done to identify and in the process check the quality requirements by the mentioned customers and the cost inefficiencies in the process of meeting them. The analysis also discusses how these factors may be interpreted into technical activities, i.e. production process and maintenance.

6.1 Company Business Requirements

The business requirements of a company expressed in a form of business objectives is the start of a business driven strategic development as pointed out in the model, in chapter 4. For the case of Getinge Disinfection, the business requirements are grouped as customer quality requirements (external) and Cost efficiency (internal) which is briefly described in the empirical findings.

6.1.1 Customer Quality Requirements

Customer quality requirements can be categorized into quality requirements by product users and quality requirements by regulatory bodies as described above. The analysis on these two categories of quality requirements is discussed below.

Brainstorming sessions followed by the application of an AHP model were used to analyze the influential quality requirements and the respondent for this discussion was the quality assurance and regulatory affairs manager of the company with the mandate of managing all quality related issues in-house and outside. The different quality requirements by customers were identified and then compared by making use of an AHP’s pair wise comparison procedures. The response by the respondent and the scales utilized are presented in appendices 2 and 3. The results from an AHP software showing the priority of requirements by product users is as presented below.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Priority %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing Time (PT)</td>
<td>43.6</td>
</tr>
<tr>
<td>Product Price (PP)</td>
<td>34.08</td>
</tr>
<tr>
<td>Electricity Consumption (EC)</td>
<td>14.14</td>
</tr>
<tr>
<td>Water Consumption (WC)</td>
<td>8.18</td>
</tr>
</tbody>
</table>

Consistency ratio: 0.071
Respondent:
(Quality Assurance and Regulatory Affairs Manager)
It can be seen from the result that processing time of the machines and product price are the two influential customer demands. But, the products processing time is addressable at large from a design point of view, which makes it not to be considered as influential customer requirement from maintenance function point of view. Concerning the products price, the respondent justified that it is much more fixed by the market now a days than the company’s internal calculations. But production process improvements can also be significant spots to lower internal costs and maximize profit margin, which can indirectly help reduce products price and competitiveness in the market. So, this requirement can be one interest for the maintenance function to work on as it has measurable impact in lowering overall production costs.

Concerning the different authorities’ quality and legislative requirements, the major areas of interest for these bodies are: functionality/ operability, safety to equipment users and safety to the patients treated. These requirements by these bodies, expressed in ways presented in the empirical findings, are interpreted in the technical language in the following categories.

- Installation qualifications
- Performance qualifications and
- Operators qualifications

### 6.1.2 Cost Efficiency

This is the second major business requirement of the company which can be influenced by many factors emanating from the different aspects of the company’s functions. But factors affecting cost efficiency emanating only from the production process are focused on, to account for the scope of the study. The identification and analysis of the different factors affecting the cost efficiency in the production floor would enable the possible identification of production performance indicators that can be used to assess the production process against these factors, which is the second level of the model developed in chapter 4.

The previous respondent and a production engineering manager were utilized for the analysis of the different factors affecting the cost efficiency in the production floor. Then, the brainstorming sessions revealed that the following are the major factors influencing cost efficiency.

1. Personnel Performance
2. Production complexity
3. Rework
4. Work flow in production line
5. Utilities Cost

These factors were then ranked in a 1 to 5 scale and the different sub factors within these factors that are thought to affect cost efficiency from past experience were weighed and compared with a pair wise comparison (see appendix 4). The overall weights of the major factors along with the local and global sensitivities (percentages) of the sub factors for each respective major factor is then evaluated making use of an AHP software. Then, the result looks like the following. Note that the percentages in brackets are the global sensitivities of the factors and sub-factors and the italic percentages are the local sensitivities of the sub-factors. The five major categories of factors affecting cost efficiency are discussed as follows.
Fig. 6.1. Summary of the AHP Analysis on the proposed factors and sub-factors affecting cost efficiency.

### i. Personnel Performance

This factor accounts for all the human performance related costs and economic inefficiencies encountered at the production line. It can be seen that ergonomics, competence, team work and leadership are the identified sub-factors that are thought to contribute to the cost inefficient level of the personnel performance.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Priority %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ergonomics (E)</td>
<td>7.96%</td>
</tr>
<tr>
<td>Competence (C)</td>
<td>36.5%</td>
</tr>
<tr>
<td>Team work (TW)</td>
<td>29.16%</td>
</tr>
<tr>
<td>Leadership (L)</td>
<td>26.39%</td>
</tr>
</tbody>
</table>

Consistency ratio (CR)=0.222
Respondents: Quality Assurance and Regulatory Affairs Manager and the production engineering head
Since the factor is the leading one in the priority of factors, all of the sub factors except ergonomics become important to consider as also confirmed by the global sensitivities (percentages) of the sub factors in fig.6.1. The lower percentage of ergonomics is also justified in the production floor as the ergonomic considerations at the case production line, presented in the empirical findings, are in good shape, minimizing the contribution of ergonomics to personnel performance inefficiency.

