Design for Availability

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Design for Availability

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Abstract

This master thesis specifies the development of a “Design for Availability” concept for Stork Food Systems. “Design for Availability”, being concerned with cost-effectively influencing availability of equipment during its lifetime, is explained thoroughly and completed with details about improvement areas and decision-making methods. Throughout the research, a case study is performed at Stork Food Systems.

Preface

This dissertation is the outcome of my graduation project at Stork Food Systems in Boxmeer, the Netherlands. I started my education in “Business Engineering” at the K.U. Leuven, Belgium. I was very proud to get my bachelor degree at this university in 2007, and decided to continue my studies abroad. I settled on the master “Operation Management and Logistics” at the Eindhoven University of Technology. It has been a great experience to finish my master with a project at a company like Stork Food Systems.

During this project, my modesty and shyness are challenged quite a bit due to the many meetings I had to organize in order to get all required company specific information. First of all, I want to thank Jan Melssen to point out frequently that networking is important and appreciated at the company, and even more to help me to become more self-confident. Besides, I really appreciate the freedom that Jan gave me. I could not have wished for a better mentor at the company. I also want to thank Gerrit den Bok, my colleagues in the department SG-CTS, and the other employees of Stork Food Systems, for their enthusiasm on my project, and their openness to contribute.

Besides the people at Stork Food Systems, I want to thank Geert-Jan van Houtum who made me discover this motivating graduation project at Stork Food Systems. The discussions we had about my project always turned out to be informative and pleasant. He was patient, listened to my ideas about the concept I have developed, and indicated flaws as well as strengths of my thoughts. And let me not forget Fred Langerak, my second supervisor at the university. His opinion and comments improved this report considerably, and Fred really motivated me at moments the project became harder to take for. I really look forward working with him in the future. Finally, I’m willing to express my thanks to my friends and family, and especially to Paultje, for their everlasting support, for their feedback on my project, and for distracting me whenever I needed it.

Lydie Smets
Boxmeer, 2009

Executive Summary

This report is the result of a Master thesis project at Stork Food Systems (SFS). SFS delivers equipment to the food processing industry, and nowadays, slaughterers ask for better performing machines, easier maintainable equipment, and superior service. Obviously, the company wants to fulfill these high quality requirements of the customers in order to stay competitive in the food processing industry.

According to Blanchard et al. (1995), availability measures the degree to which a system or machine is in an operational and committable state at the start of a mission at whatever time the mission is called for. Availability corresponds to the high customer requirements of machine performance, and it seems interesting for SFS to examine how it can meet high equipment's availability targets against minimal costs, i.e. "Design for Availability (DfA)". Accordingly, the main research question:

What should Stork Food Systems undertake to put "Design for Availability" into practice?

Research Development

In order to answer the main research question, four research subquestions are formulated. The first research subquestion is the following:

What is the current state of Stork Food Systems regarding "Availability"?

The first step to find an answer to the main research question is to understand and explore availability as extensively as possible. As said by Blanchard et al. (1995), equipment's availability is a function of its operating time and downtime. The operating time, or Mean Time To failure (MTTF), is associated to reliability which refers to the ability of a system or item to remain functional under given operating conditions in a particular environment. Accordingly, the MTTF corresponds to the time that a machine or system is available for use. The total time that the machine or system needs to be functioning is determined by the time that it is functioning together with the time needed to repair and support, the downtime. The Mean Time To repair (MTTR) refers to maintainability that covers the ability of a system to be maintained, retained or restored. The Mean Time To support (MTTS) refers to supportability that covers the ability to provide the required resources to carry out maintenance actions. The definition of availability, composed of the MTTF, MTTR and MTTS, is used as a starting point to construct an availability framework, containing subjects that can affect the availability of equipment during its design phase or when it is already in use at the customer. Afterwards, that information is used to assess the current situation of SFS regarding the availability components by means of a SWOT-analysis. Strengths and weaknesses, as well as opportunities and threats of SFS regarding "Availability" are discovered. The strengths and weaknesses refer to aspects of the company that are helpful or disadvantageous, respectively, to achieve the preferred availability of its equipment. Opportunities and threats, however, concern external conditions that favor or harm, correspondingly, the fulfillment of the customers' availability requirements.

STRENGTHS	***WEAKNESSES***
- Reliability-Centered Maintenance - Business Process Management - Availability and Geography - Trained Field Service Engineers - Maintenance Requirements in Design	- Too little emphasis on Reliability - Monitoring Maintenance Actions - Fault discovery - Data Management - Disassembly and Maintenance ease

Concluded from the weaknesses and strengths, as represented above, the current state of SFS regarding "Availability" is moderately developed and open to improvement. The company should

keep up its strengths taking care of the threatening external conditions, and enhance its weaknesses taking advantage of the opportunities.

Now SFS is familiar with what subjects of availability can be improved regarding the company's equipment, the second subquestion arises:

What is the current state of Stork Food Systems regarding "Design for Availability"?

The company will have to know how it should organize itself to continuously act upon availability without losing its position as a market leader. Therefore, the critical success factors for implementing DfA in a company are determined to be as follows:

Good leadership: Clearly communicate the importance of the company's emphasis on availability and create lifecycle awareness. Involve all parties caught up in a product's lifetime and search jointly for elements that influence availability.

Communication: Relevant information about influencing equipment's availability can appear because of new designs, the observation of maintenance actions, feedback sessions, equipment modifications at a certain customer, and so on, and this information needs to be well managed.

Training: Because of the changing environment, it will always be possible to find new improvements regarding DfA. Therefore, it is recommended to clearly describe a decision-making process and to guide a team in getting familiar with that process. Additionally, it is necessary to built up skills in tracking and monitoring uncertainty in order to cope with risk associated to DfA.

Innovation: To make DfA promising to the company, it should not be afraid for change.

Subsequently, it is possible to identify the gap between the current situation of SFS and DfA by means of a SWOT-analysis.

STRENGTHS	***WEAKNESSES***
- Team work - Focus on quality, cost, and time - Feedback and communication - Decentralization/Hierarchy avoidance - Value to Customers - Continuous Improvement	- Focus on Product Development Process - Failing Product Lifecycle Management - No Decision-Making process - Insufficient Risk Management skills

From the weaknesses and strengths of the company, as shown in the figure above, it can be concluded that SFS is on its way to DfA, however, some changes within the company are necessary.

At this moment, it is concluded that the current state of SFS regarding "Availability" is moderately developed but open to improvement. Also some changes within the company are required to successfully apply DfA. From that, the third subquestion appears:

What are improvement opportunities regarding "Design for Availability"?

Besides keeping up its strengths regarding equipment's availability, SFS should enhance its weaknesses taking advantage of the opportunities. Weaknesses in the current situation of SFS regarding equipment's availability, and the missing success factors of DfA at SFS, lead to improvement potential regarding DfA. In order to make out how availability can be influenced in a cost-effective manner, it is necessary to know which costs are relevant to consider. Therefore, all costs that occur during the equipment's lifetime are identified, resulting in a cost breakdown structure for SFS. Consequently, it is possible to discover improvement potential regarding DfA by investigating the cost effects of acting upon availability weaknesses at SFS, and the impact of achieving the critical success factors that belong to DfA. Noticeable improvement opportunities are illustrated in the figure just below. In the list, the weaknesses of both SWOT-analyses are opposed to the improvement potential they entail.

WEAKNESSES "Availability"	IMPROVEMENT "Availability"
- Too little emphasis on Reliability	- Condition Monitoring, Failure Rates
- Monitoring Maintenance Actions	- Control Maintenance Actions
- Fault discovery	- Condition Monitoring, Failure Rates
- Data Management	- Perfect product lifecycle management
- Disassembly and Maintenance ease	- Lifecycle and Availability Awareness
WEAKNESSES "Design for Availability"	***IMPROVEMENT "Design for Availability"***
- Focus on Product Development Process	- Create Lifecycle and Availability Awareness
- Failing Product Lifecycle Management	- Perfect product lifecycle management
- No Decision-Making process	- Create Decision-Making process
- Insufficient Risk Management skills	- Grow into Risk Management

Finally, because DfA is about constantly searching for improvement potential, a dedicated team has to evaluate improvements regarding DfA and has to decide on which improvement will be put into practice, coming to the fourth and last research subquestion:

Which methods are helpful to decide on what improvement is worthwhile to put into practice?

It is not easy to make decisions based on uncertain observations. To compare and implement improvements regarding DfA it is necessary to develop a working procedure for adopting serious judgment to information, data and experience-based knowledge. According to Ullman (2006), there are no right decisions. There are only satisfactory decisions, and the goal is to find the best satisfactory decision. Many decision-making methods exist to help and support decision-makers in order to choose the best improvement. This research suggests several methods such as lifecycle costing, reflecting pros and cons, multi-criteria analysis and risk assessment. SFS is advised to select and combine those decision-making methods it thinks are useful for DfA and to incorporate them in the decision-making procedure.

Conclusions

- In the literature, much can be read about "Design for X". However, a definition for "Design for Availability" still seemed to be missing. In this research, "Design for Availability" has been defined as cost-effectively influencing equipment's availability following its entire lifetime.
- To understand and explore availability as extensively as possible, an availability framework has been constructed.
- In order to continuously act upon availability without losing competitive advantage, the company will have to know how it should organize itself. Therefore, the critical success factors to apply DfA have been defined in this project.

Recommendations

- It is necessary for the company to further develop the availability framework. Therefore, the company has to announce its emphasis on availability together with a clear description of the term.
- It has been concluded that SFS seems on its way to DfA. Yet, the company has to realize that some changes are necessary, i.e. create lifecycle awareness, recognize the value of data coming from all parties involved in the life cycle of equipment and manage this data, find new opportunities regarding DfA, describe a decision-making process, and deal with risk.

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Chapter 1: Research Assignment

1.1. Introduction

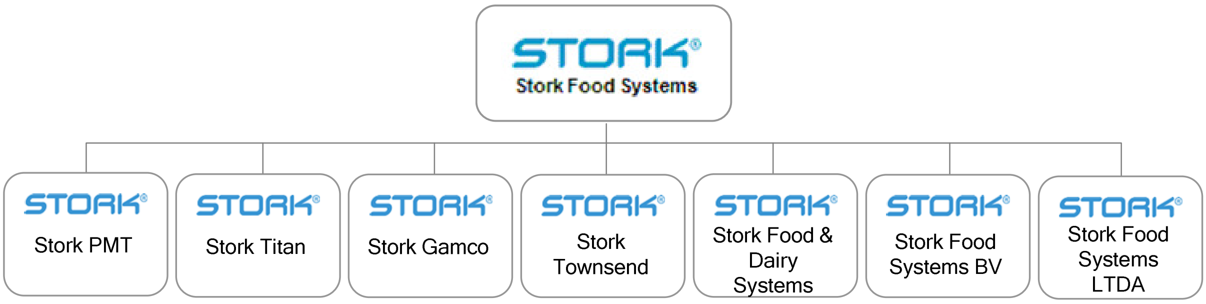
This research assignment is executed at Stork Food Systems (SFS) and is specifically focused on "Design for Availability (DfA)". Because availability of equipment is of great importance to the customers of SFS, the company wants to keep up with the high availability requirement at minimized cost. The company "Stork Food Systems" will be introduced in Section 1.2. This section discusses the company's history and development, the market characteristics and developments, the characteristics of the customer process, and the use of SFS' equipment in the customer process. After that, further details about DfA are given in Section 1.3., followed by the exact research description, development and scope in Section 1.4.

1.2. Stork Food Systems

1.2.1. Company's history and development

Stork NV started its activities in the poultry processing industry in 1963 and decided to expand its existing production facilities in Boxmeer by taking over a local machine factory. The original activities of that factory regarding poultry processing were expanded to an entire Stork poultry division. From that moment on, the establishment of SFS was initiated. In 1975, an independent subsidiary under the name Stork PMT, Poultry processing Machinery and Technology, was born. Barely one year later, Stork PMT decided to expand its activities to the USA, the biggest poultry market in the world. It took over the company Gainesville Machine Corporation, currently known as Stork Gamco. Stork Gamco quickly received the status of the most important poultry processing equipment supplier in the USA.

Stork PMT continued growing, and its facilities have been expanded ever since. Moreover, Stork PMT significantly developed its capabilities in the poultry processing industry to pork and beef processing. In 2006 a new member joined the group: Stork Townsend. Townsend develops and produces specialized equipment for the meat processing industry. In 2007, it acquired the French Nijal S.A.S. which manufactures machines for processing of meat, and related further processing products and developments were acquired from Proval B.V.



Nowadays SFS consists of seven subsidiaries, namely Stork PMT, Stork Titan, Stork Gamco, Stork Townsend, Stork Food & Dairy Systems, Stork Food Systems BV and Stork Food Systems LTDA. In total, SFS employs about 1875 employees. Stork PMT BV is the leading and trend setting company in poultry processing equipment and systems located in Boxmeer and Dongen in the Netherlands. Stork PMT has about 750 employees. Stork Titan produces sophisticated systems for the further processing of poultry, red meat, potato and fish products into semi finished, convenience food and meal component items. This subsidiary has about 70 employees. Stork Titan BV is located in Boxmeer together with Stork PMT and Stork Titan Inc. in Gainesville. Next to these Dutch corporations, two sister companies take care of the American continent, i.e. Stork Gamco and Stork Townsend. Stork Gamco is located in Gainesville together with Stork Titan Inc. and employs about 175 people. This subsidiary takes care of the North American market, Central America and a part of South America, and delivers poultry processing systems. Stork Townsend is based in Iowa (Stork Townsend Inc, USA) and Oss (Stork Townsend BV, NL), and also has a site in Nijal. Around 160 people work in Oss whereas about half that number works in Iowa. The South American market is also served by SFS, specifically by the subsidiary Stork Food Systems LTDA located in Brazil. This company operates as a modest company with about 20 employees but is expanding rapidly. This leaves another 2 subsidiaries of SFS. There is Stork Food & Dairy Systems which is based in Amsterdam and appeals on about 180 employees. This business is specialized in the development and manufacturing of machines that extent product life and package dairy products and other food. Next there is Stork Food Systems BV, purely the name of all the international sales and service offices that come under the Food Systems group.

In November 2007, SFS had announced an agreement on its acquisition by Marel Food Systems, subject to various conditions. These conditions have now been met. United, the two companies will be a predecessor in the development of equipment for the food processing industry, with a combined yearly turnover of 660 million Euros and more than 4000 employees. Together, the companies have a balancing product collection with almost no overlap. Many customers will discover that Marel's and SFS' solutions match and complement each other in production. Joined together, the companies expect to further improve on the integration of such solutions.

1.2.2. Market characteristics

Today, SFS is the leading global provider of equipment and systems to the poultry processing industry in Europe, as well as in South America. In North America, it ranks first in primary processing and the 'back end' of secondary processing, with weighing and batching systems. Plans are underway to reinforce the company's network in Asia, which will strengthen the market position in this region.

Furthermore, SFS has an increasingly strong market position in all phases of meat processing. The time is right to promote the company's position as a one-stop-shop for everything, from stand-alone machines to complete integrated systems, supported by a single software platform and maintained by one global service organization. Many opportunities exist in emerging markets like China, Brazil and Russia, which ask for increased production capacity and efficiency. Especially China requires an enormous increase in automation to keep up with the high level of consumption.

Additionally, SFS has a strong and comprehensive range of further processing equipment to present to the market, and the convenience food market is expected to perform better than most other industry segments.

Finally, SFS is currently one of the market leaders on spare parts. Unfortunately for SFS, a number of pirates are active on the market of spare parts for poultry, fresh meat, as well as for further processing equipment.

1.2.3. Market developments

Several developments are noticeable in the food processing industry on which it can focus to outperform its competitors:

1. <u>Customers ask for more support</u>: After sales service is becoming more important and will play a bigger role in buy decisions. As a result, demand on product and process support is increasing.
2. <u>Focus on Total Cost of Ownership</u>: Customers start asking for guarantees on Total Cost of Ownership (TCO) and performances in their contracts.

TCO refers to all costs related to the acquisition, operations, maintenance and support which are borne by the customer (Dinesh et al., 2006).

Furthermore, customers want fixed-price agreements for maintenance and spare parts, and leasing of equipment is becoming more popular.

3. Food processing companies are getting bigger: In the food processing industry, it is conspicuous that small companies seem to go bankrupt or seem to be taken over by big companies. Additionally, slaughterhouses are starting further processing activities more often. As a result, the number of customers is decreasing, and customers become more and more professional.

The international financial crisis and the slowdown of the global economy have affected all industries. Yet, compared to most others, the food processing industry is well placed to weather the storm.

1.2.4. Characteristics of the Food Processing Processes

SFS distinguishes three production processes, i.e. poultry processing, fresh meat processing and further processing. SFS is a full line supplier of equipment for poultry and further processing, whereas for fresh meat processing the company only delivers machines for part of the process. Further details about the three processes are presented in Appendix 1.1.

1.2.5. The use of Stork equipment

On the one hand, the use of SFS' equipment varies *between* customers. Some slaughterers produce 3 shifts a day, 6 days a week, and 12.000 birds per hour. Other slaughterers produce only 4 hours a day, 5 days a week, and 500 birds per hour. Some pieces of equipment are used constantly, while others only for particular batches. Some customers replace equipment every 5 years, and others only every 25 years. Some customers focus on corrective maintenance while others have an extensive preventive maintenance program. Obviously, these differences result in diverse wear and failure behavior of the equipment.

On the other hand, the significance of Stork equipment *within* a customer specific process is also diverse. Further processing customers and poultry processing customers in North America usually have equipment of different suppliers combined into one process. These customers have more of a 'Have it your way' mentality, and pick the 'best' machines instead of the 'best' lines. Poultry processing customers in other parts of the world prefer one supplier for the majority of the process.

1.3. Design for Availability

SFS noticed that slaughterers ask for better performing and more reliable machines which are at the same time easy to maintain. Quality attributes, measuring the performance of a system, obviously become increasingly important. According to Blanchard et al. (1995), availability is the measure of the degree to which a system or machine is in an operational and committable state at the start of a mission when the mission is called for at an unknown random point of time (operational readiness). Accordingly, availability is a function of operating time (reliability) and downtime (maintainability and supportability).

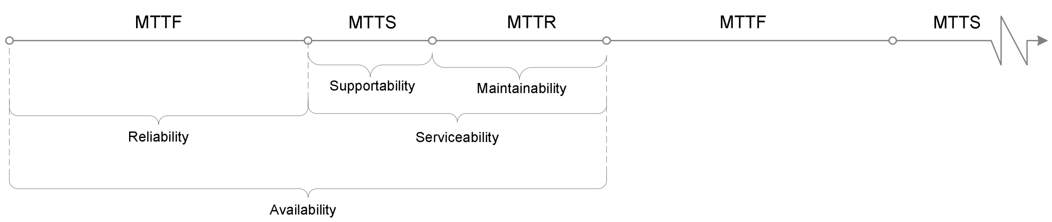


Figure 1.1.: Measures of Design for Availability

As shown in Figure 1.1., the Mean Time To Failure (MTTF) is associated to reliability which refers to the ability of a system or item to remain functional under given operating conditions in a particular environment. Accordingly, the MTTF corresponds to the time that a machine or system is available for use. The total time that the machine or system needs to be functioning is determined by the time that it is functioning together with the time needed to repair and support. The Mean Time To Repair (MTTR) refers to maintainability that covers the ability of a system to be maintained, retained or restored. The Mean Time To Support (MTTS) concerns the ability to support customers, which is supportability. As a result, availability can be expressed by equation 1.1.:

$$A = \frac{MTTF}{MTTF + MTTS + MTTR} \tag{1.1.}$$

“Design for X” is about the development of a system that fulfills appointed requirements in a cost effective manner (Blanchard et al., 1995). In the literature, much can be read about “Design for Reliability”, “Design for Maintainability”, “Design for Serviceability”, and more. However, a definition for “Design for Availability” still seems to be missing.

In this research, “Design for Availability” is defined as cost-effectively influencing equipment’s availability following its entire lifetime.

It follows that all businesses of the product development process and after sales process, such as the product design, the customer support, and maintenance management, are of great importance in DfA. The decisions made during these businesses will have a major influence on the operational effectiveness and the equipment’s lifetime costs (Kumar et al., 2000).