Concerning the other three sub factors to consider in this category, they have general percentages within the same margin emphasizing that they need to be given similar attention. In addition, the interdependence nature of the three sub factors also supports the approach to their solutions from similar area; that is, from the human resource management perspective.

**ii. Production complexity**

This is the second most important factor that affects the cost efficiency in the production line (Fig.6.1.). The production complexity is referred to as the complexities in the production process that can emanate from product design complexity that manifests in the production process. The different sub factors that influence this factor are: *production team involvement (PTI) in the design process, quality requirements (by authorities), work flow validation, machine defect and competence* with percentages shown in the following table 6.3. Among these sub factors, quality requirements has the highest priority as it is the major factor that gives ‘green light’ for productions to commence and products to be salable in the market, as pointed out by the respondents too.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Priority %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production team involvement in design( product complexity)(PTI)</td>
<td>7.4</td>
</tr>
<tr>
<td>Timely inclusion of quality requirements(QR)</td>
<td>65.48</td>
</tr>
<tr>
<td>Work flow validation(WFV)</td>
<td>5.32</td>
</tr>
<tr>
<td>Personnel competence(C)</td>
<td>9.72</td>
</tr>
<tr>
<td>Machine Defect (MD)</td>
<td>12.08</td>
</tr>
</tbody>
</table>

Consistency ratio (CR) =0.119

Respondents: Quality Assurance and Regulatory Affairs Manager and the production engineering head

Even if the percentages of the other four factors are far in the list of sub factors when compared with the first one, they are argued by the respondents as important while discussing the result of the analysis. One possible reason for a lower percentage of the other factors is that they are compared with a factor that is much more important, the quality requirements by the authorities. And concerning competence, since it has a higher global percentage as a sub factor under the personnel performance factor discussed earlier, it automatically becomes important even if it has a lower percentage under this factor. So taking all these considerations, all the factors are taken as important for the next evaluations to follow.
iii. Rework

This factor also is affected by all the sub factors under the production complexity factor except for production team involvement in the design process. So, the four sub factors would automatically be considerable for the above mentioned reasons. In addition, supplier quality comes to picture here as shown in the table below.

<table>
<thead>
<tr>
<th>Table. 6.4. Ranking of factors affecting Rework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors</td>
</tr>
<tr>
<td>Supplier quality assurance (SQA)</td>
</tr>
<tr>
<td>Machine defects (MD)</td>
</tr>
<tr>
<td>Work flow validation (WFV)</td>
</tr>
<tr>
<td>Personnel competence (C)</td>
</tr>
<tr>
<td>Timely inclusion of quality requirements (QR)</td>
</tr>
<tr>
<td>Consistency ratio (CR) = 0.05</td>
</tr>
<tr>
<td>Respondents: Quality Assurance and Regulatory Affairs Manager and the production engineering head</td>
</tr>
</tbody>
</table>

Even if the global sensitivity of this sub factor (supplier quality) is minimum in fig. 6.1., compared with the other factors, it is also considered important for the upcoming analysis for it is one of the reasons becoming important for quality deviations, which accounts for 60% of the monthly total quality defects, as described in the empirical findings.

iv. Work flow in production line

This is a factor that has the fourth standing in the factors hierarchy of the AHP result shown in fig. 6.1. The possible sub factors that affect it are: machine defect, work flow validation and competence. The pair wise comparison priority listing is shown in the following table.

<table>
<thead>
<tr>
<th>Table. 6.5. Ranking of factors affecting work flow in the production line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors</td>
</tr>
<tr>
<td>Personnel Competence (C)</td>
</tr>
<tr>
<td>Work flow Validation (WFV)</td>
</tr>
<tr>
<td>Machine Defects (MD)</td>
</tr>
<tr>
<td>Consistency ratio (CR) = 0.0</td>
</tr>
<tr>
<td>Respondents: Quality Assurance and Regulatory Affairs Manager and the production engineering head</td>
</tr>
</tbody>
</table>

Among the sub factors presented above, machine defect stands out from the other two making it to have a competitive percentage of 8.04% in the overall list of the global priorities in fig 6.1. The personnel competence sub factor is automatically taken as important one as it has global priorities of higher percentages under other factors with greater impact on cost efficiency, like: personnel performance. The work flow validation is also argued by the respondents as important to be considered to assess its cross factor effects and its impact on other sub factors in the analysis to follow.
v. Utilities Cost

This factor has the least percentage amongst the factors and with a greater difference from the other four. The reasons for this may be that it only accounts for 5% of the total cost of production, as presented by the production engineering head. In addition, the factor is much more influenced with an effort from the design level than production. This is because of the reason that most of the utility is accounted for performance testing of products, which are designed along with system functions at the design stage. But, it was considered to be taken to the next level of the analysis to see its effect in cross factors evaluation if there are any unseen impacts of it on other sub factors.