In conclusion, DfA repeatedly searches for possibilities to reduce the costs for given availability requirements, or elevates the availability level at minimized costs. Thus, DfA concerns an eternal decision-making process in which many parties are involved. Because of new information regarding the product lifecycle, several opportunities in order to reduce the costs will appear. Each time it should be decided which occasion to put into practice, and in what order. Accordingly, DfA can improve the company’s performance, but only if the company commits to it. The company should be open to change its current way of doing business towards doing business in line with DfA.

Besides reducing the costs, DfA contributes to customer satisfaction and employee satisfaction. The company is given the opportunity to broaden its activities due to the increasing popularity of the service business, and to dominate its market.

1.4. Research Description

1.4.1. Main Research Question

SFS notices that slaughterers ask for high availability of food processing equipment. The longer the production runs and the narrower the downtime possibilities, the higher the revenues towards the customer can be. After being informed about DfA and noticing its potential, the company became curious about how it should influence the quality attribute “availability” and what the impact would be cost-wise. Additionally it wondered whether many changes regarding the current manner of doing business are required to come to DfA. This resulted in the following main research question:

What should Stork Food Systems undertake to put “Design for Availability” into practice?

1.4.2. Research development

In order to answer the main research question, four subquestions are formulated. The first subquestion is the following:

What is the current state of Stork Food Systems regarding "Availability"?

A first step to answer the research question is to understand and explore availability as extensively as possible. In Chapter 2, the definition of availability, composed of the MTTF, MTTR and MTTS, will be used as a starting point to construct an availability framework, containing subjects that can affect the availability of equipment during its lifetime. In Chapter 3, that information will be used to assess the current situation of SFS regarding the availability components by means of a SWOT-analysis.

Having answered subquestion 1, SFS will be familiar with what subjects of availability can be improved on the topic of the company's equipment, and the company will have to know how it should organize itself to continuously act upon availability without losing its position as a market leader. The second subquestion arises:

What is the current state of Stork Food Systems regarding "Design for Availability"?

To find an answer to this question it is necessary to specify DfA and to identify the critical success factors belonging to DfA, which will be the subject matter of Chapter 4. Afterwards, in Chapter 5, it will be possible to identify the missing success factors to apply DfA at SFS, as a result of which it will be feasible to determine the current situation of SFS regarding DfA.

Whereas Chapter 3 will show what subjects of availability can be improved regarding SFS' equipment, Chapter 5 will reveal the actions that need to be taken to successfully introduce DfA at the company. Just then, it is useful to search for opportunities for SFS to cost-effectively influence equipment's availability, creating a better situation for the company as well as for the customer. From that, the third subquestion appears:

What are improvement opportunities regarding "Design for Availability"?

Chapter 6 will be dedicated to the identification of improvement areas regarding DfA at SFS. First, a cost breakdowns structure will be formulated that will help SFS to get familiar with the relevant costs regarding DfA. Then, combining this cost breakdown structure with the information about the current state of SFS regarding "Availability" and DfA, will make it feasible to track possibilities to cost-effectively influence equipment's availability.

Finally, DfA is about constantly searching for improvement potential. A dedicated team has to evaluate improvements regarding DfA and has to decide on which improvement will be put into practice, coming to the fourth and last research subquestion:

Which methods are helpful to decide on what improvement is worthwhile to put into practice?

In order to give SFS a start in the decision-making process, Chapter 7 will suggest several decision-making methods from which the company will have to select the most appropriate.

1.4.3. Scope of the Research Project

Prospect

SFS usually foresees five years in order to carry out modifications at the strategic level. The strategic level focuses on the business practices. If DfA implies changes regarding the current business practices of SFS, these changes will be implemented within a period of five years

Service Contracts

SFS currently offers service contracts to its customers. This means that a service specialist visits the customers one or more times per year. During these visits, the technical and technological state of the equipment at the customer is analyzed. Any problems are discussed and the performance of the equipment is checked against SFS norms. At the end of the visit there is a final discussion with the customer and a written report is prepared and sent. The level of service depends on what is agreed in the service contract and may differ per customer. This means that SFS has some customers that choose not to opt for a service contract, while others prefer full service. Besides these contracts, SFS offers professional software support contracts by means of a 24 hour help desk. The customer can expect free support 24 hours a day, and 7 days a week.

Availability level

In the program of requirements, SFS defines an availability level of 99.9% concerning single machines, and 99% regarding complete lines of equipment. This research assumes that the machines are all designed in order to reach such availability levels and quality. It is however possible that the level decreases over time because SFS' operation and maintenance prescriptions are not followed by the customer.

Design requirements and constraints

It is not always possible for the designers to just do whatever they want during the creation of a new system. Throughout the design process there will always be certain given requirements that need to be taken into consideration. Also SFS has made up general directives which need to be obeyed. First of all, hygienic design is necessary considering the risk of contamination of food. Next, machine design requirements for transportation are formulated. Finally, a list of standards which are related to the safety of machines is drawn up. Within this research, these directives are seen as fixed specifications and will not be used in order to influence the availability level.

Costs

Lifecycle Cost (LCC) and Total Cost of Ownership (TCO) are both important financial measures used to assess total effectiveness of a product and procurement decision making (Kumar et al., 2006). The LCC is related to the product lifecycle from SFS' point of view, whereas the TCO is focuses on the new owner of the product. Because in this research regarding DfA the emphasis is set on the company's point of view, LCC is considered.

Chapter 2: Availability

2.1. Introduction

DfA is about influencing equipment's availability in a cost-effective manner during its entire lifecycle. It repeatedly searches for occasions to reduce costs for given availability requirements, or influences availability while minimizing costs. Thus, to be competent at fine-tuning the availability level of equipment, it is first of all essential to understand and explore "availability". In Chapter 1, availability is defined by means of equation 1.1. This definition is used as a starting point to construct an availability framework, containing subjects that can affect the MTTF, MTTS and MTTR, and thus the availability of equipment. Data to explore and explain the components MTTF, MTTS and MTTR is based on a literature study. Subsequent to this literature study, the data collection concerning MTTF, MTTS and MTTR is classified under two extra categories: "during Design" and "during Operations". Some subjects influence equipment's availability during design and development activities, and therefore belong to the category "during Design". It is however also possible that elements influence equipment's availability whenever a machine is already in use. Consequently, "during Operations" seems an appropriate category for those elements. The result of the exploration of availability is shown in Figure 2.1. and this chapter will be dedicated to further explain the framework. Section 2.2., 2.3. and 2.4. discuss the elements that influence MTTF, MTTS and MTTR respectively. Also, each section is subdivided in the two categories "during Design" and "during Operations".

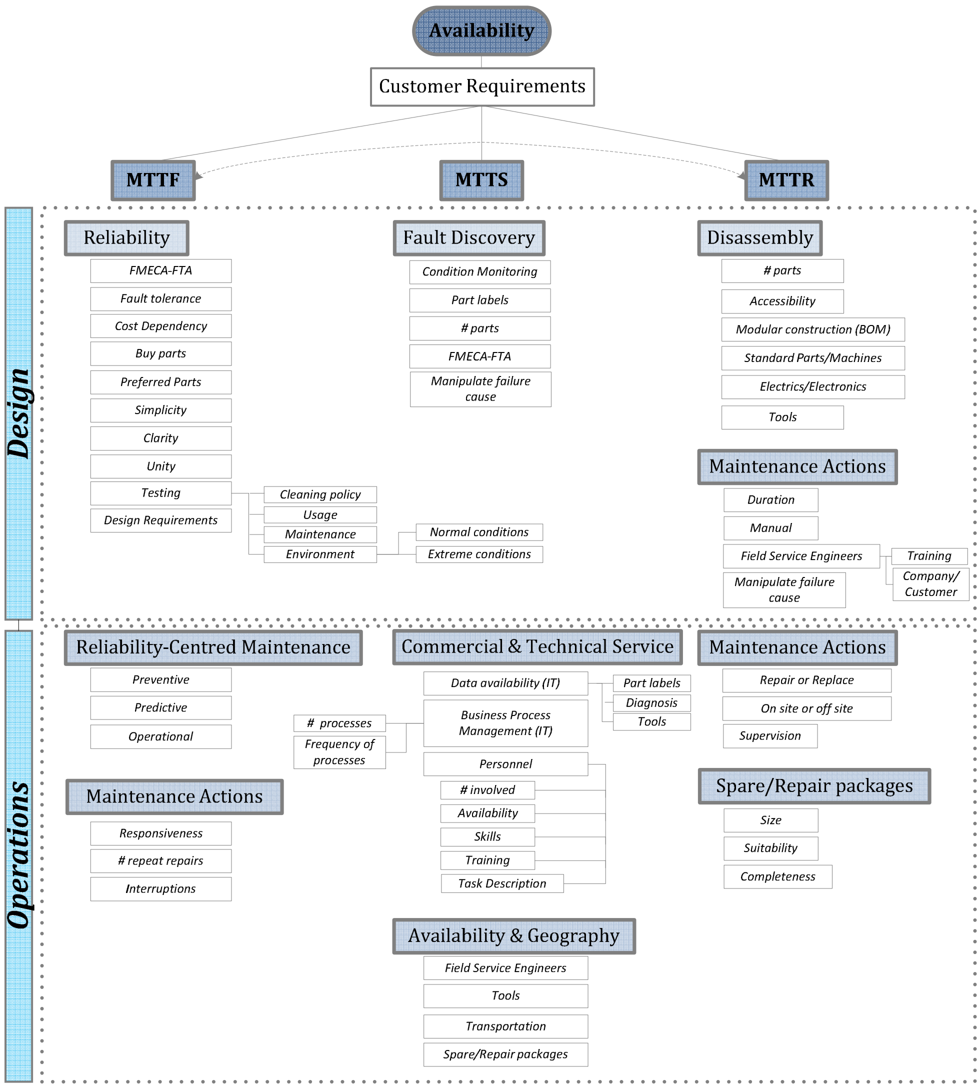


Figure 2.1.: Availability Framework

2.2. MTTF

The Mean Time To Failure is defined as the average life of a non-repairable system or the average time before the first failure of a repairable machine (Kumar et al., 2000).

Thus, the MTTF is closely related to the failure rate of a system. The failure rate of a system, thus its MTTF, can be influenced by the following elements:

- Reliability of equipment
- Reliability-centered maintenance schemes
- Control of maintenance actions

2.2.1. MTTF during Design

2.2.1.1. Reliability

Reliability refers to the ability of a system or item to remain functional for a specified time under given operating conditions in a particular environment (Kumar et al., 2000).

In order to control reliability, many subjects such as certain analysis and tests, requirements of a system and its usage, have to be considered.

FMECA-FTA

FMECA stands for Failure Mode, Effect, and Criticality Analyses, which consists of a methodology for examining all the ways in which a system failure can occur, potential effects of failures on system performance and safety, and the seriousness of these effects. Thus, the FMECA enhances knowledge of the system and insights into its expected behavior which support the development of a cost-effective preventive maintenance program and a focused control plan (Blanchard et al., 1995). FTA signifies Fault Tree Analysis and is often used when insufficient data is available to perform a FMECA. FTA represents a top-down causal hierarchy of failure incidents, and shows the probability of occurrence of the top-level failure. If the probability of the top-level failure is too high, redesign has to be considered to make the system or item more reliable (Blanchard et al., 1995). FMECA and FTA are both design techniques in order to identify where certain failures can occur (Appendix 2.1.).

Fault Tolerance

Fault tolerance describes how easily a system will stop functioning because of the presence of a failure. High fault tolerance of equipment indicates that it can suffer quite a bit. Consequently, fewer breakdowns occur during its lifetime which results in a lower failure rate and thus a higher MTTF.

Cost Price Dependency

Obviously, when the designers have to take into consideration budget restrictions, the reliability of new items or systems is affected. Instead of choosing the best material available, the designer will be burdened to find the finest materials available without exceeding a given budget. Consequently the MTTF is dependent on the budget boundaries that are given to the designers to create a new item or system.

Buy Parts

The reliability of a system is dependent on the quality of the buy parts it contains. Most of the companies are not able to produce each one of its equipment's components itself. It is advised to define requirements that a buy part should meet. Based on those requirements it is possible to select the most excellent supplier.

Preferred Parts

Designers create, during their career, a certain preference to parts that are required in a system. The problem is that those parts will not always be the best suitable parts in all of the machines, endangering the optimization of its reliability. Designers have to be willing to search for the most appropriate parts over and over again. It is possible that alternative parts are already available at the company itself. Sometimes it is even possible that it is profitable for the company to design new parts. However the company can also decide to buy certain parts. Thus, more scenarios have to be considered in the selection of required parts.

Simplicity, Clarity and Unity

Simplicity, clarity and unity are the main requirements to attain a reliable system. Simplicity implies that the number of components and interfaces in a system is minimized. Clarity indicates that each function has to be able to operate independently in order to reduce variation and ambiguity. Unity denotes that each component should equally contribute to the accurate operation of a system (Huang, 1996).

Testing

Testing is referring to the phase in which a prototype comes into existence. After the initial design of a machine, it is important to consider real use conditions, and to fall back on redesign if necessary. Environmental characteristics (temperature, dust, corrosion, humidity, vibrations, and so on), support equipment, cleaning policies, operating and maintenance procedures, and so on, have to be tested before a system is produced for use.

Design Requirements/Constraints

It is not always possible for the designers to just do whatever they want during the creation of a new system. Throughout the design process there will always be certain given requirements that need to be taken into consideration. Sometimes, a designer is limited in the choice of materials due to the fact that not every kind of material is allowed in a certain industry. After that, geographical characteristics can bring about new constraints to the designer. When a company produces for a wide market, it is important to consider for instance cultural differences and dissimilar climates. Also safety requirements can depend on which country a company serves. Finally, all the previous mentioned requirements go hand in hand with styling requirements. The designer is not always allowed to create a system or item that they think looks nice because they are limited by geographical and material requirements. In addition, a designer can be restricted in its creation because the company or a customer specifically asks for a certain styling.

2.2.2. MTTF during Operations

2.2.2.1. Reliability-Centered Maintenance

Reliability-centered maintenance is a systematic approach for selecting applicable and effective maintenance tasks for each item in a system taking into account failure consequences.

Applicable implies that if the maintenance task is executed, it will realize the prevention or cutback of a failure, or the detection of a hidden failure (Kumar et al., 2000). Reliability-centered maintenance only considers proactive maintenance and not reactive maintenance. Reactive maintenance, more recognizable as corrective maintenance, is required to correct a failure or an unacceptable performance that has occurred (or is still occurring). These activities can consist of repair, restoration or replacement of components. Reactive maintenance actions are not planned and are required when a system is not performing anymore, and thus these actions do not influence the MTTF. Proactive maintenance actions however, are designed to minimize the risk of failing systems. They are planned, scheduled and executed before a breakdown occurs, and therefore contribute to a longer performance period of a system. Examples of proactive maintenance actions are preventive and predictive overhauls.

2.2.2.2. Maintenance Actions

Besides the reliability-centered maintenance it is important to monitor the maintenance actions that are performed in the field in order to optimize the MTTF of a system. For instance the time to react to a prospect of failure, the time and number of interruptions to perform maintenance and the number of repeat repairs are characteristics of maintenance actions that can influence the MTTF and therefore should be refined.

2.3. MTTS

The Mean Time To Support covers the period from a failure report until the corrective maintenance action is initiated.

The MTTS is dependent on the following elements:

- Fault discovery process
- Commercial and Technical Service
- Availability and Geography of field service engineers, tools, and spares and repairs

2.3.1. MTTS during Design

2.3.1.1. Fault Discovery

Each time a failure occurs it is important to find out what the exact cause of failure is. According to Blanchard et al. (1995) failures must be traced from the initial “symptom” at the system level. Several methods, such as condition monitoring, minimizing the number of parts and labeling parts, can greatly facilitate this process of tracing failure roots. Additionally incorporating FMECA and FTA could lighten the fault discovery process as well.

Condition Monitoring

Condition monitoring is a device used to inspect or examine an item or system in order to provide data and information about its condition at any instance of operating time (Kumar et al., 2000). In other words, it makes the nonstop assessment of an item or system’s state possible. Techniques for condition monitoring have to be considered during the design process of an item or system. Inspection can be based on visual images from cameras in the machine or by means of ultrasound, optics, temperature, and so on. Active condition monitoring facilitates the discovery of breakdown occasions and accordingly helps to quicken the maintenance support process.

Part Labels

In case a failure is detected and the cause of failure is identified, it has to be reported to a service engineer. Neither the company, nor the customer is always aware of all kind of parts that belong to a specific machine. Therefore it can be difficult to identify failed parts and to report the exact failure to the service engineer. Part labels with the intention of identifying parts can be pretty helpful to make the message to the service engineer clear-cut.

 # Parts

The more parts a machine contains, the more complex the machine becomes. It is necessary to minimize the number of parts in a system in order to facilitate the search for failure causes. Remember that this requirement is also relevant for the reliability of a system. Simplicity, one of the three main reliability requirements, implies that the number of components and interfaces in a system has to be minimized. Thus simplicity already signifies double benefit.

FMECA-FTA

Remember that FMECA and FTA are both design techniques in order to identify where certain breakdowns can occur. FMECA is a method for analyzing the ways of system failure, potential effects of failures on system performance and safety, and the criticality of such effects. FTA concerns the graphical listing and analysis of the diverse ways in which a particular system failure can occur, and the probability of its occurrence. Obviously, applying such techniques will contribute to the speed of fault discovery.

Manipulate Failure Cause

In the design phase it is possible to manipulate the cause of failure. A constructor engineer strives to design a machine in such a way that he can determine beforehand which part fails where exactly. In this way, the fault discovery process is shortened.

2.3.2. MTTS during Operations

2.3.2.1. Commercial and Technical Service

The way of arranging the procedures of customer support and especially maintenance can greatly influence the time to help clientele. The more people involved in the customer support process, the greater the possibility that information gets lost, and the more difficult it becomes to quickly support clients.

Data Availability

If failures have occurred it is important to write down all relevant details about these failures in order to have that information available for anyone anywhere (Blanchard et al., 1995). Appropriate details to record are details about the concerning customer, the setting in which the failure occurred (human behavior, environment …), the exact cause of failure (often discovered from FMECA or FTA), and the action taken to correct for the breakdown (utilized tools, spares/repairs …). As a result, an easy accessible database comes to existence, and customers can be assisted sooner.

Business Process Management

It is important to organize the customer support process in such a way that the customer can be supported as quickly as possible. Next, this process needs to be in black and white to facilitate the accumulation of necessary process information, to fine-tune the process, and to gear different processes with one another.

2.3.2.2. Availability and Geography

The availability of servicemen, tools, spares and repairs can contribute considerably to the time of customer assistance in case of corrective maintenance.

Field Service Engineers, tools and transportation

In some cases of equipment failure, a customer calls the company for support and needs assistance from field service engineers to fix the problem. To deliver quick support to this customer it is necessary for the company to have sufficient field service engineers available which are able to reach the customer with the accurate tools. If no service engineers with the right tools can be transported to the customer immediately, the MTTS will inevitably be extended.

Inventory Management

One of the main objectives in the food processing industry is to minimize unplanned downtime. Having complete spare/repair packages available makes it possible to avoid those situations in which one has to wait for specific components for an extended time while complete lines are inoperable.

2.4. MTTR

The Mean Time To Repair is simply the time it takes to bring the machine or system to its satisfactory working condition (Thompson, 1999).

In other words, MTTR is directly related to the following elements:

- Ease of disassembly of machines
- Management of maintenance actions
- Composition of spare/repair packages

2.4.1. MTTR during Design

2.4.1.1. Disassembly

Certainly a customer demands quick and cheap repair of a broken machine since each minute of downtime is precious. An interesting detail is that the structure of a machine determines the difficulty and duration of maintenance actions very much. A complex machine with a lot of non-standard parts which are difficult to reach will be more difficult to repair then a machine with standard parts, tools and fasteners. It is recommended to consider the simplicity of maintenance actions throughout the design phase of a machine in order to reduce the length of repair procedures.

 # Parts

The more parts a machine contains, the more difficult it will be to maintain a machine. It is necessary to minimize the number of parts in a system. After that, it will not only be easier to find the cause of failure, but it will also be easier to reach the failure. As a result, a service engineer can perform efficient and effective maintenance actions with minimized efforts. Moreover, remember that this requirement applies not only in order to reduce the duration and facility of maintenance actions. Simplicity also contributes to the MTTF and MTTS. This proves the magnitude of part reduction.

Accessibility

How easily a particular item of a complex machine can be reached plays an important role regarding the time to repair. And notice that the ease of access of an item is closely related to the number of parts a machine contains. The more parts involved, the higher the probability that a part is difficult to access.

Modular Construction

The bill of materials (BOM) of a machine is the hierarchical exposition of the assembly of every single one of the parts from a machine. An exemplar of a BOM is exposed in Appendix 2.2. The more parts in a machine, the more complex the BOM. In case it is impractical to further develop simplicity of the machine to facilitate repair, one should try to enable the disassembly of the machine at the highest possible hierarchical level of the BOM. This means that the company has to check whether it is feasible to create modules of parts in order to make maintenance actions easier.

Standard Parts/Machines

Not only the number of parts, but also the number of variants of a part is important to minimize. This is what is called standardization. In this way, it is easier for a service engineer to get familiar with maintenance procedures and to reduce the time to repair.

Electrics/Electronics

The customers of food processing equipment manufacturers require more and more precision and performance of machines in order to miss as little of merit possible. Owing to technological development, the manufacturer is able to better satisfy its customers. Providing the machines with electric components and electronics makes it possible to better control the systems and to evade inaccuracy of human actions. However, because of the electrics and electronics, a machine becomes more and more complex and maintenance is harder to take for. Disassembly turns out to be more fragile and besides that, the service engineer is required to not only have mechanical and industry specific knowledge but also skills in electrics and electronics. In conclusion, the adoption of new technologies goes hand in hand with superior performance of the machines. On the other hand, technological progress is the occasion for longer downtimes in case of breakdowns.

Tools

How many companies do not face the problem of thousands of different screws, for each part of a machine a different size or form? As a result, an overload of tools is required to carry out repairs. The number of tools needed in order to perform a maintenance action is closely related to the standardization of parts and machines. Standardization reduces the number of variants of parts in the fields, and thus also the number of part specific tools. Besides standardization, the designers need to opt for a limited selection of for instance screws and not take a different kind of screw for each part. The perfect picture would be to have only one size of screw for all parts in all machines, but certain requirements regarding the reliability, environment, industry, use, safety, and so on, hinder this prospect.

2.4.1.2. Maintenance Actions

Maintenance actions have to be considered in the design phase of a machine in order to improve on the MTTR. The duration of a repair, the training of servicemen, manuals, and so on, are all a result of how a machine is developed.

Duration

The duration of the maintenance actions can partly be determined by the design of a machine. The more complex the machine is built, the longer it will take to repair it. It is important for the company to consider repair times in the design process of a machine, however should be careful in the engagement of requirements. The objectives should be feasible and may not lead to frustration with regard to the developers.

Field Service Engineers

The field service engineer is the main person involved in the maintenance actions. One should be aware of the fact that not each one of the servicemen has the most excellent skills in performing maintenance actions. Maintenance actions are sometimes performed by untrained repairmen appointed by the customer, increasing the time that is needed to repair a system.

Manual

Whenever restoration actions can be performed by the customer itself it is important to provide them with clear manuals of the machine, containing all necessary information to maintain a machine. This will help the customer to minimize or even avoid equipment's downtime.

Manipulation of failure cause

Remember that it is possible to manipulate the cause of failure during the development of equipment. A constructor engineer strives to design a machine in such a way that he can determine in beforehand which part fails where exactly. In this way, it is not only possible to cut down the fault discovery process, but also to foresee the ease of maintenance.

2.4.2. MTTR during Operations

2.4.2.1. Maintenance Actions

Maintenance actions and their duration are not only influenced in the design phase, but also at the time when the machines are already in use by the customers. As a consequence, flexibility with regard to certain decisions exists on how maintenance actions are carried out.

Supervision

Monitoring maintenance actions that are performed in the field in order to advice service engineers on how to make their actions more effective and efficient could improve the MTTR.

Repair or Replace, On site or Off site

One decision regarding to maintenance actions is whether to replace a failed item by another one and to repair the failed part afterward, or to repair the failed part and subsequently put it back into the system. A different decision is to repair the item immediately on site, or to take it to a general repair station. Of course, immediate repair leads to more machine downtime than replacing the failed item. Repairing off site without replacing the failed item is altogether not an option in order to improve the MTTR.

2.4.2.2. Spare/repair Packages

Size

It is unnecessary to provide the customer with too many spares and repairs resulting in redundant inventory costs. However, it is more vital for equipment's availability to guarantee the customer that the packages are composed of a sufficient amount of spares and repairs.

Suitability and Completeness

Obviously, when the spare/repair packages are not specifically designed for each independent machine at the customers, it is possible that the packages will not be appropriate or complete. Because each customer is able to modify its machine, for instance by changing the type of its consumables, it is required to keep up with those modifications in the formulation of spare/repair packages. Otherwise, unsuitable parts will reach the customer, or components will be absent, both resulting in an unnecessarily high MTTR.

2.5. Conclusion

This chapter presents an availability framework, the basis for DfA. The framework contains the elements that influence equipment's availability during its development, or whenever the machine is already operational at the customer.

Chapter 3: SWOT-analysis regarding Availability

3.1. Introduction

In Chapter 2, an availability framework is constructed and explained thoroughly. The framework contains subjects that affect equipment's availability during its design phase or when the machine is already in use at the customer. By means of this availability framework, SFS can fine-tune the availability level of equipment. In this Chapter, the state of SFS will be determined on the subject of its equipment's availability. Section 3.2., 3.3. and 3.4. discuss the current situation of SFS regarding the elements that influence MTTF, MTTS and MTTR respectively. And because the availability framework covers two more categories, "during Design" and "during Operations", each section is subdivided in these categories. Furthermore, the sections end with a representation of a SWOT-analysis related to the subject. In conclusion, a complete SWOT-analysis regarding availability, combining the three separate SWOT-analyses, is represented and explained in Section 3.5. The methodology which is used to gather the company specific information, applied for the SWOT-analysis regarding availability, can be retrieved in Appendix 3.1.

3.2. MTTF

3.2.1. MTTF during Design

3.2.1.1. Reliability

If SFS wants to refine its equipment's availability, it will be necessary to identify reliability requirements, and execute the right analyses and tasks to ensure the product will meet its requirements. The current condition of SFS' equipment on the topic of reliability is a weak spot regarding its equipment's availability, and is definitely capable of improvement.

FMECA-FTA

Unfortunately, SFS does not perform any FMECA or FTA because no details about the exact failure rates of components, modules and equipment are gathered. Yet, the company has software available including tools to carry out such analyses, i.e. Optimizer+ (Appendix 3.2.).

Fault Tolerance

To come to the fault tolerance and failure rates (λ) of items from systems of Stork Food System, the company's parts coding should be clarified. Each part is allocated a code indicating its service character within a system. There are five codes (Appendix 3.3.):

- A-parts: Consumables that make contact with the product to be processed and have a direct effect on the technological action of the system.
- B-parts: "Breakdown" parts which, if defective, make it difficult or impossible to continue the production.
- C-parts: Small overhaul parts which are to a great extent subject to wear and tear.
- D-parts: Major overhaul parts.
- E-parts: Condition-dependent overhaul parts dealing with wear that will be added to an overhaul package depending on their condition at the time of inspection.

Suppose that a machine of SFS at a slaughterer operates in double shifts (16 hours) for 255 days per year and with an uptime of over 99.9% regarding one system and of 99% regarding a full line. Under these conditions, the machines of SFS need to fulfill the following requirements (Appendix 3.4.):

- Minimal technical lifecycle of 10 years

- Time needed for replacement including adjustments:
  - A-parts: < 15 minutes (at most once per production day)
  - B-parts: < 30 minutes
- Time frame:
  - Small overhaul (C-parts) After at least 9 production months ($\lambda \leq 1.33$)
  - Large overhaul (C and D-parts): After at least 18 production months ($\lambda \leq 0,66$)
  - Total overhaul (C, D and E-parts): After at least 36 production months ($\lambda \leq 0.33$)
  - All overhauls may not confiscate more than 12 hours non-production time

Yearly production costs (spares and repairs included):

- A-parts: not more than 1% of the machine's total cost price
- B-parts: not more than 5% of the machine's total cost price
- C+D+E-parts: not more than 25% of the machine's total cost price

In conclusion, currently three maintenance requirements should be considered throughout the design phase of a machine which influences its fault tolerance and thus failure rate, mostly downwards. Firstly, the time to repair a system is confined. A- and B-parts are given a rather short time to repair. This is because those parts need to be replaced more often or can cause unexpected production stops. For C-, D-, and E-parts, the time to repair is limited to 12 hours of non-production time. These parts are included in the spare/repair packages to carry out preventive maintenance, and are therefore replaced while the system is not operating. Secondly, the time until a certain overhaul is allowed is specified, thus also the highest failure rate of C-, D-, and E-parts. Furthermore, A-parts should not be replaced more than once a day. And finally the maintenance costs are restricted and determined by the number of A- to E-parts that a system contains.

Cost Price Dependency

In Appendix 3.4. it is shown that SFS takes into account the cost price of an entire machine. Parts are not allowed to cost more than a certain percentage of the machine's production price a year. For consumables (A-parts) and breakdown parts (B-parts), this percentage is extremely low. A-parts have to be replaced quite often which means high demand. Other companies saw opportunities and decided to focus on the production of such parts. Consequently those companies are able to offer A-parts of the same (or less) quality at lower costs. In spite of the fact that more customers seem to consider total cost of ownership, or after sales costs, at the time of procurement, still many customers seem to opt for parts with the lowest purchasing price. This is one of the reasons why SFS needs to consider the cost price of consumables obviously influencing the reliability, and thus MTTF of such parts. B-parts are often parts which are not produced by SFS itself. The low cost price boundary gives a maximum purchasing price of breakdown parts, also having a limited effect on the reliability of equipment.

Buy Parts

SFS is not able to produce every component, required to assemble a system, itself. The company focuses on both quality improvement and cost reduction, and for that reason it is important to define requirements that a buy part should meet. Based on those requirements it is possible for the company to select the most excellent supplier. SFS currently defined at least one such requirement, i.e. the maximum cost price of B-parts, often purchased parts.

Preferred Parts

It is important that all needs of the customer and especially those of SFS are identified and listed. At the present, the company is assessing the requirements that seem to be vital to the company. Additionally, SFS often visits its customers as a result of which the company can identify customers' requirements.

Simplicity, Clarity and Unity

SFS is aware of the importance of simplicity, clarity and unity in the design of an item or system and takes those requirements for granted. However, the designers do not explicitly focus on these conditions what could block reliability enhancement. Recommended is to write down the famous design rules of simplicity, clarity and unity as a reminder.

Testing

Making profit of technological advances, SFS integrated testing and redesign in the product development process. Tests are performed with regard to system robustness, lifespan, and stress situations, and are especially based on experience. Nevertheless, black on white theoretical models and implemented software are absent at the company, but desirable.

Design Requirements/Constraints

Because Stork Food System is active in the food industry, material, safety and hygienic constraints are inevitable. Besides, since the company wants to satisfy its customers spread all over the world, it also needs to consider styling preferences, cultural differences and dissimilar climates. The diversity in customers' preferences and several constraints and requirements threats the company to create machines pleasing all customers. SFS has made up general directives which need to be obeyed and which are consistence with the performance requirements that describe the tasks of a new system and the required quality of tasks execution, and therefore hopes to cover about 80% of the market.

3.2.2. MTTF during Operations

3.2.2.1. Reliability-Centered Maintenance

It shows that these days (full) service contracts become more and more popular.

Full service can be defined as the total bundle of products and services that fully satisfies the needs and wishes of a customer related to the performance of the Stork equipment (van Stratum, 2006).

SFS initiates the reliability-centered maintenance approach in the product development process by drawing up equipment specific maintenance schedules with the help of the software Optimizer+ (Appendix 3.2.). Each month a feedback session with different departments is organized in order to bring reliability-centered maintenance to perfection. Moreover, the company supplements reliability-centered maintenance with continuous modifications and improvements of the equipment. However, currently, the company not yet possesses sufficient resources to accomplish full service.

Preventive Maintenance

SFS defined preventive maintenance as an equipment maintenance strategy that can consist of replacement actions, and the overhauling or remanufacturing of items. The actions are executed at fixed intervals and independent of the condition of the equipment at that time. Therefore preventive maintenance is also referred to as periodic maintenance. The intervals can be expressed in either time-based intervals (a certain period of time), or count-based intervals (a count of tasks) and are based on the failure rate and experiences.

Predictive Maintenance

Predictive maintenance, or condition-based maintenance, is an equipment maintenance strategy that rests on measuring the condition of equipment in order to assess whether it will fail in the near future. As a result, SFS wants to avoid the consequences of by taking instant proper actions. Methods of monitoring the equipment could be inspection, condition monitoring, statistical process control techniques, or monitoring equipment performance. At this moment, the company does inspection with regard to predictive maintenance, and is launching methods concerning condition monitoring, statistical monitoring, and monitoring equipment performance.

Operational Maintenance

Trained operators, working at the firm where the system is installed, perform operational maintenance actions such as cleaning and lubricating components of the system as recommended by SFS. Consequently, operational maintenance actions are often referred to as first-line maintenance. The actions should be executed at fixed intervals expressed in either time-based intervals (a certain period of time), or count-based intervals (a count of tasks).

In order to carry out the listed foreseen maintenance actions, Stork Food System created spare/repair packages. More about this can be found in Section 3.3.2.2. (Availability and Geography: spare/repair packages). Unfortunately, SFS notices that many of the slaughterers choose for reactive instead of proactive maintenance because they see preventive maintenance actions as unnecessary spending whereas the machine is still working. This illustrates the threat of customers that not yet consider total cost of ownership, or especially maintenance and service costs, at the time of an acquisition.

3.2.2.2. Maintenance Actions

At SFS, the field service engineers are trained in order to perform effective and efficient maintenance actions. This is considered to be sufficient. Field service engineers have to report details about each maintenance action but are not actively monitored. However, monitoring maintenance actions can produce relevant information to identify improvable deficiencies.

3.2.3. MTTF: Conclusion

STRENGTHS - Reliability-Centered Maintenance	***WEAKNESSES*** - Too little emphasis on Reliability - Monitoring Maintenance Actions
OPPORTUNITIES - High Availability requirements - Popularity of Full service contracts - Growing focus on TCO - Technological progress	***THREATS*** - Piracy - Cultural and geographic differences - Little focus on TCO

Figure 3.1.: SWOT analysis of Stork Food Systems regarding "MTTF"

Further details about the SWOT-analysis represented in Figure 3.1. are given in Section 3.5.

3.3. MTTS

3.3.1. MTTS during Design

3.3.1.1. Fault Discovery

At SFS, a customer can report a system's failure at all times. Subsequent to such a report, it will be necessary to discover what the exact cause of failure is. At this moment, fault discovery methods are still weakly developed at the company.

Condition Monitoring

SFS is currently active in planning the implementation of condition monitoring techniques, turning technological progress in advantage. A small number of machines are already equipped with monitoring software tools, still, fault discovery and condition monitoring at SFS is especially based on experience and visual inspection.

Part Labels

Currently, SFS does not structurally label all of its parts in order to identify parts. However, parts that are of great relevance because of, for instance, technological issues, and that contribute highly to the functionality of the system will be labeled to limit its downtime in case of a failure occurs. Parts that are not labeled can be identified with the help of manuals and the spare parts book, which can be quite time consuming and harmful for the MTTS.

 # Parts

Simplicity, one of the three main reliability requirements, implies a minimized number of components and interfaces in a system. Because of the reduced amount of parts in a machine, it will be easier to discover where its exact cause of failure is located. But, as mentioned earlier, the designers of SFS do not focus on this condition of simplicity per se.

FMECA-FTA

As discussed before, SFS does not perform any FMECA or FTA. A pity since it seems to contribute to already 2 components of availability, i.e. MTTF and MTTS.

Manipulate Failure Cause

At SFS, a constructor engineer strives to design a machine in such a way that he can determine in beforehand which part fails where exactly, which is definitely a strength regarding the length of the fault discovery process, thus the MTTS.

3.3.2. MTTS during Operations

3.3.2.1. Commercial and Technical Service

SFS is provided with a commercial and technical service department (CTS) which is in charge of the maintenance of SFS' equipment and the sales of spare/repair packages.

Data Availability

SFS uses SAP ERP to gather information from every area of the company. SAP ERP is a business data warehouse and reporting and analysis tool. This database currently provides information about phase and project related labor hours, costs, budget, progress, and so on, and about received orders for machines and spares, overall results, results per cluster, predictions, market trends, clientele, benchmarks, and the rest. All this information is available at any time for all employees involved in the support process. However SAP ERP contains a lot of information, customer specific information is not gathered together in order to create a customer specific service history. As a result, customers have to wait for quite some time until the search for further details is terminated. Obviously this is not good for the MTTS. Luckily SFS is currently fine-tuning its data management.

Business Process Management

Appendix 3.5. gives an idea about the existing maintenance support process of SFS. Every time a customer reports a failure, this process appears. Therefore it is important to organize the process in such a way that the customer can be supported as quickly as possible. At SFS, the customer support process is well arranged. Customers can report a failure to the helpdesk, the branch office, an agency or to a cluster which on its turn organizes the follow-up of the report. Additionally, the company recorded the entire maintenance support process (and more business processes) on paper.

3.3.2.2. Availability and Geography

Field Service Engineers, tools and transportation

SFS values optimal maintenance support as soon as a failure report comes in. To realize quick customer support, the company decided to divide its widespread service area into five clusters. Each one of the five clusters appeals upon a service area manager assisted by several service coordinators (SC) and around 10 specialized field service engineers (FSE). Additionally to the clusters, about 50 offices are located all over the world i.e. about 10 branch offices and 40 agencies (Appendix 3.6.). SFS' branch offices consist of at least one representative of sales and service, an administration department, and in general its own local field service engineers. Agencies mostly pass failure reports immediately to the cluster.

According to the maintenance support process as shown in Appendix 3.5., different scenarios are possible. The first scenario comprehends that the customer reports a failure to the helpdesk which is able to solve the customer's problem right away. In case that the helpdesk is not able to help verbally, the failure report is passed to the cluster responsible for the customer. The second scenario entails that the customer contacts its branch office which is able to solve the problem immediately, verbally or by sending one of its local service engineers. In case that the branch office cannot help the customer right away, the failure report is passed to the cluster responsible for the customer. It is however also possible that the customer instantly chooses to contact the cluster, or comes out at the cluster via its agency. Once the cluster is contacted, the third scenario appears. The cluster is confronted with the failure reports and starts analyzing the exact problem. In some cases, the cluster can solve the problem itself, and sometimes further assistance from other departments is necessary. If in conclusion the customer cannot be supported verbally, the cluster needs to find an obtainable service engineer with the right skills. Besides, the location of the field service engineer at that moment as well determines the speed in which the customer can be helped. Thus, the cluster needs to find an obtainable service engineer with the right skills within the accurate region. If this task seems unfeasible to the cluster, the planning coordinator will be asked to assign an obtainable field service engineer with the right skills.

Cluster	Area
1. BENELUX	BENELUX (Belgium, the Netherlands, and Luxembourg), and Germany
2. France	France, French speaking Africa, Spain, Portugal, Argentine, Chili, Switzerland, and Brazil
3. Far East	Far East (China, Japan, Philippines, India, Thailand, Taiwan, Korea), Australia, New Zealand, and Turkey
4. UK	United Kingdom, Scandinavia, Middle-East , and South-Africa
5. Italy	Italy, Eastern bloc (Poland, Romania, Yugoslavia, Ukraine, …), Russia, and Austria

By means of the five service areas and the offices, SFS attempts to support its customers as quickly as possible taking into account geographical dispersion. Of course it is not possible to immediately help each customer, yet now the process is quickened. Nonetheless, SFS can perform even better if it should have more service engineers available. Especially now the company puts more emphasis on after sales service it should be able to be more flexible with regard to its field service engineers.

Inventory Management

As mentioned before, SFS allocates a code to each service part, indicating the nature of service of that part within a system. By means of this part coding, the company is able to select one or more parts and to create machine specific spare/repair packages (Appendix 3.7.).

- A-parts are consumables that make contact with the product to be processed and have a direct effect on the technological action of the system. A-parts have to endure much and need to be replaced pretty often. Therefore SFS recommends its customers to have such parts on stock themselves.
- B-parts are "breakdown" parts which, if defective, make it difficult or impossible to continue the production. Because of the criticality of B-parts, SFS recommends its customers to also have these parts on stock themselves.
- C-parts are small overhaul parts and are to a great extent subject to wear and tear. D-parts are major overhaul parts and E-parts are condition dependent overhaul parts dealing with wear, which will be added to an overhaul package depending on their condition at the time of inspection. Because these parts do not break down that easily, SFS plans preventive maintenance actions based on the parts' failure rates and makes sure that the essential parts are available to carry out the pro-active overhaul. This means that no such parts are directly available to a service engineer in order to perform corrective maintenance.