Interaction and Dependence of Factors

Even if the sub factors under each factor are prioritized by using the AHP model, the dependence of these sub-factors with each other and the cross factor effects were not visible. So, to account for this, one of the features of a quality function deployment model; namely: ‘the house of quality’, is implemented. The house of quality (HOQ) developed for the above described and prioritized factors and sub-factors is presented below. The two respondents used for the AHP analysis were utilized for this analysis also.

It is apparent from the HOQ table below that competence, production team involvement, work flow validation and supplier quality are the four leading sub factors with an effect that crosses five major factors. But when we look at the result of the previous AHP analysis, authority quality requirements, competence, team work and leadership are the first four with global sensitivities of higher percentages. The priority ranking is different between the AHP and HOQ as the later assesses the effect of the sub factors with respect to the different factors and gives cumulative weight.

In the HOQ we can also see that quality requirement, team work and machine defect have the lowest percentages. But the dependence matrix at the top of the HOQ chart link them to the influential sub factors, making them to be considered important, as they have strong influence on the most important sub factors. On the other hand, having the dependence of the sub factors clearly indicated, also gives the opportunity to impact the important sub factors indirectly, by acting on a sub factor that has a visible link with the target sub factor. These interrelationships are ranked by making use of the respondents’ experience and the result looks like the following.
Fig. 6.2. House of Quality for sub factors affecting cost efficiency

It is visible from the above figure that competence is affected strongly by the extent to which the production team is involved in the design of the products to be manufactured and the production processes. In addition, competence moderately affects team work, leadership, machine defect and work flow validation. This cross factorial influence of competence can be one of the reasons for it to account for the 40% of quality defects encountered. So addressing this sub factor by acting on the contributing factors is a substantial step in avoiding the 40% of quality problems.

Team work has a strong dependence on the leadership and the team’s involvement from the start of the development of the machines. And it has a moderate dependence with the work flow validation as the team’s involvement in the design process minimize the need for team work to understand the work procedures as they are already understood from the time of product development. The quality of the team work is also affected by the individual competence of the team members as also pointed out in the HOQ above with a moderate dependence.

The leadership at the production floor is presented to have a strong impact on the productions team’s involvement in the design as well as on the work flow validation so as to enable standardized work procedures. It is also visible that the leadership moderately affects the machine defects as it influences the fault discovery and reporting by the production personnel, which needs a well grounded leadership which is aware of maintenance. The leadership in the

---

<table>
<thead>
<tr>
<th>Factors affecting Cost Effectiveness</th>
<th>Priority</th>
<th>Competence</th>
<th>Team work</th>
<th>Leadership</th>
<th>Quality Requirements</th>
<th>Machine Defect</th>
<th>Production Team Involvement</th>
<th>Work flow Validation</th>
<th>Supplier Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel performance</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Production Complexity</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Rework</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Work flow in production line</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Utilities Cost</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

| Importance Rating                   | 61       | 30         | 45        | 38         | 30                   | 50             | 46                         | 46                 | 0               |

Legend: Dependence Matrix

<table>
<thead>
<tr>
<th>Strong</th>
<th>Moderate</th>
<th>No Dependence</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Legend: Goals for the subfactors

<table>
<thead>
<tr>
<th>Increase</th>
<th>Not settable</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑</td>
<td>0</td>
<td>↓</td>
</tr>
</tbody>
</table>
production floor also has an influence on the team work spirit which is also evident with a strong dependence as shown in fig.6.2.

The quality requirements by the different regulatory bodies have strong influence on the time of the production team’s enrolment in the development of the machines. In addition, it also has a strong link with work flow validation, as standardization of work procedures is the key for reliable production process to produce outputs having the necessary quality requirements. The supplier quality is also one major factor affecting the quality requirements which can also be backed with the evidence that 60% of the quality defects account for supplier quality defects.

Machine defect has moderate dependence with almost all of the sub factors with production team’s involvement, work flow validation and supplier quality as the ones to mention. The production team’s involvement in the process design along with work flow validation enables the implementation of or identification of some work flow indicators that can be utilized as maintenance need indicators too.

The production team’s involvement also have a strong relationship with the work flow validation as the success to maintain the agreed standards depends at large on the operating personnel. Involving the production personnel on the supplier’s quality check ups also has a measurable impact on the quality of the finished products which is also supported by the moderate dependence shown in the HOQ above.