In conclusion, the customers are advised to have those parts on stock that endure a lot and can easily cause production downtime. As a result, the field service engineer or customer can immediately fix the failure and reorder new spares/repairs at SFS afterward. Unfortunately, many slaughterers see preventive maintenance actions as unnecessary spending whereas the machine is still working, and do not hold parts on stock. This illustrates the threat of customers that not yet consider TCO.

However, the company also keeps stock on hand. With the help of Slim4, particularly a forecasting and inventory management system, the sales of items are analyzed on a daily basis. Exception reports from Slim4 will help the company to see which items need special attention and input. Consequently, SFS is able to calculate accurate safety stocks based on the service level requirements, to plan its production and control its inventory. If Slim4 calculates that certain service parts are sold more than 5 of the 12 months, its forecasted safety stock will be integrally used for material resource planning. If demand occurs in less than 4 months a year, safety stocks will be calculated manually. Unfortunately, SFS does not immediately take into account the decreasing trend and piracy regarding the safety stock, which can lead to redundant inventory costs. The company does have a workgroup "Piracy" in order to follow certain copying trends of consumables, but the information obtained from that workgroup is not yet considered. Also in times of bad economy, the purchasing department does not immediately change its orders. SFS starts to pull down its inventory of coded parts only after such an item is not sold for quite a while. The inventory of A-parts will be reduced slowly after a period of 1 year without sales, and the inventory of B-parts, C-parts, and D- and E-parts will disappear only after 10 years, 2 years, and 5 years of no consumption respectively. More Details about the adoption of Slim4 can be found in Appendix 3.8.

3.3.3. MTTS: Conclusion

STRENGTHS - Business Process Management - Availability and Geography	***WEAKNESSES*** - Fault discovery - Data Availability
OPPORTUNITIES - Technological progress	***THREATS*** - Widespread service area - Little focus on TCO - Piracy

Figure 3.2.: SWOT analysis of Stork Food Systems regarding "MTTS"

Further details about the SWOT-analysis represented in Figure 3.2. are given in Section 3.5.

3.4. MTTR

3.4.1. MTTR during Design

3.4.1.1. Disassembly

As shown in Appendix 3.4., SFS has defined several requirements regarding maintenance that should be dealt with in the development of a machine. The program of requirements (POR) contains rules about the time of repair actions with regard to A- and B-parts. As a result, designers are obliged to create machines that can be easily or rapidly maintained.

 # Parts

As before, the number of parts that a machine contains refers to simplicity, one of the three main reliability requirements. It was then concluded that the designers of SFS do not focus on this condition as such, a weak spot regarding not only MTTR, but also MTTF and MTTS.

Accessibility

At SFS, each machine is designed with a focus on minimizing its reparation time. The accessibility of parts is without any doubt one of the issues that is considered in this mature design.

Modular Construction

SFS does apply modular construction at the moment, but not with regard to service. A machine is designed in such a way that it is easy to assemble, that it is customer friendly in use, but the time to repair is not yet taken into consideration. This is partly owing to the late intervention of the service department in the product development process. Mostly, service does not interfere before the realization phase of the product development process while the 0-series of the machine is already in existence, and the BOM of a machine is already established.

Standard Parts/Machines

At SFS, too little attention is paid to standard parts. The company did develop a classification tool though. This tool is able to classify parts on technical data and geometric characteristics. The designer can enter specifications of a desirable part and the tool lists similar parts that emerge frequently in existing designs. By means of this classification tool, SFS tries to promote the use of standard parts. On the contrary, standard machines do exist within the company. However, this does not mean that not many different variants are present among the standard machines. This is an inevitable issue. SFS wants to satisfy about 80% of the market with its standard machines. But not all customers that belong to that 80% are the same, partly owing to the geographical and cultural differences. Preferences regarding to bird measures and breads, speed, force, precision, materials, and so on, are present among that group. Next to the different variants of standard machines, each customer is able to add desired specifications to the standard. Note that SFS has to consider customer preferences in the designs of a machine if it is willing to overrule its competitors.

Electrics/Electronics

SFS is used to the adoption of new technologies in order to create better-quality machines. Because technological progress asks for new skills, it is the occasion for longer downtimes in case no such skills are available. The company tries to appoint high educated service engineers with diverse skills and additionally provides first-class trainings. This means that additional investments regarding to education and training of the field service engineers are required towards SFS. Additionally, SFS should find benefit in the popularity of service contracts and actively promote these contracts to decrease the odds that the customer arranges its own repairmen which are not provided with the right skills.

Tools

Obviously, also SFS faces the problem of thousands of different screws, for each part of a machine a different size or form. Therefore, the company should insist on minimizing the number of variants of parts in its designs, referring to part standardization.

3.4.1.2. Maintenance Actions

The requirements with regard to maintenance that should be dealt with in the development of a machine have an effect on the duration and facility of maintenance actions.

Duration

The program of requirements of SFS contains rules about the time of repair actions with regard to its parts. Repairing A-parts should not take more than 15 minutes whereas the time needed to repair B-parts is limited by 30 minutes. This time to repair is minimized because it concerns parts which endure a lot of wear and tear, or which can cause substantial machine downtime. These are also the parts that are recommended to be on stock at the customer's site. With regard to the overhaul parts (C-, D-, and E-parts), the time to perform an overhaul is limited to 12 hours of non-production time. Overhaul parts are those parts needed to carry out preventive maintenance. Such maintenance actions are performed whenever a system is not supposed to operate.

Field Service Engineers

SFS reckons with the fact that maintenance actions are sometimes performed by untrained repairmen appointed by the customer and tries to design its machines bearing in mind easy maintenance. Nonetheless, the field service engineers of SFS itself have to be trained more and more in order to carry out effective and efficient restorations. Unfortunately the communication between the service engineers and the division that writes the trainings is yet not optimal. Additionally, there is just a limited amount of specialized trainers available to give the trainings. Luckily, SFS notices that well trained personnel delivers added value to the company as well as to the customer. And also the customers are becoming aware that skilled personnel contribute to their performance as a result of what they are asking for trainings given by SFS. The popularity of training leads to increasing communication with trainees what on its turn leads to the better organization of instruction sessions.

Manual

SFS starts to write its manuals whenever the prototype of a machine is accepted and the 0-series comes to existence. As a result, manuals sometimes reach the customers too late. For that reason, the company requires writing manuals from the pre-prototype-phase on, which can afterward be developed into user-friendly manuals before the first machines arrive at the customers. Unfortunately, initiating the manual writing that soon seems to be easier said than done.

Manipulation of failure cause

In the design phase, SFS tries to manipulate the exact spot of failure. A constructor engineer strives to design a machine in such a way that he can determine in beforehand which part fails where exactly, at the same time determining the difficulty of maintenance actions, and as a result, the MTTR.

3.4.2. MTTR during Operations

3.4.2.1. Maintenance Actions

Supervision

At SFS, the field service engineers are trained in order to perform effective and efficient maintenance actions. This is considered to be sufficient. Service engineers have to report details about each maintenance action but are not actively monitored. However, supervising field service engineers can reveal relevant information about the execution of maintenance actions. This information can then be used to reduce the time needed to repair.

Repair or Replace, On site or Off site

SFS already investigated whether it is profitable for the company to replace components, and to repair them off site afterward. It is concluded that parts which are relatively cheap, and which do not need special settings, seem appropriate for repair or exchange on site. On site repair or exchange can also be beneficial for slaughterers with numerous lines given that the same components are used in every one of the lines. Central overhauls, referring to off site overhauls at a central repair shop of SFS, seem more appropriate for standard parts that are frequently used in the assembly of machines (Kaymaz, 2008).

3.4.2.2. Spare/repair Packages

SFS allocates a code to each service part, indicating the service character of that part within a system. By means of this part coding, SFS is able to select one or more parts and to create machine specific spare/repair packages (Appendix 3.7.). Five spare/repair packages can be distinguished, namely:

- Start-up kit that contains only A-parts. A-parts are consumables that make contact with the product to be processed and have a direct effect on the technological action of the system.
- Recommended spare kit that consists out of A- and B-parts. B-parts are "breakdown" parts which, if defective, make it difficult or impossible to continue the production.
- Small overhaul kit which includes A-, C-, and if necessary E-parts
- Major overhaul kit with A-, C-, D-, and if necessary E-parts
- Total overhaul kit composed out of A-, C-, D-, and E-parts

The size, suitability and completeness of these spare/repair packages partly contribute to the MTTR.

Size

The size of spare/repair packages of SFS depends on the type of overhaul that is planned. The more extensive the maintenance action, the more parts involved and the more time it will take to restore. Therefore, the management of reliability-centered maintenance is essential. Applicable and effective maintenance tasks need to be well-considered for each item in a system.

Suitability and Completeness

With the machine specifications, the accurate spare/repair kits are put together. The packages are required to be well composed in order to perform efficient and effective maintenance. On the one hand, incomplete packages increase the MTTR, and thus the machine's downtime, dramatically. In case of incompleteness, one has to wait on parts or needs to plan a new visit in order to finish the overhaul. On the other hand, when a spare/repair package is complete but is not corresponding with the specific machine, the same problem occurs. At SFS, modifications relating to customer specific machines are not linked to the original machine specifications. Thus, the current configuration of the machine does not necessarily correspond to the configuration of that machine as registered. If it concerns significant changes, it is rather possible that the spare/repair packages do not fit as required. Fortunately, SFS is busy connecting install-based management with the system that contains the original machine specifications as a result of which the occurrence of non-fitting spare/repair packages will reduce.

3.4.3. MTTR: Conclusion

STRENGTHS - Trained field Service Engineers - Maintenance Requirements in Design	***WEAKNESSES*** - Disassembly and Maintenance ease
OPPORTUNITIES - High Availability requirements - Popularity of Full service contracts	***THREATS*** - Education FSE/repairmen - Technological progress

Figure 3.3.: SWOT analysis of Stork Food Systems regarding "MTTR"

Further details about the SWOT-analysis represented in Figure 3.3. are given in Section 3.5.

3.5. Conclusion

In this Chapter, some strengths and weaknesses, as well as opportunities and threats of SFS regarding "Availability" appear (Appendix 3.9.). The strengths and weaknesses refer to aspects of the company that are helpful or disadvantageous, respectively, to achieve the preferred availability of its equipment. Opportunities and threats, however, concern external conditions that favor or harm, correspondingly, the fulfillment of the customers' availability requirements.

STRENGTHS - Reliability-Centered Maintenance - Business Process Management - Availability and Geography - Trained Field Service Engineers - Maintenance Requirements in Design	***WEAKNESSES*** - Too little emphasis on Reliability - Monitoring Maintenance Actions - Fault discovery - Data Management - Disassembly and Maintenance ease
OPPORTUNITIES - High Availability requirements - Popularity of Full service contracts - Growing focus on TOC - Technological progress	***THREATS*** - Piracy - Education FSE/repairmen - Cultural and geographic differences - Widespread service area - Little focus on TCO - Technological progress

Figure 3.4.: SWOT analysis of Stork Food Systems regarding "Availability"

Figure 3.4. joins together Figure 3.1., 3.2. and 3.3., representing the results of the SWOT-analysis regarding MTTF, MTTS, and MTTR respectively, and shows the current state of SFS regarding "Availability".

Strengths: MTTF: SFS adopts reliability-centered maintenance by drawing up equipment specific maintenance schedules. MTTS: SFS has a well arranged customer support process which is recorded on paper. By means of the five service areas, its offices, and good inventory management, SFS can quickly support its customers. MTTR: SFS' POR contains rules about the time of repair actions. Thus, designers are forced to create easily and rapidly repairable machines. Also well trained field service engineers deliver added value to the company as well as to the customer.

Weaknesses: MTTF: The lack of emphasis on reliability at SFS is definitely a weak spot. The company does no FMECA or FTA, does not track any failure rates, and the designers do not specifically focus on simplicity, clarity and unity. Additionally, SFS should actively monitor maintenance actions in order to identify improvable deficiencies. MTTS: At SFS, fault discovery methods are still weakly developed. Only few of its machines are equipped with condition-monitoring techniques, designers do not focus on simplicity, SFS does not structurally label all of its parts for identification, and no FMECA or FTA is applied. Also the data availability at SFS can be improved by gathering and classifying all information in one database only. MTTR: Throughout the development of SFS' equipment, the ease of maintenance is of minor importance. SFS does not limit its number of parts as a result of which the complexity of a machine increases and parts become difficult to reach. Also little attention is paid to standard parts.

Opportunities: MTTF: It shows that (full) service contracts, an instrument that helps fulfilling availability requirement, become more and more popular because of the growing interest in TCO. An additional opportunity is technological progress, meaningful for e.g. testing. MTTS: SFS can implement existing condition monitoring techniques, turning technological progress in advantage. MTTR: The increasing availability requirements of customers goes hand in hand with the popularity of service contracts which decreases the odds that customers arrange own repairmen not having the right skills.

Threats: MTTF: Many slaughterers see preventive maintenance actions as unnecessary spending. Not yet all customers consider TCO at the time of an acquisition. Another threat is the diversity in customers. SFS wants to satisfy all customers over the world, thus needs to consider styling preferences, cultural differences and dissimilar climates in equipment's design. Finally, companies decided to focus on the production of A-parts and are able to offer those parts at lower costs, making SFS the victim of piracy. MTTS: Because of the geographical dispersion of SFS' customers it is not easy to quickly help each customer. Keeping parts on stock at the customer's site will facilitate the support of the widespread area. However, many slaughterers see preventive maintenance actions as unnecessary spending, and do not hold parts on stock. Not yet all customers consider TCO. Another threat is that of piracy. It is difficult to immediately take into account the decreasing trend and piracy regarding the safety stock, which can lead to redundant inventory costs. MTTR: Technological progress asks for new skills regarding the field service engineers and is therefore the occasion for longer downtimes in case no such skills are available.

It can be concluded that the current state of SFS regarding "Availability" is moderately developed and open to improvement. The company should keep up its strengths taking care of the threatening external conditions, and enhance its weaknesses taking advantage of the opportunities, both being part of DfA.

Chapter 4: "Design for Availability"

4.1. Introduction

In Chapter 1, "Design for Availability" is defined as cost-effectively influencing equipment's availability following its entire lifetime. Availability is a quality attribute that measures equipment's performance, specifically the degree to which a machine is in an operational state at the start of a mission whenever the mission is called for (Blanchard et al., 1995). In Chapter 2, it is explained which elements influence equipment's availability in its development phase or whenever the machine is already in use at the customer. But how should a company organize itself to be capable of constantly improving equipment's availability without losing its performance, referring to DfA as continuous improvement method. In Section 4.2. of this chapter, DfA is compared to the most familiar continuous improvement methodologies. Moreover, this section reveals the critical success factors for implementing continuous improvement methodologies. In Section 4.3. the critical factors for successfully implementing continuous improvement method are applied to DfA.

4.2. Continuous improvement

Continuous improvement (CI) is about improving organizational performance.

DfA symbolizes the constant improvement of equipment's availability as a reaction to the high quality requirements demanded by customers. In the past, many CI methods have already been developed since companies felt forced to advance products, services or processes to stay competitive. The most familiar methodologies are Six Sigma and Lean, based on a basic concept of quality and process improvement respectively. Recently, Six Sigma has been combined with Lean, resulting in a methodology named Lean Sigma (Naslund, 2008; Bhuiyan and Baghel, 2005).

4.2.1. Continuous Improvement Methodologies

4.2.1.1. Lean

Lean strives to make companies more competitive by increasing efficiency, diminishing costs incurred due to elimination of non value-adding steps and inefficiencies in the production process, as well as reducing cycle times and increasing profit for the organization. The methodology is a systematic approach to identifying and eliminating waste in every area including customer relations, product design, supplier networks, and factory management, through CI. Visualizing the production processes helps the company to discover the existence of waste. Waste refers to everything for which the customer is not willing to pay, e.g. overproduction, waiting, wrong processing, excess inventory, and defects. Lean aims to maintain a continuous flow of products in factories in order to flexibly adjust to changes in the demand process. The basis of such a flow is called just-in-time (JIT) production, where, through systematic techniques designed to minimize inventory, quality and productivity are increased, and waste and costs are decreased (Naslund, 2008; Bhuiyan and Baghel, 2005).

4.2.1.2. Six Sigma

Six Sigma is a method of measuring process quality using statistical process control. As a result, it reduces cost by reducing the variability in the processes which leads to decreased defects. By using statistical techniques, organizations can understand fluctuations in the processes which allow them to identify the cause of problems. Long-term benefits are offered to the firm whenever it improves problem processes by eliminating root causes and controls those processes to make sure that defects do not recur. The methodology is based on the DMAIC cycle, i.e. Define opportunities, Measure performance, Analyze opportunities, Improve performance, and Control performance. It includes designing, improving, and monitoring production processes. In brief, Six Sigma is an organized and systematic method for strategic process improvement and new product and service development. The methodology relies on statistical methods and the scientific method to make dramatic reductions in the customer defined defect rates. Whereas the original focus of Six Sigma was on the production process, nowadays it is also accepted in the service and sales processes (Naslund, 2008; Bhuiyan and Baghel, 2005).

4.2.1.3. Lean Sigma

Lean and Six Sigma individually cannot achieve the required improvements at the rate at which Lean Sigma, the combination of Lean and Six Sigma, can. Lean Sigma maximizes shareholders value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed and invested capital. Whereas Lean seeks to eliminate waste, Six Sigma seeks to reduce variation. Lean Sigma incorporates the speed and impact of Lean with the quality and variation control of Six Sigma. Waste is first removed, which then enables variations to be detected more easily. Besides, Lean Sigma addresses important issues that are ignored by Six Sigma and Lean, i.e. the steps in the process that should be dealt with first, the order in which they should be applied and to what extent, and the ways in which significant improvements can be made in terms of cost, quality and lead times (Bhuiyan and Baghel, 2005).

4.2.1.4. Design for Availability

DfA is a method to satisfy customer needs by continuously improving on equipments' availability against minimized costs through the perfection of equipments' quality and business activities over their entire lifecycle. It repeatedly searches for occasions to reduce costs for given availability requirements, or influences availability while minimizing costs. Time after time, new opportunities come to light to improve equipment's availability, and it has to be decided which improvement really is profitable, and which one most. Besides, it is important to consider that the implementation of an improvement eliminates the existence of other improvement opportunities, or creates new improvement potential. It shows that Lean Sigma and DfA share the same main thoughts; however, there is some difference between the two approaches. DfA does not only appeal to the production and operations of equipment, but to its entire lifecycle. This means that DfA aims to improve the product design and development process as well. Further, DfA seeks to eliminate waste and variations with a focus on availability of equipment. Companies that deliver equipment with high availability requirements are suited for DfA. For capital goods manufacturers, for instance, an availability level close to 100% is vital because downtime has a dreadful effect on the primary processes of customers. The narrower downtime possibilities, the higher the revenues towards the customer can be.

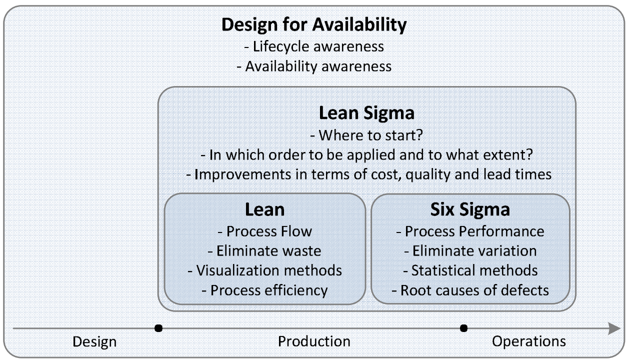


Figure 4.1.: Continuous improvement methodologies

4.2.2. Critical Success Factors for Continuous Improvement

Critical success factors determine the success of an application for the company.

The critical success factors for applying CI methodologies in a company are the following (Jha et al., 1995-1996; Naslund, 2008; Bhuiyan and Baghel, 2005):

Good leadership: Clearly communicate the long-term vision of the company to all employees and its commitment to customer satisfaction. The employees should fully accept and internalize the need for continuous improvement and develop an attitude of involvement and pride in continuous CI activities. It is necessary to make employees aware of their role in CI, and to raise employee capabilities to analyze, measure, and improve processes.

Communication: Collect and evaluate employees' ideas for improvement (elimination of poor quality), use feedback, and gather all relevant information about processes.

Training: Provide additional training to those who need it and enable employees and managers to master CI tools and to establish a basis for future improvement based on analysis of numerical data.

Innovation: Support improvement, encourage individuals to improve their work, but also support all participants involved in a process to co-operate as a team. It is important to encourage creativity and employee involvement.

4.3. "Design for Availability"

Because DfA is a CI method, it requires the recognition of the critical success factors to apply the methodology in an organization.

The base of DfA is full understanding and exploration of "availability". In Chapter 2, an availability framework has been constructed. Yet, it is necessary to constantly search for additional elements that influence the components MTTF, MTTS and MTTR, in its development phase or whenever the machine is already in use, and to further develop this availability framework. Therefore, the company has to announce its emphasis on availability together with a clear description of the term. Besides emphasizing the importance of availability in the company, good leadership also refers to the creation of lifecycle awareness. Involving researchers, designers, field service engineers, the sales department, constructors, and all other parties caught up in a product's lifetime produces a lot of new ideas about influencing and improving equipments' availability.

Additionally, promoting constant communication between all parties involved in the product's lifecycle will contribute to the discovery of improvement potential regarding DfA. Equipment passes through several subsequent phases during its lifecycle, as exposed in Figure 4.2.

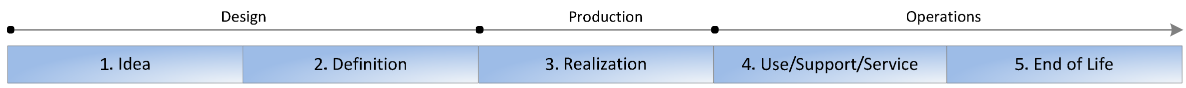


Figure 4.2.: Product Lifecycle

First a new idea pops up in someone's head which needs to be examined for feasibility and requirement fulfillment. This idea needs to be well defined before a physical product becomes visible. A prototype will appear only after the technical design and specifications are complete. This is the first stage of the realization of the product. The realization phase also includes testing and verification of the requirements and documents, and manufacturing of the final product that will be used by the customer. Whenever the product is ready to operate and is sold to a customer, it will need support and service as long as possible. However, there will be a time that the product reaches the end of its lifetime and becomes useless to the customer. This is often referred to as the equipment's disposal phase. Relevant information about influencing equipment's availability can appear because of new designs, the observation of maintenance actions, feedback sessions, equipment modifications at a certain customer, and so on. This data needs to be managed with the intention that it is easily available and in order to avoid redundancy and out of date information. Gathering and managing all relevant knowledge about the company's equipment throughout its entire lifecycle, referring to product lifecycle management, will facilitate the search for improvement potential regarding DfA.

Next, DfA is an eternal story. Because of the changing environment, it will always be possible to find advances regarding DfA. It is therefore clever to describe the process regarding the selection between improvement possibilities, to compose and train a team that takes all decisions, and to develop decision-making tools in order to facilitate the decision-making process. Additionally it is necessary to deal with uncertainty. It is not always possible to predict the exact development cost per machine because this is dependent on the expected sales, and the expected sales are subjected to constantly changing market trends. Also the maintenance and support cost are just estimates. It is not easy to faithfully forecast the number of corrective maintenance actions. In conclusion, the company faces the problem of uncertain information about the outcome of DfA actions. Therefore it is necessary to track and monitor uncertainty so as to be able to cope with the risk associated to DfA.

A final element necessary to make DfA promising to the company is that it should not be afraid for innovation. Innovation refers to fresh approaches to achieve certain targets. In other words, innovation can be a change in market positioning, processes, products and services, or organizational factors such as culture and strategy.

4.4. Conclusion

This Chapter reveals that DfA is a CI methodology, as Lean, Six Sigma and Lean Sigma. Lean Sigma and DfA share the same main thoughts; however, DfA eliminates waste and variations with a focus on availability of equipment and appeals to the entire lifecycle of products, not only to the production and operation processes.

Applying CI methodologies, thus DfA, in a company asks for the recognition of four critical success factors: good leadership, communication, training and innovation. For DfA, these success factors imply the following:

Good leadership: Clearly communicate the importance of the company's emphasis on availability and create lifecycle awareness. Involve all parties caught up in a product's lifetime and search jointly for elements that influence availability.

Communication: Relevant information about influencing equipment's availability can appear because of new designs, the observation of maintenance actions, feedback sessions, equipment modifications at a certain customer, and so on, and this information needs to be well managed.

Training: Because of the changing environment, it will always be possible to find new improvements regarding DfA. Therefore, it is recommended to clearly describe a decision-making process and to guide a team in getting familiar with that process. Additionally, it is necessary to built up skills in tracking and monitoring uncertainty in order to cope with the risk associated to DfA.

Innovation: To make DfA promising to the company, it should not be afraid for change and CI.

	Good Leadership	Communication	Training	Innovation
Lifecycle and Availability Awareness	x			
Product Lifecycle Management		x		
Decision-making and Risk Management			x	
Innovation				x

Chapter 5: SWOT-analysis regarding "Design for Availability"

5.1. Introduction

In the previous chapter, the critical success factors in order to apply DfA have been identified. Accordingly, DfA can be compared to the current situation of SFS as a result of which the actions to be taken by SFS to introduce DfA appear. The history and current situation of SFS will be the subject matter in Section 5.2. and the gap between the company and DfA will be pointed out in Section 5.3. In conclusion, a SWOT-analysis regarding DfA is represented and explained in Section 5.4. of this chapter. The methodology which is used to gather the company specific information, applied for the SWOT-analysis regarding DfA, can be retrieved in Appendix 4.1.

5.2. History and current situation of Stork Food Systems

About 50 years ago, the establishment of SFS was initiated. Obviously, the company went through several phases of change induced by the altering behavior of the environment, i.e. customers, the market, technology, politics, education, employees, and competitors. Figure 5.1. illustrates the strategic history of SFS from 1985 to its current situation.

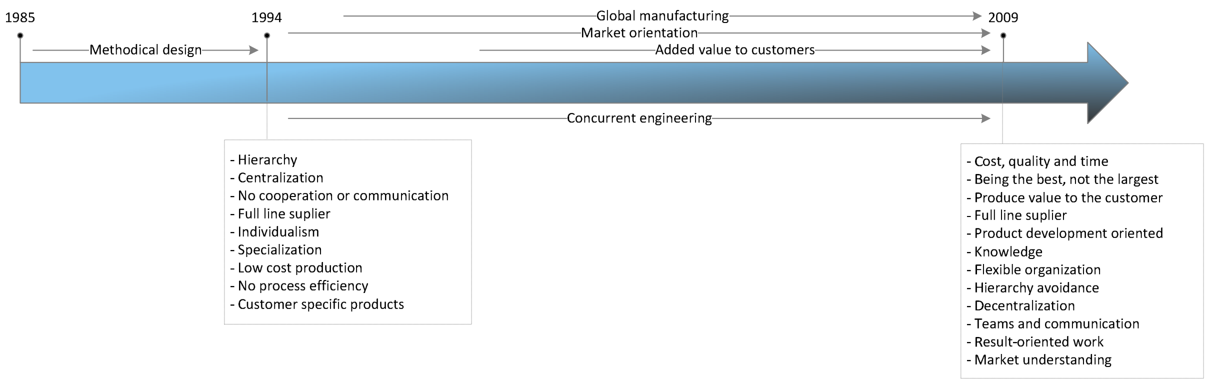


Figure 5.1.: Stork Food Systems Strategy evolution

SFS used to be a functional organization until 1994. A functional organization is characterized by a compartmental mentality. Primary processes do not run smoothly, but rather go through many transfer points in the organization. This functional set-up of SFS created various problems. First of all, processes were not carried out efficiently in terms of time, quality and costs. Next, there seemed to be walls in between the departments. The rigid organizational structure was obviously experienced as being a huge obstacle. Furthermore, there was no responsiveness to the increasing dynamics of the market. The functional organization made it difficult to meet the increasing demand for new products and new production technologies, as well as the new legislation and quality requirements. Finally, there existed scarce possibilities for employees to develop inside of the company.

From the mid 1980's, SFS responded to the difficulties associated to the functional set-up. The company felt that especially the product development process needed restructuring. The process was supported by the idea to meet customers' demand at low cost as quickly as possible, and was built on the question with what resources it was possible to execute such an idea. SFS noticed that this product development process was not carried out efficiently and picked up about the existence of methodical design formulated by Professor Van den Kroonenberg. He defined methodical design as a systematic approach based on answering the right questions on the right moment: first "What is going to be done?", next "How?", and finally "What with?". In this way, three subsequent phases make out the product development process, being the determination of requirements, the description of the procedure, and fixing the resources. Nowadays, this approach of methodical design survives in SFS' well-defined product development process.

Since 1994, SFS really started focusing on the product development process, the beginning of an entire new organization strategy. Important revisions to come to the current modernized organization were increasing market-orientation, global manufacturing, and striving to parallel product development. Accordingly, the competitive advantages of the company have been developed into the delivery of best performing equipment and superior price-quality systems. The most noticeable change was that the company started to operate in a company-wide process-based manner. In contrast to the functional organization, the processes and their relationships are centrally established. As a result, the cooperation between the departments and the employees is far more intense as before. Also the service department became more and more involved in the product development process. In the late 1990's, customers started asking for better performing equipment. As a reaction to this demand and to highlight the importance of added-value to the customer, SFS coded service parts and developed tools to provide customers with maintenance schedules and spare part packages. Thus, knowledge exchange between several departments was essential, and working in multi-disciplinary teams became more and more significant.

Today, SFS obviously values quality, cost and time a lot. The company strives to be market leader and full line supplier by being the best in the poultry and further processing industry, and not by being the largest company. This translates itself in a business culture typical of SFS. In order to produce value to the customer, it is necessary to motivate and inspire each employee and to be open and communicate. In 2002, ten pillars regarding the organization of SFS are developed.

- Trust
- Equivalence
- Openness
- Fun
- Responsibility
- Dynamics
- Knowledge
- Respect
- Commitment
- Freedom

In conclusion, the company wants to be a flexible organization by using an organizational structure that stresses hierarchy avoidance, decentralization of management functions and tasks, shortening the reporting and communication loops, efficient and result-oriented work and continuous improvement.

5.3. Stork Food Systems versus "Design for Availability"

SFS notices that it is of increasing importance to focus on equipment availability improvement. Figure 5.2. shows the current situation of SFS compared to the situation matching DfA which SFS should be able to create within a period of five years. It shows that SFS currently misses several critical success factors in order to successfully apply DfA. In the figure, the missing factors are represented in red.

A first step towards DfA is the creation of lifecycle and availability awareness within the company in addition to the current focus of SFS regarding quality, cost and time. From the moment SFS is fully conscious of the importance of the entire lifecycle of equipment, and not only its product development process, it will be possible to search for more new specific information and knowledge regarding availability. Subsequently, this information needs to be well managed because it is precious to the company to find its way to DfA. Unfortunately, not all information is as reliable as desired as a result of which risk needs to be dealt with carefully. Finally, the organization needs to develop and define a thorough decision-making process in order to be capable of improving on equipment availability.

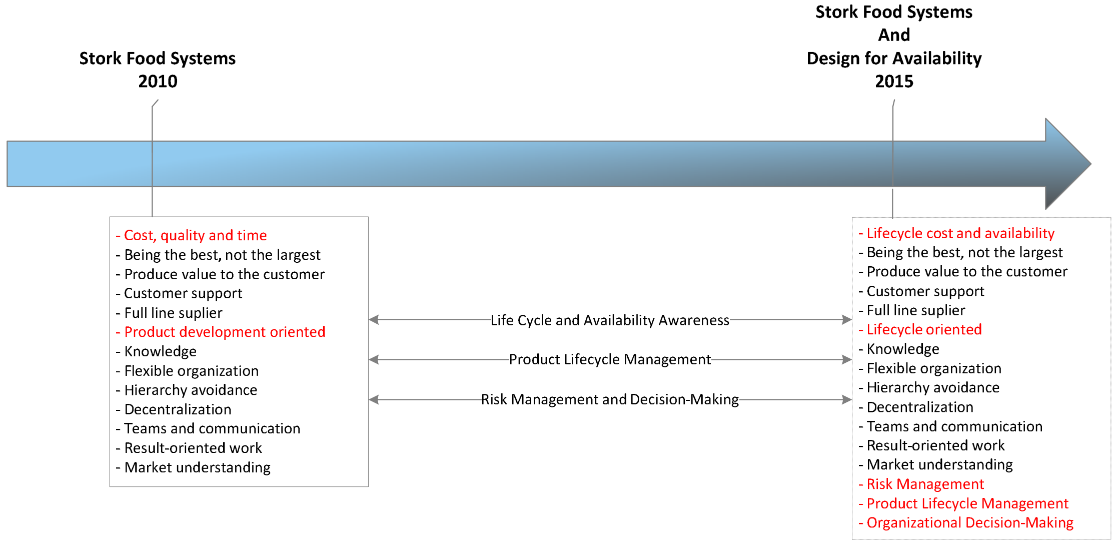


Figure 5.2.: Stork Food Systems to "Design for Availability"

5.3.1. Lifecycle and Availability Awareness

Currently, SFS has well defined its own product development process because of its emphasis on parallel product development in the modernized organization strategy. In the description, the project phases, project activities and milestone-reporting are identified.

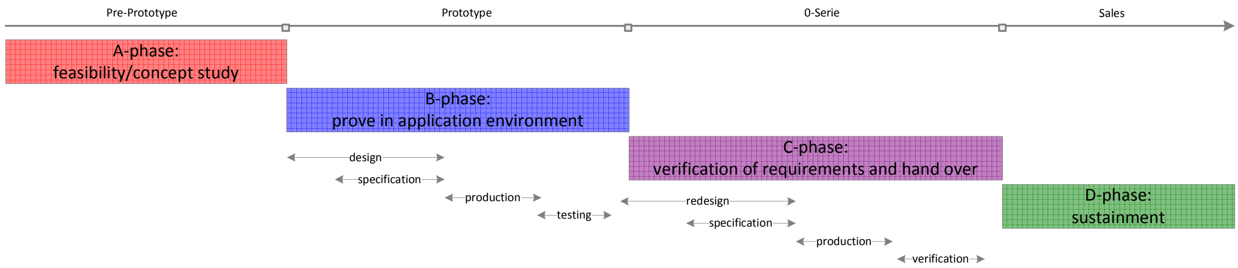


Figure 5.3.: Product Development Process at Stork Food Systems

As shown in Figure 5.3., the process is split up into four main phases, i.e. the A-phase, B-phase, C-phase and D-phase. The A-phase entails the feasibility and concept study of a new project, thus no deliverables are handed in at the end of this phase. The B-phase is the product design phase and involves the design of the product, the description of product specifications, the production of parts and software, and the testing and modification of the prototype. Next there is the C-phase. This phase is about the verification of each one of the requirements. After the C- phase, wherein the 0-series of the machine comes to existence, the product evolves to the last phase, the D-phase. The D-phase is characterized by the sustainment of the product and comes down to the project shut down. This phase is not yet described in details as the other phases while it makes just as much part of the equipment's lifecycle. Information that appears from after sales activities that act upon equipment's availability has to be recognized and gathered by the company. Deliberately defining and communicating each one of the roles in the product's lifecycle provides the basics for efficient co-operation (i.e. team work) and procedures for problem solving (Heemstra et al., 1997).

As illustrated in Figure 5.4., SFS distinguishes 4 primary processes in which it invests all the existing knowledge. First, the purpose of the Offer and Order Process (OOP) is the sale of newly built equipment. This process runs from the initial contact with the client up until the moment that the equipment is delivered and the client receives the transfer-of-ownership protocol. Next, the idea behind the Innovation Process (INNOP) is the development, maintenance, purchase and optimization of SFS' range of products. The final result of this process is incorporated in a standard range of products which is the base for the OOP price list. In a limited number of cases, client-specific solutions can be offered. Third, the principle of the Production Process is to manufacture the products within the planned period of time in compliance with high quality requirements at competitive prices. A broader perspective of production is to support and maintain unique market position and to protect the company's technologically strategic components. Finally, the Spare Parts and Service Process (ODP) is divided into two parts. On the one hand, the process entails the installation and putting into operation of the equipment at the customer. The aim is to deliver a product as specified in the purchase order. On the other hand, the ODP is concerned about spare parts and services. The aim is to supply spare parts and services after delivering the product.

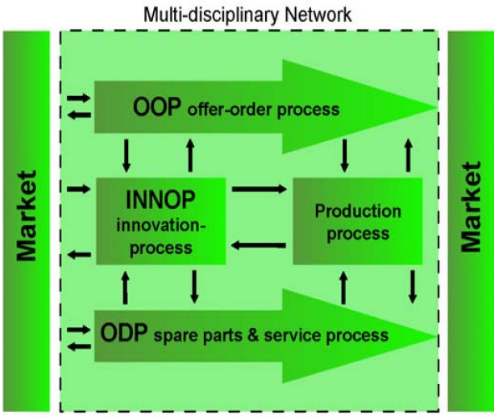


Figure 5.4.: Primary processes at Stork Food Systems

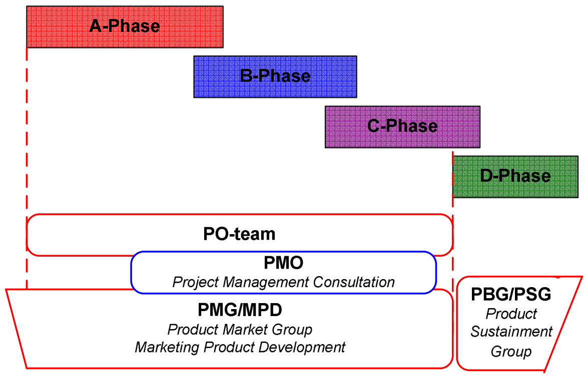


Figure 5.5.: Steering bodies at Stork Food Systems

The four primary processes in the network are connected to each other and carried out on a multi-disciplinary level, characterized by continuous exchange of knowledge among employees. As a result, several steering bodies are established for Innovation and Sustainment activities, i.e. the Product Market Group (PMG), the Product Sustainment Group (PSG) and the Project Management Consultation (PMO) (Figure 5.5.). By utilizing these bodies, SFS wants to formulate an optimal product and market development policy in order to improve its competitive edge. The PMG has a multi-disciplinary set-up including representatives from the management team. Its main task is to initiate, control and manage the innovation policy in terms of Time, Quality and Costs, Information and Organization (TKKIO). Note that for DfA, the stress on Time, Quality and Costs needs to shift to an emphasis on equipment availability and lifecycle cost. Vital input to the PMG comes from R&D, customers and proposals of the PSG. The main task of the PSG is to organize the process for maintaining the standard equipment. This means controlling new versions, standardization of the package of products, cost monitoring on the standard packages, delivering feedback, and proposing the start-ups of new developments. Note that their role comes into existence only just at the C-phase within the product development process, just before the machine is declared free for sale. Lifecycle awareness goes together with the recognition that earlier involvement of these departments is necessary to provide relevant knowledge regarding DfA to the developers of equipment. People need to think about more than one activity at a time. Designers need to think regarding manufacturing, field service engineers need to think about product development, constructor engineers need to consider maintenance, and so on. The final steering body is PMO which has to support the parallel development (PO) team leaders. The PMO has to provide the PMG input questions and feedback. Besides, its task is to discuss the progress reports of the projects, exchange experience and advice in case of bottlenecks such as personnel capacity.