The strong dependence between the work flow validation and the supplier’s quality is brought about by the current impact of the supplier’s quality defects, which reaches up to 60% of the total defects experienced, on the production processes and the final products as well. The nearer the supplier’s quality to the validated process parameters raw material requirement, the lesser the production defects from the validated production process.

Generally, the production team’s involvement in the product and process design is the leading sub factor with many strong impacts on the other sub factors followed by work flow validation, quality requirements and leadership. Supplier quality and team work also have a considerable weight next to the above mentioned ones. So, planning improvements with a major attention to these sub factors can address the other influential sub factors with higher probability of success, depending on their dependence intensity.

### 6.2 Production KPI’s

Some parts of the production function like: the rolling and bending, welding and the assembly section have tighter job orders resulting from no excessive production and an inventory application to account for the lower lead time. In addition, the lesser availability of back up systems for any possible failure of the different machines in theses stations make them be the critical system components in the production line. The added quality requirements in addition to the above mentioned tense production nature also contributes a lot to the criticality nature of these sections of the production process.

The production floor is now utilizing time and products per time as measurements to check production efficiency and also measure the availability of the system for the intended production planning. These parameters are chosen to account for the weekly work load planning that exists in the critical parts of the plant currently. This weekly work load specification is brought about by the company’s need to reduce tied up capital in inventory for in process and final products buffer that can result if a production planning of longer lead time
is to be implemented. In addition to this measurement on production effectiveness, reworking time is also used as one form of measurement to evaluate the level of success of the production line in addressing the set product standards.

So, the best way to achieve good result from the production performance indicators in addressing the set business objectives is to check whether these performance measurement methods really address the chosen business objectives. In this regard, using time (or products per unit time) as a production performance indicator is a good choice as the production process is bounded by tight schedules of delivering weekly workloads. The utilization of reworking time can also be a good indicator in the production floor in assessing the reliability of the production process and come up with a standard working time. But the utilization of reworking time as an indicator to check the effectiveness of the production process in making products compliant to the expected standards may be misleading as time can’t always be a good measure of compliance to quality requirements.

So, to account for the above mentioned flaw of the reworking time as a measure of production performance by utilizing quality checks at the final step of production, validating the production process with process quality indicators put in place is a better approach. And the company is working well in this aspect as it currently is working on validating production processes for standardized work flow incorporating the different requirements.

6.3 Maintenance Strategy Development with KPI’s

The maintenance strategy is developed in accordance with the current needs of the production process, which are linked with the business objectives of the company in ways that are discussed earlier in the theory development chapter and previous analysis discussions. The different elements and factors impacting the maintenance strategy are described in the following schematic diagram for better visualization.

As can be seen on the diagram below, the company’s weekly work load planning of the production is taken as the starting point of the maintenance strategy development. This weekly work load specification has made the production floor to adopt time of production and products per unit time as the chosen production performance measurement methods. The lesser reaction time to cope with a shorter lead time and the tight quality requirements by the different stakeholders would induce the need for a closer follow-up of the machines’ state, which calls for greater leadership element in motivating and coordinating maintenance activities as shown in figure 6.3.
The two major goals for the closer follow-up on the machines condition are availability and reliability of production system components. The availability measurement is to account for the unplanned downtime within the planned weekly production load. And the reliability measurement is to account for the reliability of the system for the quality requirements, which is one of the major sub factors, after the product passes through the validated production processes.

The closer follow up of the machines’ state in the above mentioned two approaches should then be backed with a well organized maintenance planning that manifests in the three maintenance activity categories performed in the production floor. These are: operator maintenance, maintenance by the maintenance department and maintenance by machine suppliers. The necessary inputs for an effective maintenance planning are past maintenance data starting from the fault reports, production information, resources information encompassing tools, spares and personnel, and an improvement thinking mindset, which is one aspects of a good leadership. These input information categories are chosen as they can successfully address the different factors, discussed earlier in this chapter, which affect the overall company’s quality and cost efficiency performances.
The past maintenance data can give information about technical activities on preventive actions, past faults encountered and the maintenance actions performed. In addition to this, the production information is also a necessary input to the maintenance planning with the potential of directing maintenance efforts in accordance with the changing production situations, which has variable nature brought about by the production load specification enabling lesser reaction time and the tight quality requirements. The resources category of input to the maintenance planning includes the spare parts, human resource and the maintenance tools information. Planning the resources acquisition and utilization, in accordance with the maintenance work loads, increases the maintenance effectiveness. The different information input to the maintenance planning can be made to incorporate economic, organizational and technical aspects so that an overall performance measure can be achieved in assessing work effectiveness with performance indicators application, which are presented below.

The improvement mindset is also presented as one of the inputs which is necessary to account for the changing demands of the maintenance function performance with respect to the above discussed inputs. The inclusion of this element became important as all of the suggested cost affecting factors in the production function like: competence, production team’s involvement, work validation, leadership and team work, which are also shared by the maintenance function, are traceable and improvable with such frame of mind, which is what the company is working on theses days.

The above mentioned inputs to the maintenance planning can best be handled with a proper utilization of computerized information management system (CMMS) to make use of its features in planning, monitoring and controlling maintenance activities effectively. And along with this, the communication methods for different information transfers between the different stakeholders within the overall maintenance planning, is a mandatory necessity too so that the problems associated with the oral communication method can be eliminated with proper documentation templates.

Then the overall performance of the above laid out maintenance strategy implementation is checked by making use of different key performance indicators giving information and insights on how the system is effective and efficient in achieving the intended targets. These performance indicators are also needed to incorporate the technical, economic and organizational aspects in alignment with the dominating factors that are targeted to be worked on, which are pointed out to affect the dominating company business objectives. The performance indicators are presented in different forms with performance information varying to the different levels of organizational functions like management, middle management and maintenance function level. The different maintenance related key performance indicators that are thought to appropriately address the different aspects of the above laid out maintenance strategy and thus the business drivers, through addressing the pointed out factors, are presented below.

<table>
<thead>
<tr>
<th>Performance Indicator</th>
<th>Measurement Role</th>
<th>Input data</th>
<th>Organizational level-KPI aspect</th>
</tr>
</thead>
</table>
| Total Maintenance Cost/Asset Replacement Value | Shows the cost effectiveness of maintenance against the asset replacement value | • Total Maintenance Cost  
• Overall Asset replacement value | Management level- Economic                   |
| Total maintenance Cost/ Quality of Output | Measures maintenance cost efficiency against products quality | • Total maintenance cost  
• Product quality rating       | Management level- Economic                   |
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
<th>Calculation</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability related to maintenance /Total maintenance Cost</td>
<td>Measures maintenance impact on availability through cost</td>
<td>Availability gains, Total maintenance cost</td>
<td>Management</td>
</tr>
<tr>
<td>Average inventory value of maintenance resources/ Asset replacement value</td>
<td>Measures the cost efficiency of inventory against asset replacement value</td>
<td>Average inventory value, Asset replacement value</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Total personnel cost in maintenance/ Total maintenance cost</td>
<td>Measures the percentage of personnel cost over total maintenance cost</td>
<td>Total personnel cost, Total maintenance cost</td>
<td>Middle</td>
</tr>
<tr>
<td>Total contractor cost/Total maintenance cost</td>
<td>Measures the economic implication of outsourcing</td>
<td>Total contractor cost, Total maintenance cost</td>
<td>Middle</td>
</tr>
<tr>
<td>Maintenance cost of specific maintenance type/ Total maintenance cost</td>
<td>Measures cost percentage of maintenance types against total maintenance cost</td>
<td>Maintenance cost of a maintenance type, Total maintenance cost</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Cost of maintenance training/ # of maintenance personnel</td>
<td>Measures the budget allocated for professional competence</td>
<td>Maintenance training cost, Number of maintenance personnel</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Total operating time/(Total operating time+ Maintenance Down time)</td>
<td>Measures availability related to maintenance</td>
<td>Total operating time, Maintenance Down time</td>
<td>Management</td>
</tr>
<tr>
<td>Achieved up time during required time /Required time</td>
<td>Measures Operational availability</td>
<td>Uptime within required time, Required time</td>
<td>Management</td>
</tr>
<tr>
<td>Total operating time/(Total operating time+ Down time due to planned and scheduled maintenance)</td>
<td>Measures availability with respect to planned maintenances</td>
<td>Total operating time, Down time due to planned maintenance, Down time due to scheduled maintenance</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Man-hours used for continuous improvement/Total maintenance personnel man-hours</td>
<td>Measures the effort put to continuous improvement.</td>
<td>Man-hours for continuous improvement, Total maintenance personnel man-hours</td>
<td>Management</td>
</tr>
<tr>
<td>(OEE) Availability<em>Performance rate</em> Quality rate</td>
<td>Overall Equipment Effectiveness (OEE) Measures the level of success of maintenance in addressing losses due to downtime, speed reduction and quality defects.</td>
<td>Achieved availability, Performance rate measuring production speed, Quality rate measuring quality effectiveness</td>
<td>Management/ mid-management</td>
</tr>
<tr>
<td>(MTBF) Total time of operation in a given time/ number of failures in that time</td>
<td>Mean time between failures (MTBF) Measures the reliability of a system in a given period</td>
<td>Total operation time, Number of failures encountered in that given time</td>
<td>Mid management/maintenance</td>
</tr>
</tbody>
</table>
Measuring the total maintenance cost against asset replacement value would give information on the necessity of maintenance when maintenance cost is compared to the money invested on a machine. On the other hand, measuring total maintenance cost against quality of output gives an insight on the proportion of maintenance cost allocated to the quality of the products produced. And this linkage can trigger a good deal of attention to the maintenance especially in a company like GETINGE whose primary requirement is the quality of products. In addition to the quality, the maintenance cost when compared to the availability benefit of the manufacturing system also becomes a good indicator of comparing the benefit of maintenance in making a system available to maintenance related costs.