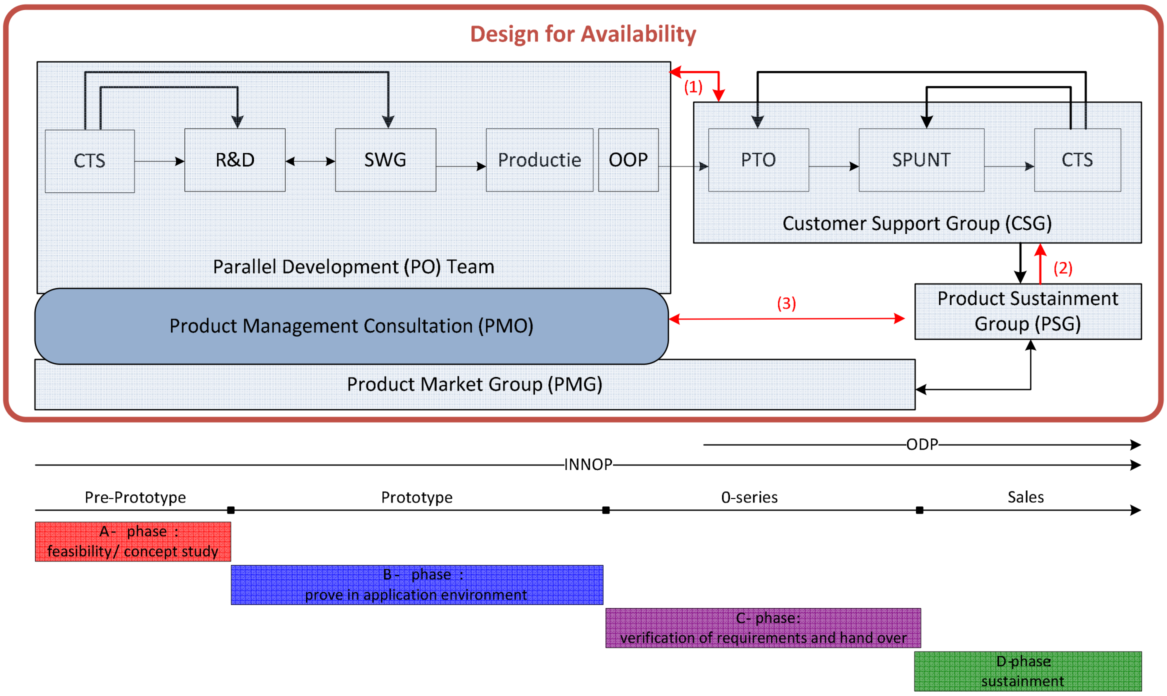


Figure 5.6.: Feedback loop at Stork Food Systems

Figure 5.6. illustrates the primary processes combined with the steering bodies and the existing feedback between departments during the product's life cycle. The Parallel Development (PO) team designs all new machines which SFS launches onto the market. This team is characterized by constant communication between several departments during and after the design process. Whenever this development process is completed, the project design and all relevant documents are transferred to the department SPUNT (Specials, Updates, Follow-Up & Technical developments). Together with PTO and CTS, SPUNT forms another feedback group concerning the support of customers, in this research referred to as the CSG. Problems that occur in the field are reported to PTO and/or SPUNT which try to solve these problems. If substantial changes are required in order to solve field related issues, permission of the PSG is essential. However, if the substantial changes ask for additional funds, permission of the PMG is desired. Lifecycle awareness features superior communication between all the separate groups and the realization of the importance of that communication. Lifecycle awareness, thus good communication, can help the company to improve effectiveness, efficiency and control because it enables the company to capture customer requirements and market trends better, improve the sales process, provide superb support of product use, prevent future product failures through knowledge of past failures, schedule maintenance effectively based on knowledge of the actual use of the product, and very much more (Stark, 2005).

At first sight, no great problems seem to exist at SFS regarding communication. Unfortunately, that is not completely factual. Feedback "within" the existing groups is quite okay, still, it is not always possible to have all relevant departments attended. However, the problem occurs when communication is desired "between" the separate groups. Notable is that CTS is present in two feedback groups, the PO team and the CSG, but the role they play is different in each group. In the PO team, CTS will report difficulties with regard to maintenance actions whereas in the CSG the report is about a failure at a customer which cannot be immediately fixed with a usual maintenance action. Unfortunately, direct communication between the PO team and the CSG or PSG seems not to exist (Figure 5.6., (1) and (3)). Another problem in this feedback loop is that whenever a member of a particular department or feedback group reports observations or disturbances, decisions concerning these matters are not integrally communicated back to this member (Figure 5.6., (2)). For example, a service engineer fixed one and the same part at a certain customer more than three times in a month, while that part should last for more than nine months. He mentions this issue in a meeting among participants of the CSG. The PSG is acquainted with this issue but notices that it does not concern a structural problem and decides not to take actions yet. This decision should be reported back to the field service engineer. Nevertheless this feedback is often disregarded. As a result, the service engineer thinks not to be taken serious and can decide to never report any bizarre observation again. Thus, avoid that groups become self-contained entities by frequent and open communication within and between them (Heemstra et al., 1997).

In conclusion, before it is possible to create relevant knowledge about the equipment's lifecycle, and thus regarding DfA, each member of SFS needs to understand the sense and importance of a product's lifecycle. Therefore, the worth of extending the product development process of the company by describing the D-phase is desired. Additionally, early participation in the product's lifecycle of departments especially occupied with after sales processes is essential for the optimal generation of information regarding availability. A final necessity to create useful knowledge regarding DfA is the stimulation of communication and feedback between each one of the steering groups and departments involved in the equipment's lifecycle.

5.3.2. Product Lifecycle Management

Due to the availability and lifecycle awareness, a lot of ideas to improve on the availability of SFS' equipment will come to light. These ideas create information and data that needs to be managed to avoid an ocean of product data with little meaning and many unknown relationships (Stark, 2005).

Product lifecycle management is a systematic, controlled concept for managing and developing products and product related information (Saaksvuori and Immonen, 2008).

It enables the company to take responsibility for the product and services across the lifecycle. Mastering the lifecycle activities makes it easier to provide reliable products, sell services on them, and even sell services on competitors' products (Stark, 2005).

Today, SFS is already familiar with product lifecycle management. The company owns a PLM-system that manages information from product drawings, product structures, instruction manuals, and so on. The lifecycle of a machine, with the corresponding role of the PLM-system at the company, is defined as follows:

Machine Lifecycle	PLM-system
1. The customer orders a machine at Stork Food Systems	A layout drawing is obtained from PLM and the customer machine number is put into PLM
2. The machine will be specified for that customer	Drawings are created, changed, updated, … and put into PLM
3. Machine development taking into account customer requirements	The machine structure is added to PLM next to the corresponding customer machine number
4. Machine production and assembly	Drawings (also for external suppliers) are obtained from PLM and files for laser or cutting machines made in CAD are managed in PLM
5. Installation of the machine at the customer	Layout drawings and technical data are obtained from PLM

6. Service and maintenance	Spare parts packages and modification kits are put together in PLM and prices and consumption values are added to the system

In brief words, the PLM-system at SFS includes standard parts and standard structures of machines. Standard machine designs can be supplemented with certain specifications by any customer and each special design is added to the system. Subsequently the spare parts package related to the customer specific machine can be drawn up with the help of the software.

Next to the PLM-system, SFS uses the application SAP ERP. SAP ERP is a business data warehouse and reporting and analysis tool. This database currently provides information about phase and project related labor hours, costs, budget, progress, and so on, and about received orders for machines and spares, overall results, results per cluster, predictions, market trends, clientele, benchmarks, and the rest. All this information is available at any time for all employees involved in the support process. Consequently, SAP ERP seems a very important application for SFS in order to manage and develop products and product related information.

Appendix 4.2. illustrates which information can and should be integrated in SAP ERP for effective lifecycle management. It can be seen that the information from the PLM-system at SFS is supposed to be part of SAP ERP (e.g. production management). Unluckily, this is not yet the case. This means that a lot of important lifecycle information is missing in SAP ERP. At SFS, the PLM-system manages a product and its lifecycle including technical data, documents and drawings, and spare part packages and modification kits with regard to service and maintenance, but the system should be connected to information from SAP ERP such as analysis results, test specifications, quality standards, engineering requirements, change orders, manufacturing procedures, product and company performance information, component suppliers, and environmental information about customers, the market and competitors (Saaksvuori and Immonen, 2008). Another problem that occurs at SFS is that information about customer service is not immediately available in SAP ERP. Because after sales customer services are an important part of the product lifecycle, the customer support database is essential to integrate with SAP ERP.

Product lifecycle management is seen as the way to address all the relevant product-related issues during its lifecycle (Stark, 2005). But what exactly is relevant product lifecycle-related data with regard to DfA? On the one hand, information about the product's processes, structure and costs, and about the performance and popularity of the product and processes is required. The performance of the product specifically refers to its availability. Thus, it is necessary to bring up a clear-cut description of what availability exactly means. Additionally the costs need to be associated to the processes in which they occur. As a result it is possible to compose and calculate the costs emerging in a product's lifetime, and to include this in SAP ERP. Therefore it is essential that conformity about the definition of availability and lifecycle exists. Lastly, customer requirements and design guidelines (Program of Requirements) should be integrated in SAP ERP. On the other hand, besides this product specific data, information about customers and suppliers, about the market and the performance of the company in that market, about procedures and values typical of the company, about ideas on improvement potential regarding DfA, and about the success or failure of changes due to DfA should be gathered and managed.

In conclusion, SFS is on its way to product life cycle management, but it needs some enhancement. At this moment, a lot of product specific information can be found in the PLM-system, e.g. layout drawings, machine structures, files for laser or cutting machines, technical data, spare parts packages and modification kits, and more. In addition to this product specific data, SFS possesses a lot of information about change orders, customer calls, project related labor hours, costs, budget, progress, and about predictions, market trends, clientele, benchmarks, and the rest, collected in SAP ERP. However, currently, the PLM-system is not directly linked to this information. As a final point, SAP ERP needs to be complemented with improvement potential regarding DfA, and tools to calculate costs emerging during a product's lifetime, to forecast trends, and to facilitate organizational decision-making. SFS should be aware that PLM is more than product data collection. Product lifecycle management is a fulltime activity involving many departments and a team should be created which is engaged permanently in PLM activities.

5.3.3. Organizational Decision-Making and Risk Management

SFS still needs to describe a decision-making process with regard to DfA.

A first step in the decision-making process is to develop a working procedure for adopting serious judgment to information, data and experience-based knowledge in order to make a fair decision between several improvement occasions. According to Ullman (2006), there are no right decisions. There are only satisfactory decisions, and the goal is to find the best satisfactory decision. Decision-making methods that will help the team to decide are the pro-and-cons analysis, a multi attribute analysis, LCC estimations, a SWOT- analysis, best practices, and so on. More about these methods can be found in Chapter 7 of this report.

A next step is putting together a team which is repeatedly engaged in deciding what change regarding DfA should be put into practice. The team should be fixed, and composed out of stakeholders from different departments and feedback groups of SFS which are involved in the equipment's lifecycle. Looking at Figure 5.7., this implies that the team should consist out of a member from CTS, R&D or SWG (both concerned with product development), production, OOP, PTO, and SPUNT. Besides, an associate from PSG, PMG, PO and CSG should be included in the team. In this way, knowledge from different processes, functions and groups of the company comes together. Also a risk advisor, or someone who is specialized in risk management, should be involved. Note that the more people involved in the decision-making process, the harder it is to manage the different promises, criteria and evaluations (Ullman, 2006). It is advised to limit the size of the team to not more than one member of each department or feedback group to avoid knowledge overload or redundancy, and to keep order during the judgment meeting. In addition to selecting the appropriate people, it is necessary to assign key roles within the team in order to steer the decision-making process in the right direction. It is for instance useful to assign a person in charge of the meeting, timekeepers, motivator, and a meeting facilitator.

Step three of the decision-making process is to inform each member of the team about the objective of DfA and the associated requirements. Besides, the team needs to be informed about the repeatedly occurring procedure of the selection between improvement possibilities, i.e. the decision-making methods, the team composition, and the division of roles. Thus, the entire team has to agree on their participation and on their commitment to the working procedure since tight cooperation will be inevitable. If no such agreement or commitment follows, the decision-making procedure or team composition needs to be reassessed.

Up to now, the taken actions can be seen as a preparation to the actual decision-making. Next, a meeting, which all team members have to attend, should be organized. During this meeting, improvements regarding DfA will be identified and the decision-making procedure will be initiated. At this moment, risk management and the risk advisor becomes relevant. Risk management is a process focused on the attainment of certain goals and to assess and control potential disturbances (Heemstra et al., 1997). Advances in DfA appear by looking at the information gathered by means of product lifecycle management. This can be information about design problems, LCC, machines that break down because of environmental issues, inventory, customer support issues, sales forecasting, experiences of the field engineers, and so on. Founding decisions on such uncertain information brings along quite some risk which needs to be assessed for each improvement area independently. By questioning each one of the team members, the risk advisor can track all the specific sources of risk and their probability of appearance and impact. As a result, improvement potential can also be compared based on the risk they bring about. Besides this risk assessment, the risk advisor, together with the team members, should also control the risk. Once the risk associated to certain improvement opportunities has been identified, a strategy for dealing with that risk should be selected. There are four basic strategies available, being risk avoidance, risk reduction, compensation of risk, and contracting.

Finally, when the improvement is put into practice, it has to be checked whether the risk is properly assessed and whether the actions taken were successful. As a result, an evaluation report can be made which can provide a reference for future decisions (Heemstra et al., 1997).

5.4. Conclusion

In this Chapter, some strengths and weaknesses, as well as opportunities and threats of SFS regarding DfA appeared. The strengths and weaknesses refer to aspects of the company that are helpful or disadvantageous, respectively, to successfully apply DfA. Opportunities and threats, however, concern external conditions that favor or harm, correspondingly, the application of DfA.

The current state of SFS regarding DfA is represented in Figure 5.7.

STRENGTHS - Team work - Focus on quality, cost, and time - Feedback and communication - Decentralization/Hierarchy avoidance - Value to Customers - Continuous Improvement	***WEAKNESSES*** - Focus on Product Development Process - Failing Product Lifecycle Management - No Decision-Making process - Insufficient Risk Management skills
OPPORTUNITIES - Enthusiasm of employees - Employees' willingness to change - IT developments - Development in Decision-making tools - Risk Management expertise	***THREATS*** - Unforeseeable Future - Strong employees' commitment to existing culture

Figure 5.7.: SWOT analysis of Stork Food Systems regarding "Design for Availability"

Strengths: SFS obviously values quality, cost and time a lot. The company notices that it is important to motivate and inspire each employee, and to be open and to communicate, in order to produce value to the customer. The company wants to be flexible by avoiding hierarchy, decentralizing management, shortening the reporting and communication loops, and promoting efficient and result-oriented work in teams. CI is of great importance to SFS.

Weaknesses: SFS has well defined its own product development process, but the D-phase is not yet described in details. Additionally, the role of OOP and the CSG comes into existence only just at the C-phase within the product development process. Lifecycle awareness recognized the early involvement of these departments. Next, it is essential that information from departments involved in equipments' lifecycle is gathered and managed. At SFS, a lot of product specific information can be found in the PLM-system, and a lot of other information is collected in SAP ERP. However, the PLM-system is not linked to SAP ERP. Finally, a decision-making process and risk management skills with regard to DfA are missing at SFS.

Opportunities: Changing the culture of SFS is facilitated whenever employees are enthusiasm and willing to change. Besides, the increasing developments in information technology e.g. new computer programs to collect and manage information, a range of existing decision-making tools proved to be successful, and growing expertise in risk management activities, exist to support the introduction of DfA at the company.

Threats: Advances in DfA appear from data gathered by means of product lifecycle management, often uncertain data. It is not always possible to predict the exact development cost per machine and also the maintenance and support cost are just estimates. Another aspect that threatens the successful application of DfA is that employees are devoted to the current way of doing business and not willing to change.

Chapter 6: Improvement Areas

6.1. Introduction

At this moment, it is concluded in Chapter 3 that the current state of SFS regarding "Availability" is moderately developed but open to improvement. Besides keeping up its strengths regarding equipment's availability, SFS should enhance its weaknesses taking advantage of the opportunities. Weaknesses in the current situation of SFS regarding equipment's availability, and the missing success factors of DfA at the company, lead to improvement areas regarding DfA. In order to make out how availability can be influenced in a cost-effective manner, it is necessary to know which costs are relevant to consider. In Section 6.2., all costs that occur during the equipment's lifetime are identified, resulting in a cost breakdown structure for SFS. Consequently, in Section 6.3., it is possible to discover improvement potential regarding DfA by investigating the cost effects of acting upon availability weaknesses at SFS, and the impact of achieving the critical success factors that belong to DfA.

6.2. Costs

DfA is about cost-effectively influencing equipment's availability during its entire lifetime. This means that it is of great importance to identify all costs that occur during that lifetime.

6.2.1. Lifecycle Cost vs. Total Cost of Ownership

Lifecycle Cost (LCC) and Total Cost of Ownership (TCO) are both important financial measures used to assess total effectiveness of a product and procurement decision-making (Kumar et al., 2006). Because equipment's availability can be influenced in the design phase, but also when the system is already in use, it is necessary to seek after all costs that can emerge during the equipment's lifetime. Consequently, these costs will be dependent on the availability level.

The LCC is related to the product's lifecycle from SFS' point of view. The cost is made up of the design and development cost D, the production and assembly cost P, and the operation, service and maintenance cost M (Basten, 2005).

Because most of the machines of SFS are used until the end of their lifetime, the cost related to the removal of machines at the customer is negligible in comparison with the other costs. Therefore this cost should not be considered regarding DfA.

$$LCC(availability) = D(availability) + P(availability) + M(availability) \qquad (6.1.)$$

TCO is comparable with the LCC but focuses on the new owner of the product. TCO covers all costs related to the acquisition (A), operations, maintenance and support (M) which are borne by the customer (Dinesh et al., 2006).

The acquisition price A is composed out of the design and development cost D, and production and assembly cost P augmented with a profit margin.

$$TCO(availability) = A(availability) + M(availability) \qquad (6.2.)$$

As mentioned before, customers focus more and more on cost of ownership at the time of a purchasing decision. They start asking for guarantees on cost of ownership and performances in the purchase contract of equipment. Figure 6.1. hypothetically shows how TCO can make a contribution to SFS. It shows that the company is given the opportunity to ask more money for their machines than the competitors at the time of procurement, showing the customer that its operation, service and maintenance cost are minimalistic. Thus, SFS can keep up with the TCO of its competitors by creating machines against higher design and development cost, and production and assembly cost if necessary, but against minimalistic operation, service and maintenance cost.

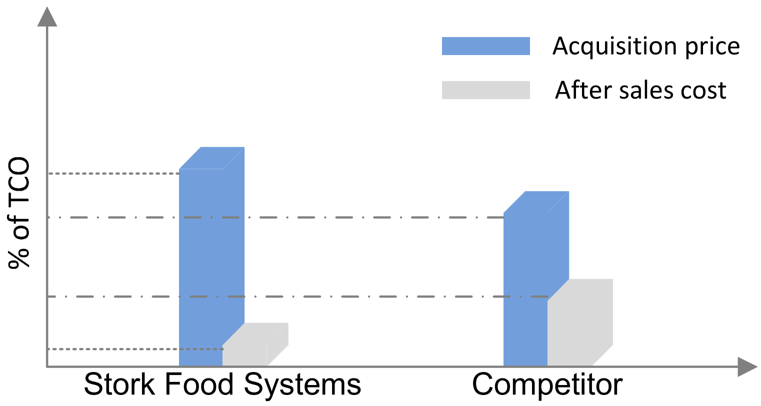


Figure 6.1.: Hypothetical contribution of TCO to Stork Food Systems

The issue is that not yet all of the customers take into consideration the after sales costs at the time of procurement. In that case a customer will opt for the machine with the lowest acquisition price, not yet considering the operation, service and maintenance costs. This is especially the case in times of bad economy. For example the existence of poultry diseases in the beginning of the 21st century and the current credit crisis make customers of SFS to decide to keep its cash.

Whereas TCO can be useful as a selling instrument, LCC will be more appropriate to asses DfA because this research especially focuses on the product's lifecycle from the company's point of view.

6.2.2. Lifecycle Cost Breakdown Structure

Because the LCC takes a central role in DfA, it is essential to identify all costs that need to be considered and where in the product's life span these costs emerge.

As before, the LCC is related to the product's lifecycle from SFS' point of view, and is made up of the design and development cost, the production and assembly cost, and the operation, service and maintenance cost. The design and development cost, and the production and assembly cost emerge in the three first phases of the product development process. These phases specifically indicate the design of a machine, and the production at whatever time the machine is accepted. Note that the production and assembly cost can be calculated and assigned to one machine in particular. The design and development cost however, has to be divided over the expected sales of the machines for which the design and development contributes. This brings along uncertainty regarding the calculation of the LCC, because the expected sales depend on frequently changing market trends. To deal with this uncertainty, Stork Food System is advised to put quite some emphasis on the management of the demand forecasting process.

Besides the design and development cost, and the production and assembly cost, a lot of attention needs to be paid to the operation, service and maintenance cost. This cost occurs in the last phase, namely the D-phase or sustainment phase of the product development process. The operation cost contains the costs related to the main resources required for operating the machine such as energy, ingredients and manpower, and fixed company costs regarding to the procurement and operation of the machine such as the required space to place the machine, depreciation costs, trainings, taxes, insurances, permits, and interest. The service cost covers the sales related cost, costs associated with the customer support process such as machine downtime due to customer assistance, the installation cost and the costs related to the availability and transportation of field service engineers and spare and repair parts. This leaves the maintenance cost, denoting the costs related to the maintenance actions such as labor hours, tools, training required to perform a certain overhaul, the consumption of spares and repairs and the downtime caused by maintenance.

Currently, details of the design and development cost, and the production and assembly cost are already drawn together at SFS. Unfortunately, estimations of the operation, service and maintenance cost are still missing since they are related to the customer use and not yet considered relevant for the company. Further in this Section, a lifecycle cost breakdown structure will be drawn up for SFS.

Design and Development cost
This cost element includes the wages of personnel involved in the research and development of machines, and costs of material to built the (pre-)prototype.

Production and Assembly cost
At SFS, the production and assembly cost of a machine is better known as the L+M cost, referring to the wage and material cost with regard to the machine's production. The wages includes the wages regarding the production department, temporary workers, and other departments involved in the production of the machine. Besides, this cost includes the costs of tools, depreciations, costs of maintenance, and electricity. The material cost to produce a machine is determined by the net material elevated by a wage percentage.

Operation, Service and Maintenance cost
In the past, SFS oriented itself regarding TCO and drew up a list of operation, service and maintenance costs that should be taken into account. Unfortunately, this list is actually never used until now. For DfA the overview is a great starting point to draw up the LCC for SFS, yet needs to be reviewed. The revised list of costs associated to the operation, service and maintenance cost can be found in Appendix 5.1. Crossed-off items are deleted from the original list whereas italic items are added. Important to know is that all costs on the list are available for the company, although not always as easy to retrieve.

Operation cost
The second hand value and depreciation of machines is deleted from the original list because, as said earlier, most machines of SFS are used until the end of their lifetime. For that reason, the cost related to their disposal is negligible in comparison to the other costs. Interest is also left out of consideration in this study because SFS has no control on this cost element. The same stands for taxes, insurances and permits. After that, training of operators is added to the fixed operating cost and has replaced the availability of (skilled) labor as variable operating cost. This cost element is taken into account because SFS can control the complexity of its machines, thus can influence costs related to the education of the operators of the machine. The other operating costs related to the space that a machine captures, utilities, cleaning actions, yield, ingredient consumption and manpower all seem to be significant costs that SFS can act upon. But bear in mind that the difficulty lies in the determination of the variable operating costs because these depend on customer related variables such as environment, usage and politics.

Service cost
In the directory of operation, service and maintenance costs, SFS left the entire service cost out of thought. For DfA, the customer support process and especially the time related to this process is very important. That is why service cost elements are added to the list, such as sales related costs, costs associated with the customer support process, downtime cost due to customer assistance, the

installation cost and the costs caused by the availability and transportation of field service engineers and spare and repair parts.

<u>Maintenance cost</u>

Besides consumable part consumption, spare part consumption, and labor cost, the training of field service engineers, supervision or monitoring, and downtime, cause considerable costs that Stork Food System is able to influence. Thus, the maintenance cost is expanded with these costs.

The final result of the lifecycle cost breakdown structure is illustrated in Figure 6.2. More details about exact cost estimations will be discussed in Chapter 7 of this report.

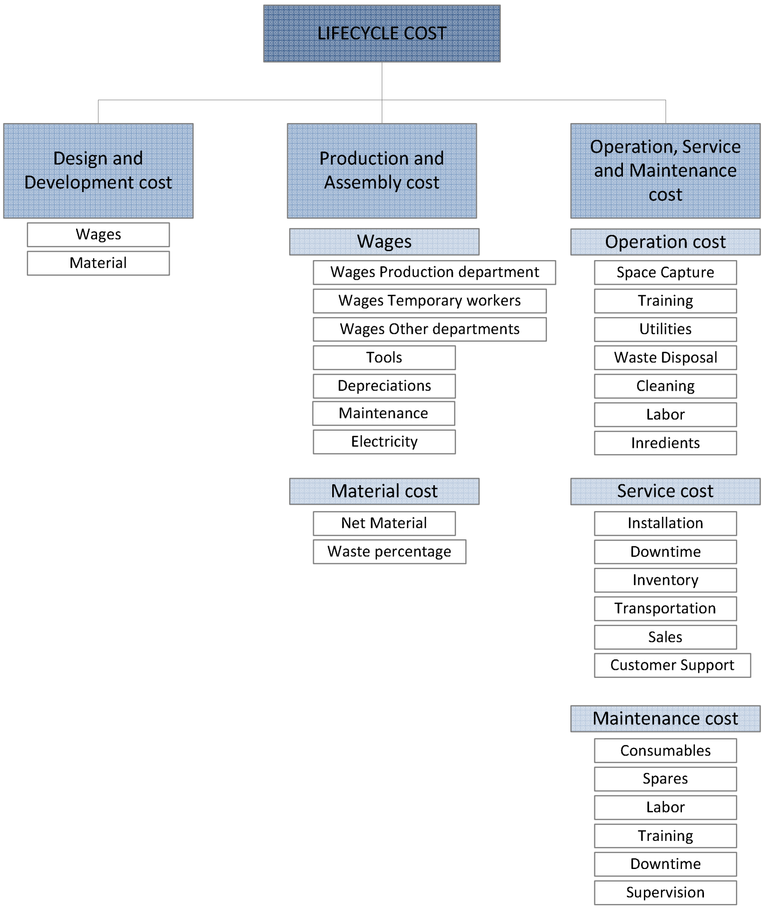


Figure 6.2: Lifecycle Cost Breakdown Structure

6.3. Identification of Improvement Potential at Stork Food Systems

SFS guarantees 99,9% availability of their machines assuming that they operate in double shifts, thus 16 hours per day, for 255 days per year. Part of DfA is to determine whether these levels of availability are required by the market. If the market does not yet require such elevated equipment availability, SFS should not yet offer it. Obviously, changing the availability level as a response to the market will influence the LCC, and give SFS the opportunity to perform better. However, the most relevant improvement scenario for Stork Food System seems to be the decrease in costs at the selected availability level of 99% regarding lines, and 99,9% regarding separate machines. Thus, it should be investigated whether changing and optimizing the current approach of SFS regarding the availability components will suggest LCC reduction possibilities.

Using the results from the SWOT-analyses regarding availability, in Chapter 3, and the critical success factors of DfA, in Chapter 5, it is possible to discover improvement potential by investigating the cost effects of acting upon availability weaknesses at SFS, and the impact of achieving the critical success factors that belong to DfA. Noticeable improvement opportunities are illustrated in Figure 6.3. In the list, the weaknesses of both SWOT-analyses are opposed to the improvement potential they entail.

WEAKNESSES "Availability"	IMPROVEMENT "Availability"
- Too little emphasis on Reliability	- Condition Monitoring, Failure Rates
- Monitoring Maintenance Actions	- Control Maintenance Actions
- Fault discovery	- Condition Monitoring, Failure Rates
- Data Management	- Perfect product lifecycle management
- Disassembly and Maintenance ease	- Lifecycle and Availability Awareness
WEAKNESSES "Design for Availability"	**IMPROVEMENT "Design for Availability"**
- Focus on Product Development Process	- Create Lifecycle and Availability Awareness
- Failing Product Lifecycle Management	- Perfect product lifecycle management
- No Decision-Making process	- Create Decision-Making process
- Insufficient Risk Management skills	- Grow into Risk Management

Figure 6.3.: Improvement opportunities regarding "Availability" and "Design for Availability"

6.3.1. Condition-Monitoring

Condition-monitoring needs not to be an expensive matter. Adding simple software to the machines can make the fault discovery process a lot easier and faster. It is even possible to use condition monitoring tools as testing device to increase the reliability of a machine, or as a tool to predict upcoming failures or collect information on failure rates. The additional design and development cost in order to implement condition monitoring is determined by the software acquisition or development price which is once-only and which can be divided over the expected sales amount of one or more machine types. However, the L+M cost per machine, specifically the material costs, will also increase by the implementation of the software in each machine. Whenever the decrease in operation, maintenance and support cost is higher than the increase of development and production costs, it will be worthwhile to implement condition monitoring. As a result, condition-monitoring has great improvement potential regarding DfA but to take away any doubt, detailed calculations of the LCC are desired.

6.3.2. Failure Rates

Currently SFS does not actively track machines' failure rate. Failure rates can be estimated by collecting historical data about mean time to machine and component failures, by condition monitoring, or by consulting existing failure rate databases outside the company. The costs related to these actions are composed by extra labor hours and R&D efforts to search for and manage relevant information, and maybe by the purchasing price of a failure rate database or condition monitoring software. However, these costs are once-only and can be divided over the expected sales of more than one machine type. Keeping up with failure rates contributes to the appearance of several improvement opportunities regarding DfA:

a. From the moment that data on failure rates is maintained, FMECA and FTA become a lot more feasible. FMECA and FTA are both design techniques in order to identify where certain breakdowns can occur. The cost associated to the use of FMECA and FTA is determined by an investment in software, but such software is already available at the company (Appendix 3.2.: Optimizer +). FMECA and FTA give the designers the opportunity to better aim at the reliability requirements and to lower the after sales costs. Additionally, both techniques can contribute to the fault detection process. Because FMECA and FTA can be used for existing, as well as future systems of Stork Food System, the extra costs are negligible in comparison to the revenues from quicker support and improved product reliability.

b. Being acquainted with failure rates, it will be easier to set up desired preventive maintenance schemes. On the one hand, it is possible that at the moment too many preventive maintenance actions are carried out. If this is the case, it is obvious that less maintenance actions will reduce the LCC. Also the costs related to keeping up with failure rates are obviously negligible compared to the potential cost reduction. On the other hand, performing more preventive maintenance can result in reduced downtime situations at the customer. Moreover, preventive maintenance can be done in the 8 hours that the system is not active. The cost will be reduced at least with the downtime cost because of customer support or corrective maintenance, and with the labor costs associated to corrective maintenance which is mostly about the same as those of preventive maintenance. Also the probability of additional damage has shrunk. However, the spare part consumption will grow and the hours going to preventive maintenance will rise, unfortunately both increasing the LCC. In conclusion, further calculations are necessary to prove whether performing more preventive maintenance actions really comes under improvement area.

Also the use of better materials and buy parts will reduce its failure rate, thus increase the reliability and MTTF of a machine. Additionally, the possibility for downtime situations at the customer is reduced, which involves falling support and maintenance costs. The increase in the design and development cost is negligible and limited to the hours needed to search for better material. The production cost will go up or down dependent on the cost price of the new material. Thus, increasing the reliability of systems could be improving the current LCC but this needs to be confirmed by means of more detailed calculations.

6.3.3. Control Maintenance Actions

At this moment, SFS does not control any maintenance actions. However, carrying out maintenance actions as prescribed is necessary to attain the original availability level. If the machine at the customer keeps performing at the original availability level of 99,9% instead of degrading to a level of for instance 98% because of bad maintenance, the annual returns for the customer will not decrease over time. Monitoring maintenance actions is one of the options that will help the company to discover causes of bad maintenance. Sending trained field engineers to carry out maintenance actions is another option. SFS already sells service contracts that guarantee better performance and added-value to the customer because of good maintenance. Recommended is to lay more emphasis on the “selling” part by for instance the use of tools that show the customers what improvements are possible. For a matter of fact, such a tool is already available at the company. As long as SFS asks more money for the service contracts than the extra costs for material and personnel, and less money than the gains regarding the customer, a win-win situation appears. A last suggestion to uphold the equipment’s availability level of 99,9% is the training of clientele in order to assure that they can handle the system as prescribed. Again, tools can be created and used in order to persuade the customer of the added value of such trainings. As a result, SFS can sell the instruction sessions, and create a win-win situation by asking more cash for trainings than the extra expenses for material and personnel, and fewer than the added-value to the customer.

6.3.4. Perfect product lifecycle management

SFS faces some troubles with its current databases. SFS uses SAP ERP, a business data warehouse and reporting and analysis tool, in order to gather information about the install based configuration. This database provides information about phase and project related labor hours, costs, budget, progress, and so on, and about received orders for machines and spares, overall results, results per cluster, predictions, market trends, clientele, benchmarks, and the rest. The issue is that customer specific information in SAP is not gathered together in order to create a customer specific service history. As a result, it is possible to reduce the time that customers have to wait until they are supported. Also linking the PLM-system, which manages product specific information, to SAP ERP contributes to the reduction in support and maintenance time. At the moment, the commercial service is not informed by the current machine configuration at the customer, and it is possible that incomplete and not suitable spare/repair packages are send to the customer. Optimizing the current databases of SFS asks for extra labor hours, but huge savings can be made with regard to customer support (and satisfaction) and maintenance efficiency.

6.3.5. Create Lifecycle and Availability Awareness

Creating lifecycle awareness within the company will contribute to the communication between departments and feedback groups and will only cost many efforts, but not definitely extra cash. The more communication, the more understanding, and thus the more information available to search for improvement potential regarding "DfA'. However it is necessary that the employees of the company are aware of what availability exactly means. Combined with the suggestion of improving the company's database, lifecycle awareness actually becomes of a lot extra significance.

6.3.6. Create Decision-Making Process

DfA is an infinite course of action. Because of the changing environment, it will always be possible to find advances regarding DfA. Thus, it constantly needs to be decided which advance is (most) worthwhile to put into practice. It follows that it is necessary to describe a procedure regarding the selection between improvement possibilities, to compose a team that takes all decisions, and to develop tools in order to facilitate the decision-making process. Creating an appropriate decision-making process will cost the company time and efforts, but not necessarily money, whereas it is vital for DfA.

6.3.7. Grow into Risk Management

Advances in DfA appear by looking at the information gathered by means of product lifecycle management. However, product lifecycle management includes a lot of uncertain information, such as cost estimates, demand prognoses and upcoming trends, and founding decisions on such uncertain information brings along quite some risk which needs to be assessed for each improvement area independently. A skilled risk advisor is required to track all the specific sources of risk and their probability of appearance and impact, thus the company needs to hire such a risk advisor. Besides risk assessment, the decision-making team, including the risk advisor, should decide on how to control risk which will take time and efforts but not necessarily money. Without risk assessment and control, SFS stakes the success of DfA and the company's performance.

6.4. Conclusion

It is shown that the SWOT-analyses of "Availability" and DfA regarding SFS, combined with a LCC breakdown structure, contribute to the appearance of improvement opportunities. This indicates the importance of being acquainted with availability and the life cycle cost elements, i.e. the design and development cost, the production and assembly cost, and the operation, service and maintenance cost. To perpetually find improvement opportunities on the topic of DfA, it is necessary to proceed in extending the availability framework, and to keep on gathering and managing product lifecycle information. DfA is an eternal problem solving process which continuously requires new information about SFS' machines lifecycles. Constant communication between all departments of the company will definitely contribute to the appearance of new improvement potential.

Chapter 7: Decision-Making Methods

7.1. Introduction

In Chapter 6, several occasions to improve the performance of SFS came into sight by using the results from the SWOT-analyses regarding “Availability” and DfA, and the LCC breakdown structure related to the machines. Subsequently it has to be decided which improvement really is profitable, and which one most. It is not easy to make decisions based on uncertain observations. To compare and implement improvements regarding DfA it is necessary to develop a working procedure for adopting serious judgment to information, data and experience-based knowledge. According to Ullman (2006), there are no right decisions. There are only satisfactory decisions, and the goal is to find the best satisfactory decision. Therefore, this Chapter provides a range of decision-making methods that can help the team to make fair decisions regarding DfA.

7.2. Decision-Making Methods

7.2.1. Lifecycle Costing

One of the main objectives of DfA is to minimize the LCC keeping up with a specified availability level. Thus, a potential improvement induces a reduction in the LCC.

Lifecycle costing consists of the process of evaluating system design configurations from an economic perspective (Blanchard et al., 1995).

The process related to lifecycle costing is illustrated in Figure 7.1.

Figure 7.1.: Lifecycle Costing process

In Chapter 6, the LCC breakdown structure is drawn up and discussed into more detail. Based on obtainable information at SFS, it is possible to estimate the design and development cost, the production and assembly cost, and the operation, service and maintenance cost. Note that these cost estimation needs to address discounting, inflation and learning curves (Blanchard et al., 1995). Time is valuable, and therefore all future expenses need to be adjusted to the present value. Discounting refers to the application of a selected interest rate to a cost stream such that each future cost is adjusted to the point when the decision is made. Additionally, costs need to be estimated for each year and inflated to cover similar activities in future years of the lifecycle. The translation of a future expense into an equivalent present value can be expressed by $P = F\left[1/\left[1+\left(r-i\right)\right]^{n}\right]$ (7.1.) with P the present value, F the cost incurred at a future point in time, r the annual interest rate, i the inflation rate, and n the relevant interest period. Finally, learning and experience are the cause of reduced costs in the future. Just think about the increase in maintenance performance because actions are carried out time after time resulting in a decrease of material, labor and downtime costs.

Information about where which cost occurs, obtainable from SAP, help to uncover the design and development cost, the production and assembly cost, and the operation, service and maintenance cost. Consequently, SFS can calculate the LCC of its equipment and of the improvement opportunities regarding DfA, using the cost estimates as input to the LCC model. After comparing these LCCs, it will become clear which improvement area leads to the greatest LCC reduction and could be most appropriate to put into practice first.

Estimation of design and development cost and production and assembly cost

Currently, details of the design and development cost, and the production and assembly cost are already drawn together at SFS in SAP ERP. The estimates are based on direct estimation of the costs by examining the equipment development and manufacturing process, or are drawn on past data from other equipment with similar size, technology, design and production characteristics.

Estimation of operating cost

It is difficult to calculate the precise operating costs regarding specific customers because SFS has clients all over the world and therefore faces the problem of diverse cost prices. Luckily, the exact cost prices of training, utilities, wages, and the rest, are not really essential to the company. It is the required amount of these cost-inducing elements which needs to be taken into consideration for DfA. Consequently, SFS can estimate the operating cost by maintaining fixed values for the prices and relate them to the cost-generating variables.

Estimation of service cost

There is sufficient information to estimate the service cost obtainable at SFS, but still needs to be gathered. The financial department has data about the installation cost and the sales cost. Furthermore, it is possible to estimate the customer support labor cost by tracking the average duration of a customer support activity combined with the possibility that something goes wrong unexpectedly. Next, the inventory and transportation cost can be calculated based on information about spare and repair packages, available in the PLM-system, and at the service department of the company. Finally, the cost caused by machine downtime due to customer assistance, DTC_{MTTS}, can be determined by equation 7.2.:

$$DTC_{MTTS} = \left[\left(P_0 - P_{rp} \right) + \left(R_0 - R_{rp} \right) \right] \cdot \left[MTTS \right] \tag{7.2.}$$

with MTTS expressed in hours, and P_0 denoting the original hourly productivity of the machine/line, P_{rp} the average reduced machine/line productivity, R_0 the normal revenues/hour, and R_{rp} the reduced revenues/hour. $\left(P_0 - P_{rp} \right)$ and $\left(R_0 - R_{rp} \right)$ denote the labor cost and the lost revenues, respectively.

Estimation of maintenance cost

Data on the costs of consumables, consumption of spares and repairs, and of training related costs is available at the financial department and service department of SFS. The average downtime cost caused by maintenance actions, DTC_{MTTR}, can be estimated as follows:

$$DTC_{MTTR} = \left[\left(P_0 - P_{rp} \right) + \left(R_0 - R_{rp} \right) \right] \cdot \left[MTTR \right] \tag{7.3.}$$

with MTTR expressed in hours, and P_0 denoting the original hourly productivity of the machine/line, P_{rp} the average reduced machine/line productivity, R_0 the revenues/hour, and R_{rp} the average reduced revenues/hour. $\left(P_0 - P_{rp} \right)$ and $\left(R_0 - R_{rp} \right)$ denote the labor cost and the lost revenues, respectively. Finally, the maintenance labor cost can be valued by estimating the average duration of a maintenance activity, based on historical data, combined with scheduled maintenance and the possibility that something goes wrong unexpectedly.