Comparing the total personnel cost and trainings costs to the overall maintenance cost gives a good overview on the amount of attention given to maintenance personnel in developing their competence, which is one of the biggest sub factors contributing to the cost inefficiency.

The measure of total maintenance cost to the average inventory cost can also be a good indicator for the percentage of finance the inventory is taking in assisting the maintenance function to address the different maintenance benefits. And this can be one of the measures for the resource utilization of the maintenance function that is one input to maintenance action execution shown on the strategy picture above (fig 6.3.).

The measure of the percentage of cost allocated for the different types of the maintenance actions and the different parties handling maintenance like, contractor can enable the visibility of maintenance budget percentage allocated for these. This can show the level of commitment by the maintenance department and also the attention to the different beneficiaries of the maintenance planning shown in the strategy model above in figure 3.1.

The measure of man hours for continuous improvement against the man hours of maintenance personnel can be a good indicator for how well the maintenance function is giving attention to the mindset of improvement thinking and continuous improvement moves, which is one of the major inputs to an effective maintenance planning presented in the strategy development model. The availability measurement with respect to planned maintenance actions can show the impact of planned maintenance actions when compared to the availability of a system incorporating all maintenance unavailability. This can enable the maintenance organization assess the effectiveness of the planned maintenance actions and also initiate a transition to more effective planned maintenance actions minimizing unnecessary stoppages due to unplanned maintenance actions. This also can be an input in checking the level of the improvement actions in handling maintenance actions.

The achieved availability calculation is utilized as one of the inputs for the OEE calculations in showing the availability element of the OEE measurement. And the OEE parameter measures the level of success of maintenance in addressing losses due to downtime, speed reduction and quality defects. The operational availability can be used as a measure of the performance rate in the OEE calculation as it can measure the level of success in achieving the intended production speed.

The reliability measure utilizing mean time between failures (MTBF) can be used as a measure of the production system’s obedience in producing the needed products in a given time with the required quality.
7 Results

In this chapter the major results of the analysis made on the empirical findings with the background of the theory discussed is presented.

Quality requirements of product users and the requirements by regulatory bodies are the two business objectives that the company needs to address as outside objectives. And cost efficiency in different activities within the company is the inside business objective that the company wants to address.

Personnel performance, production complexity, reworks, work flow in production line and utilities costs are the major factors that are affecting the cost inefficiency currently. And the analysis of the sub factors under these major factors revealed that production team’s involvement in the product and process design, work flow validation, quality requirements and leadership are the most influential ones with magnified impacts on other sub factors too. The suppliers’ quality level and the team work spirit also have a considerable weight.

The implementation of time measurement as a production performance indicator is shown to be a good approach for the wasted production time related losses in the production floor. And extending the reworking time per product measurement that currently exist to assess quality performance, to process quality validation for quality can effectively address the quality expectations reliably. This effort would enable quality to be inserted onto the products passing through different work stations than inspect quality at the final stage, which is costly.

A maintenance strategy with an emphasis in ensuring plant availability for the intended production planning and reliability for the quality specifications can address the dominating business objectives reliably. It was also apparent that the maintenance strategy can be implemented by making use of maintenance planning on the actions to take and with appropriate inputs to effective planning. Then, it was shown that the success of the strategy can be measured by making use of appropriate performance measures with potential information to the different levels of the company’s functions.
8 Conclusions

In this part of the paper, the conclusions that can be derived based on the theoretical findings which are justified by the studied case setting are presented.

Maintenance, with a holistic view of its impact on availability, cost reduction, product quality, environment preservation and safety, can be worked on to have a considerable impact. It is also pointed out that business objectives should be interpreted in a maintenance strategy so as to make sure that the equipment state compiles with the required level. The balanced maintenance score card approach also supports that resources inside the different functions within a company be directed in support of agreed overall business objectives. And this approach also goes hand in hand with the role of a maintenance management which is presented as to optimize maintenance resources so as to make the maintenance function contribute to its best capacity in assisting a company’s business.

The model that has been suggested by the author which combines the strategic maintenance management and the maintenance score card approaches can effectively make sure that the maintenance function contribute to the business objectives of a company in a traceable and measurable way. The impact of the maintenance function can be traced as the business objectives would be visible in the production process through the implementation of appropriate production performance indicators, which are also the inputs for the development of the maintenance strategy along with information on the critical system components. A maintenance strategy that addresses the requirements of the production process can be called business driven as it works in making sure that maintenance requirements by the production, which is linked with the business objectives, are met.

The performance of the developed maintenance strategic components can be measured by implementing maintenance performance indicators with an overall insight on the economic, organizational and technical indications. And such an approach has the benefit of showing the holistic impacts of the maintenance function than the traditional perception on the maintenance function as a cost center.
9 Further Studies

In this part of the paper the potential areas of further study in the topic that is studied in this paper and other potential areas are discussed to enhance the benefit from the topic of study.

The main aim of this study is to highlight general procedures and considerations that can be utilized as guidelines in assessing the existing maintenance function and improve its impact on company’s business objectives. But, the delimitations made the study not to be that deep. So, the author recommends that the results of the study be verified by quantitatively validating the impact of the developed framework and the identified factors in impacting the company’s business objectives. This further effort would also be a good ground to show how addressing the study topic can affect the two business objectives of the company and thus trigger more support by stakeholders for its implementation.

Systematic critical system components identification making use of different tools is also one of the recommendable further study area that can focus the implementation to key influential areas enabling the results to be visible enough for continuing attention to the studied topic. The effective identification of the specific production sub systems would also enable the development of distinct maintenance policies with particular maintenance echelon, the indenture level and the level of maintenance, that are capable of addressing the particular maintenance needs of the sections in consideration.
10 Recommendations

This portion forwards the recommendations by the author for faster, easier and enhanced application of the different results of this study in the practical realm.

It is nice that the company is implementing time based production performance measurement to minimize the production inefficiency associated with time lost resulting from different factors. In addition, validating the production processes to account for the quality requirements at every work station before it reaches to the final quality check up stage is also a notable effort. And these approaches can in effect address the two influential business objectives i.e. quality requirement and cost efficiency. However, the author wants to recommend the current process validation moves to continuously supplement the maintenance efforts with inputs of quality parameter deviations that are associated with maintenance needs as these would be great assets for improvement. And this effort would also integrate the quality validation moves with the maintenance function’s efforts.

In addition, the inputs to the maintenance planning, which is one element of the strategic model, can best be handled with a proper utilization of computerized information management system (CMMS) to make use of its features in planning, monitoring and controlling maintenance activities effectively. And along with this, the communication methods for different information transfers between the different stakeholders within the overall maintenance planning, is a mandatory necessity too so that the problems associated with the oral communication method can be eliminated with proper documentation templates.

Moreover, the implementation of the suggested strategic approach in the study paper can be started smoothly by adding the considerations suggested onto the already existing good cultures in the case company. These cultures include: the existing operator maintenance culture, the weekly and daily meetings, the maintenance activities reporting culture, validated process parameters utilization and the existing performance indicators.
11 References


2. Company PowerPoint Presentations (GETINGE Group, GETINGE Disinfection AB)


Appendix 1- QFD and AHP utilization in the project

1. Brainsorm on company needs
2. Brainstorm on company’s major and sub activities that address the ‘what’s’
3. Weigh the interrelationship between the what’s and the how’s
4. Weigh the importance of targets
5. Check the counter effects of the how’s
6. Assess the relative importance of targets
7. Break down the targets to further performable activities

- Use affinity diagrams and tree diagrams to sort
- Use 5 scales:
  0: None
  1: Low
  3: Medium
  5: High
- Use planning matrix weighing and interrelationship matrix
- Repeat the above steps taking the targets as primary aim.

- An AHP model may be used for this.
- 1-5 scale is used:
  5: Very important,
  1: Unimportant
Appendix 2- Fundamental Scale for pairwise comparison in an AHP model
(Source: Doumpos et al. 2002)

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two elements contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgment slightly favor one element over another</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>Experience and judgment strongly favor one element over another</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
<td>One element is favored very strongly over another; its dominance is demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favoring one element over another is of the highest possible order of affirmation</td>
</tr>
</tbody>
</table>

Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.

Appendix 3- Pairwise comparison and priority percentages for customer quality requirements (By Respondents)

<table>
<thead>
<tr>
<th>Compared Factors</th>
<th>Comparison Scale</th>
<th>Remarks (Supportive documents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC-WC</td>
<td>3</td>
<td>Cost of electricity is higher</td>
</tr>
<tr>
<td>EC-PT</td>
<td>-5</td>
<td>The time operation is preferred for facilitated business at customer sites.</td>
</tr>
<tr>
<td>EC-PP</td>
<td>-3</td>
<td>PP is a one time intensive investment compared to distributed running cost of electricity</td>
</tr>
<tr>
<td>WC-PT</td>
<td>-5</td>
<td>PP directly affects customers cash flow/customer satisfaction.</td>
</tr>
<tr>
<td>WC-PP</td>
<td>-3</td>
<td>One time investment of PP</td>
</tr>
<tr>
<td>PT-PP</td>
<td>1</td>
<td>Much work/time is the motive but equipment investment is also</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors</th>
<th>Priority %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing Time (PT)</td>
<td>43.6</td>
</tr>
<tr>
<td>Product Price (PP)</td>
<td>34.08</td>
</tr>
<tr>
<td>Electricity Consumption (EC)</td>
<td>14.14</td>
</tr>
<tr>
<td>Water Consumption (WC)</td>
<td>8.18</td>
</tr>
</tbody>
</table>

Consistency ratio: 0.071
Respondent: Quality Assurance and Regulatory Affairs Manager
Appendix 4- Pair wise comparison and priority percentage for sub-factors under the cost efficiency affecting major factors. (By Respondents)

1. **Personnel Performance**

<table>
<thead>
<tr>
<th>Compared Factors</th>
<th>Comparison Scale</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-C</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>E-TW</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>E-L</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>C-TW</td>
<td>3</td>
<td>The availability of some skills is uncompromisable.</td>
</tr>
<tr>
<td>C-L</td>
<td>1</td>
<td>✓ They are in equal weight needed in the current organization.</td>
</tr>
<tr>
<td>TW-L</td>
<td>3</td>
<td>✓ Team work can increase possibility of technical problem solving-which is the needed thing in the floor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors</th>
<th>Priority %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ergonomics (E)</td>
<td>7.96</td>
</tr>
<tr>
<td>Competence (C)</td>
<td>36.5</td>
</tr>
<tr>
<td>Team work (TW)</td>
<td>29.16%</td>
</tr>
<tr>
<td>Leadership (L)</td>
<td>26.39%</td>
</tr>
</tbody>
</table>

Consistency ratio (CR)=0.222
Respondents: Quality Assurance and Regulatory Affairs Manager and the production engineering head

2. **Production complexity**

<table>
<thead>
<tr>
<th>Compared Factors</th>
<th>Comparison Scale</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTI-QR</td>
<td>-9</td>
<td></td>
</tr>
<tr>
<td>PTI-WFV</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>PTI-C</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>PTI-MD</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>QR-WFV</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>QR-C</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>QR-MD</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>WFV-C</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>WFV-MD</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>C-MD</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors</th>
<th>Priority %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production team involvement in design (product complexity) (PTI)</td>
<td>7.4</td>
</tr>
<tr>
<td>Timely inclusion of quality requirements (QR)</td>
<td>65.48</td>
</tr>
<tr>
<td>Work flow validation (WFV)</td>
<td>5.32</td>
</tr>
<tr>
<td>Personnel competence (C)</td>
<td>9.72</td>
</tr>
<tr>
<td>Machine Defect (MD)</td>
<td>12.08</td>
</tr>
</tbody>
</table>

Consistency ratio (CR)=0.119
Respondents: Quality Assurance and Regulatory Affairs Manager and the production engineering head

53
3. **Rework**

<table>
<thead>
<tr>
<th>Compared Factors</th>
<th>Comparison Scale</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQA-MD</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SQA-WFV</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>SQA-C</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>SQA-QR</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>MD-WFV</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>MD-C</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>MD-QR</td>
<td>-9</td>
<td></td>
</tr>
<tr>
<td>WFV-C</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>WFV-QR</td>
<td>-9</td>
<td></td>
</tr>
<tr>
<td>C-QR</td>
<td>-9</td>
<td></td>
</tr>
</tbody>
</table>

Factors

<table>
<thead>
<tr>
<th>Supplier quality assurance (SQA)</th>
<th>13.64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine defects (MD)</td>
<td>14.58</td>
</tr>
<tr>
<td>Work flow validation(WFV)</td>
<td>4.89</td>
</tr>
<tr>
<td>Personnel competence(C)</td>
<td>5.13</td>
</tr>
<tr>
<td>Timely inclusion of quality requirements(QR)</td>
<td>61.76</td>
</tr>
</tbody>
</table>

Consistency ratio (CR) =0.05
Respondents: Quality Assurance and Regulatory Affairs Manager and the production engineering head

4. **Work flow in production line**

<table>
<thead>
<tr>
<th>Compared Factors</th>
<th>Comparison Scale</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-L</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>C-MD</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>L-MD</td>
<td>-3</td>
<td></td>
</tr>
</tbody>
</table>

Factors

| Personnel Competence(C) | 20 |
| Work flow Validation(WFV) | 20 |
| Machine Defects(MD)    | 60 |

Consistency ratio (CR) =0.0
Respondents: Quality Assurance and Regulatory Affairs Manager and the production engineering head