7.2.2. Pros and Cons

A simple list of pros and cons of each one of the improvement opportunities makes qualitative comparison feasible. The pros describe the benefits associated to an improvement area whereas the cons refer to its disadvantages. Brainstorm sessions can be very useful to identify many good and bad elements of improvement potential. Eventually, the idea is that the option for which the pros exceed the weaknesses in amount or significance is chosen as the best improvement. The problem is that whenever each member of the team individually draws up a list of pros and cons, it will be difficult to come to terms about what pros or cons are important to consider and what side exceeds to other. Stakeholders represent many different viewpoints, areas of expertise, and organization functions, and therefore consider different aspects as being important (Ullman, 2006).

7.2.3. Multi-Criteria analysis

If an improvement area looks good on some, but not all criteria, estimating the LCC would tend to hide contrasting patterns of results, whereas multi-criteria analysis can report this finding in easily understood terms. Multi-criteria analysis accepts and builds upon this multidimensional set of objectives (Ackerman, 2008). In order to compare improvement potential based on more than only the LCC, the problem can be decomposed into a set of separate smaller problems, the so-called divide and conquers principle. Weights are then assigned to these sub-objectives to reflect their importance in the decision and the best option is identified as the one achieving the highest weighted average score (Hodgkinson and Starbuck, 2008). Thus, besides minimizing LCC, other important objectives regarding DfA need to be identified. In Chapter 2 is shown that availability elements can influence the MTTF, MTTR and MTTS, in the design phase of a product or whenever the machine is already in use at the customer. Differentiation between the effect of improvement changes on MTTR, MTTF or MTTS could therefore be significant. Next, depending on the situation of the company, it is possible that it is worth more to influence the development of the equipment instead of making changes in the use-phase of the equipment. After that, in Chapter 6 it is illustrated that calculating failure rates brings into sight new improvement opportunities. New improvement potential that arises with the implementation of another improvement change can therefore be relevant to consider. Finally, other important objectives could be the contribution of the improvements to the customer satisfaction, or the employees' satisfaction, and the ability and duration of introducing the improvement opportunity.

7.2.4. Risk Assessment

Obviously, adjusting one of the components of availability will have an influence on the LCC. Some of these adjustments will be easy to value, but unfortunately, most changes result in more uncertain LCC calculations and outcomes because of imprecise lifecycle data and modeling. Founding decisions on such uncertain information brings along quite some risk which needs to be assessed for each improvement area independently. Note that completely eliminating risks keeps on being impossible. But by questioning each one of the decision-making team members, specific sources of risk and their probability of appearance and impact can be tracked, as a result of what it becomes easier to manage risk. First, all risk sources that seem to be of importance need to be identified and listed so that the same aspects of risk will be evaluated for every area of improvement by each respondent. This activity should be part of the risk management. Examples of risk sources are the complexity of the design changes (long execution period, too many efforts, or increasing probability of production faults), changing behavior of the environment which threatens forecasting accuracy (TCO awareness, customer use of equipment, popularity of vegetarianism, chicken diseases, trust of suppliers, changes in the competitions behavior, or economic crises), loss of equipment functionality (loss of yield or capacity), jeopardizing safety and hygienic standards, problems with data, disagreement among the decision-making team members, and experiences from the past. Next, both the probability and impact of risk sources can be assessed based on predefined scales. The company is free to decide which scale to use, as long as it is clear of meaning and easy to apply by the decision-making team. An often used scale is for instance a Likert scale, or five point scale (Heemstra et al., 1997). In this case, the scale can take the following form:

Impact evaluation score	Probability evaluation score
1. Very low impact	1. Very low probability (0 - 20%)
2. Low impact	2. Low impact/probability (20 - 40%)
3. Moderate impact	3. Moderate probability (40 - 60%)
4. High impact	4. High probability (60 - 80%)
5. Very high impact	5. Very high probability (80 - 100%)

Based on the evaluation scores of the risk source impact and probability, it becomes possible to weight or rate the significance of the risk associated to an improvement area. Suppose a respondent answers a certain risk source to be very low of impact and arising with moderate probability. This respondent gives the risk source a score 1*3 = 3. Obviously, each respondent can have a different opinion on the importance of that specific risk source. As a result, the final score associated to that risk source will be the average of all scores. Additionally, an improvement can be subjected to several sources of risk, one being of more significance than another. The final score associated to the improvement area will therefore be determined by the weighted sum of all final scores of the individual risk sources.

In conclusion, it shows that opportunities can be compared to each other based on the risk they bring about. Obviously, based on this decision-making method, it will be the improvement potential with the least risk that will be favored to put into practice.

7.3. Conclusion

It is not as straightforward as it seems to decide on which improvement area should be put into practice first. Many decision-making methods exist to help and support decision-makers in order to choose the best improvement. Yet, it is possible that the improvement with the greatest decrease in LCC can additionally generates little new improvement potential, long and complex implementation and no extra customer or employee satisfaction. It seems that besides LCC reduction, there are other important qualitative elements to consider in the decision associated to the implementation of improvement potential regarding DfA such as risk, new arising improvement opportunities, and the rest (Hodgkinson and Starbuck, 2008). It is therefore recommended to complement lifecycle costing with other tools to succeed in organizational decision-making. SFS is advised to select those decision-making methods they think are useful for DfA and to incorporate them in the decision-making procedure. The entire team has to agree on their commitment to this selection. As a result, the team has the time to get familiar with the chosen decision-making methods and will be ready to apply them when the decision meetings will be initiated.

Chapter 8: Conclusion and Recommendations

This master thesis specifies the development of a DfA concept for SFS. DfA, being concerned with cost-effectively influencing availability of equipment, is explained thoroughly and completed with details about improvement potential and decision-making methods. Throughout the research, a case study is performed at SFS. This Chapter describes the most important conclusions and recommendations related to this project.

8.1. Conclusions

- In the literature, much can be read about "Design for Reliability", "Design for Maintainability", "Design for Serviceability", and more. However, a definition for "Design for Availability" still seemed to be missing. According to Blanchard et al. (1995), "Design for X" is about the development of a system that fulfills appointed requirements in a cost effective manner. Accordingly, in this research, "Design for Availability" is defined as cost-effectively influencing equipment's availability following its entire lifetime.
- The first step to find an answer to the main research question was to understand and explore availability as extensively as possible. Therefore, an availability framework is constructed, based on the definition of availability, composed of the MTTF, MTTR and MTTS. The framework contains subjects that can affect the availability, or MTTF, MTTR and MTTS, during the development of equipment, or whenever the machine is already in use at the customer.
- The availability framework is used to assess the current situation of SFS regarding the availability components, indicating the weaknesses and strengths, and opportunities and threats of the company regarding its equipments' availability.
- In order to continuously act upon availability without losing competitive advantage, the idea behind DfA, the company will have to know how it should organize itself. Therefore, the critical success factors that belong to DfA are defined in this project.
- In this research, the presence of the critical success factors to apply DfA is examined at SFS. Right now it seems that SFS is on its way to DfA, however, some changes are necessary.

8.2. Recommendations

- SFS is advised to constantly search for elements that influence equipment's availability in its development phase or whenever the machine is already in use at the customer. It is necessary for the company to further develop the availability framework. Therefore, the company has to announce its emphasis on availability together with a clear description of the term.
- It is concluded that some changes are necessary at SFS in order to successfully apply DfA.
    - At this moment, the company already promotes constant communication between several departments and feedback groups. However, creating lifecycle awareness, thus involving researchers, designers, field service engineers, sales, constructors, and all other parties caught up in a product's lifetime is required for DfA.
    - The company needs to recognize the importance of information coming from all parties involved in the life cycle of equipment. This data needs to be managed with the intention that it is easily available and in order to avoid redundancy and out of

date information. It is also needed to identify all costs, i.e. its development, design and production cost, as well as its operations, maintenance and support cost, and to establish the assumptions on which cost calculations are made. If all the costs and assumptions are identified, they can be used as an input to decisions regarding DfA.

- Because of the changing environment, it will always be possible to find new opportunities regarding DfA. It is therefore recommended to describe the process regarding the selection between improvement possibilities, to compose a team that takes all decisions regarding DfA, and to develop tools in order to facilitate the decision-making process.
- Advances in DfA appear by looking at the information gathered by means of product lifecycle management. However, product lifecycle management includes a lot of uncertain information, such as cost estimates, demand prognoses and upcoming trends. Founding decisions on such uncertain information brings along quite some risk which needs to be assessed for each improvement area independently. Without risk management, SFS stakes the success of DfA and the company’s performance.

References

Ackerman, F. (2008), *Critique of Cost-Benefit Analysis, and alternative Approaches to Decision-Making,* Tufts University, Medford.

Basten, R. (2006), *Design for Life Cycle Cost: Literature Study, PhD Literature Study*, University of Twente, Twente.

Bhuiyan, N. and Baghel, A. (2005), *An overview of continuous improvement: from the past to the present*, Management Decision, Vol. 43 No. 5, pp. 761-771.

Blanchard, B.S. and Verma, D. and Peterson, E.L. (1995), *Maintainability: A Key to Effective Serviceability and Maintenance Management*, John Wiley & Sons, NY.

Farrah, J., Felix, R., Greenstein, J., de Haan, E.H., Levin, M., Matsumoto, E., Rosen, J.B., Sappington, C., Schwarting, R.H. and Warren, D. (2001), *Best Practices Reports: Strategic Planning*, the Foundation for Community Association Research.

Heemstra, F.J., Kusters, R.J., Nijhuis, R., and van Rijn, Th.M.J. (1997), *Dealing with risk: beyond gut feeling: an approach to risk management in software engineering*, Eindhoven University of Technology, the Netherlands.

Hodgkinson, G.P. and Starbuck, W.H. (2008), *The Oxford Handbook of Organizational Decision Making*, Oxford University Press inc., NY.

Huang, G.Q. (1996), *Design for X: Concurrent Engineering Imperatives*, Chapman & Hall.

Jha, S., Noori, H., and Michela, J.L. (1995-1996), *The dynamics of continuous improvement: Aligning organizational attributes and activities for quality and productivity*, International Journal of Quality Science, Vol. 1 No. 1, pp. 19-47.

Katsioloudes, M.I. (2006), *Strategic Management: Global Cultural perspectives for Profit and Non-Profit Organizations*, Elsevier Inc.

Kaymaz, O. (2008), *Redesign of maintenance practices by line replaceable units: Application on an original equipment manufacturer*, MSc Thesis, Eindhoven University of Technology, Eindhoven.

Kumar, D.U. and Crocker, J. and Knezevic, J. and El-Haram, M. (2000), *Reliability, Maintenance and Logistic Support: A Life Cycle Approach*, Kluwer Academic Publishers, Calcutta.

Kumar, D.U., Crocker, J., Chitra, T., and Saranga, H. (2006), *Reliability and Six Sigma*, Springer.

Lindholm, A. and Suomala, P. (2004), *The Possibilities of Life Cycle Costing in Outsourcing Decision Making*, Frontiers of E-Business Research.

Naslund, D. (2008), *Lean, six sigma and lean sigma: fads or real process improvement methods?*, Business Process Management Journal, Vol. 14 No. 3, pp. 269-287.

Saaksvuori, A. and Immonen, A. (2008), *Product Lifecycle Management*, Springer-Verlag Berlin Heidelberg.

Stark, J. (2005), *Product Lifecycle Management: 21st Century Paradigm for Product Realisation*, Springer-Verlag London Limited.

Stratum, M.E.L. van (2006), *The Design of a Performance Measurement Model Based on Service Level Agreements*, MSc Thesis, Eindhoven University of Technology, Eindhoven.

Thompson, G. (1999), *Improving Maintainability and Reliability through Design*, Professional Engineering Publishing Limited, London and Bury St Edmunds, UK.

Ullman, D.G. (2006), *Making Robust Decisions: Decision Management for Technical, Business, & Service Team,* Trafford Publishing.

Abbreviations

A-parts:	Consumables
A-phase:	First phase of the product development process of SFS
B-parts:	Breakdown parts
B-phase:	Second phase of the product development process of SFS
BOM:	Bill Of Materials
CI:	Continuous Improvement
C-parts:	Small Overhaul parts
C-phase:	Third phase of the product development process of SFS
CSG:	Customer Support Group, including members of the department PTO, SPUNT and CTS.
CTS:	Commercial and Technical Service department
DMAIC:	Define, Measure, Analyze, Improve and Control
D-parts:	Major Overhaul parts
D-phase:	Last phase of the product development process of SFS
DfA:	Design for Availability
E-parts:	Condition-dependent Overhaul parts
FMECA:	Failure Mode, Effect, and Criticality Analysis
FSE:	Field Service Engineer
FTA:	Fault Tree Analysis
IBM:	Install-Based Management
INNOP:	Innovation Process
JIT:	Just-in-Time
LCC:	Lifecycle Cost
MTTF:	Mean Time To Failure
MTTR:	Mean Time To Repair
MTTS:	Mean Time To Support
ODP:	Spare Parts and Service Process
OOP:	Offer and Order Process
PLM-system:	Computer software that manages information from standard product drawings, structures, instruction manuals, and so on.
PMG:	Product Market Group
PMO:	Project Management Consultation Group

PO-team:	Parallel Development team, including members from the departments CTS, R&D, SWG, production and Sales.
POR:	Program Of Requirements
PTO:	Product, Technology and Development department
PSG:	Product Sustainment Group
R&D:	Research and Development department
SAP-ERP:	A business data warehouse and reporting and analysis tool.
SC:	Service Coordinator
SFS:	Stork Food Systems
SG-CTS:	Structural Group of Commercial and Technical Service department
SPUNT:	Specials, Updates, Follow-Up and Technical development department
SWG:	Development department
SWOT-analysis:	Strengths, Weaknesses, Opportunities and Threats analysis
TCO:	Total Cost of Ownership
TKKIO:	Time, Quality, Cost, Information and Organization

Appendices

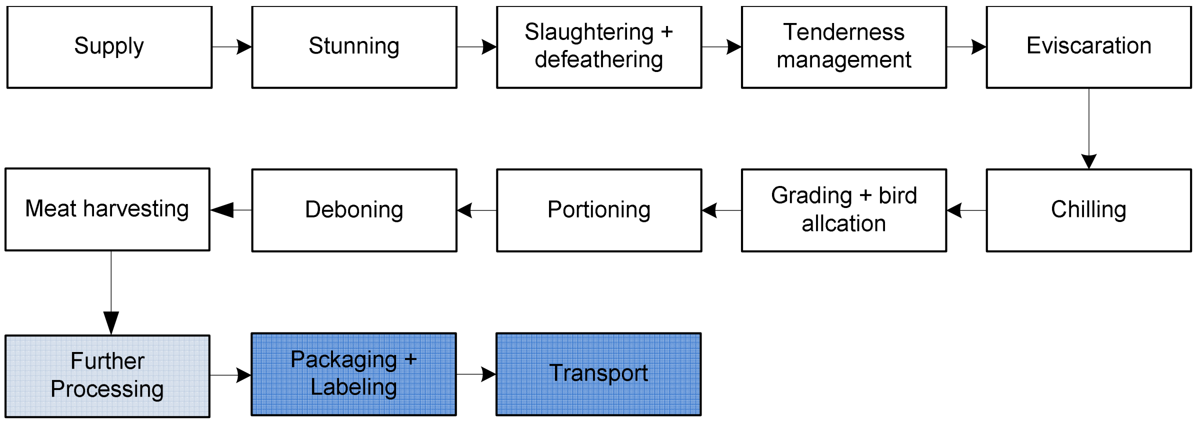
Appendix 1: Research Assignment

Appendix 1.1.: Poultry, fresh meat and further processing

Appendix 1.1.1.: Poultry Processing

Poultry processing can be characterized by line production. Birds are suspended on shackles on a chain that crosses a specific line. Each line consists of a number of machines that perform operations on the birds. However, it is sometimes possible that a bird does not require each operation of a line. In that case, machines that perform such redundant operations can easily be elapsed by the birds.

The complete poultry processing process can be divided into a number of sub-processes, each consisting of one or more modules.

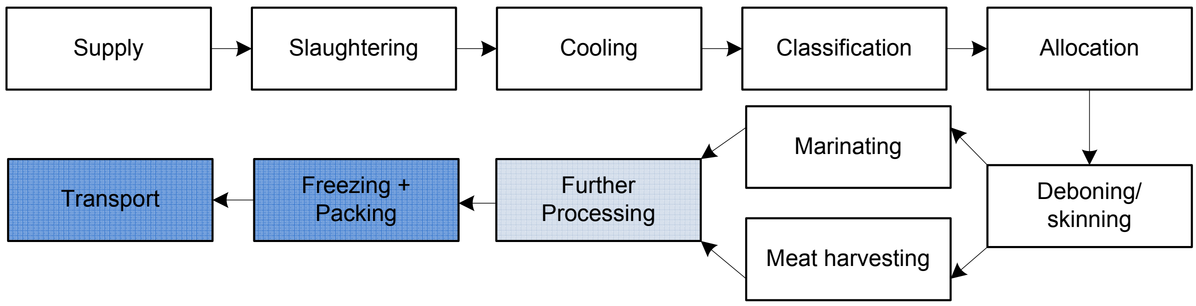


Birds arrive at the factory in crates or containers. They are shackled manually and the crates or containers are cleaned. Then, the birds are stunned and their necks are cut. The birds bleed and are scalded, and the feathers are plucked. After that they are re-hung on different shackles. The intestines are separated from the carcass, also called the evisceration process, and transferred to a separate pack shackle, ready to get processed. After the processing, veterinary inspection of the organs takes place to detect illnesses. Subsequently, birds and organs can be chilled, birds can be weighted, and the quality of birds is graded. Based on weight and quality ratings, the birds are allocated to different parts of the process through which the yield of each individual bird can be optimized. In the end of the poultry processing process, the birds are cut into portions, and bones are removed to get bird breast and leg meat for sale or further processing. If necessary, tissue left on the bones is recovered by the process of meat harvesting.

At each slaughterhouse, the composition can be different. Each production step can be automated or conducted manually and the customer has a choice in how far to process the birds. The birds can be sold in one piece or birds can be separated into different parts that are sold separately. The performance of the process is determined by parameters like line speed, measured in birds per hour or in shackles per hour, and temperature. For maintenance, parameters such as production hours per week and type of cleaning are important.

Appendix 1.1.2.: Fresh Meat Processing

At first sight, the process of fresh meat processing resembles the line production of poultry processing. Before the real meat processing, the animals are slaughtered, cooled, classified and allocated. After that, the animals are skinned and deboned, and the processing will be characterized by batch processing. Subsequently to the deboning, just before the further processing or sales, the meat is marinated (seasoned) or the tissue left on bones is recovered by the process of meat harvesting. At the moment, SFS only delivers machines for the production steps following on the allocation of classified of pieces of meat.

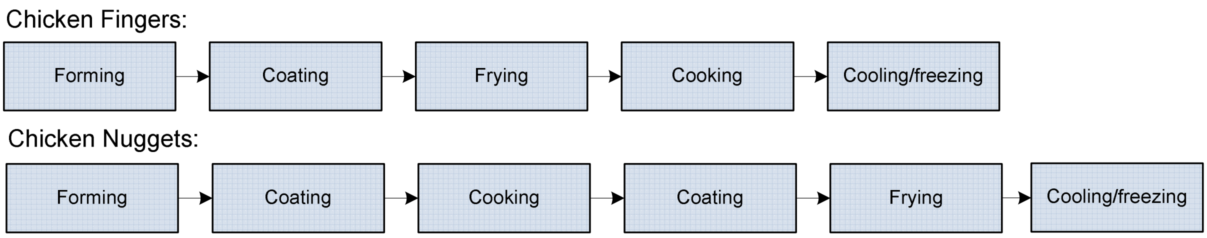


Also for fresh meat processing, the structure of the process can be diverse at each slaughterer. Production steps can be automated or conducted manually and the customer has a choice in what part of the animal is desired to be used. The performance of fresh meat processing is appointed by parameters like capacity, and yield. For maintenance, parameters such as production hours per week and type of cleaning are important.

Appendix 1.1.3.: Further Processing

Further processing uses poultry, meat, fish or potatoes as ingredient of snacks, meal components and convenience food. The ingredients can be pasted or cut into bits of meat. Different from poultry processing, further processing can be characterized by batch production. Consequently, transportation usually takes place on transportation belts.

Further processing factories usually have flexible layouts and can be adjusted to the product that is processed.

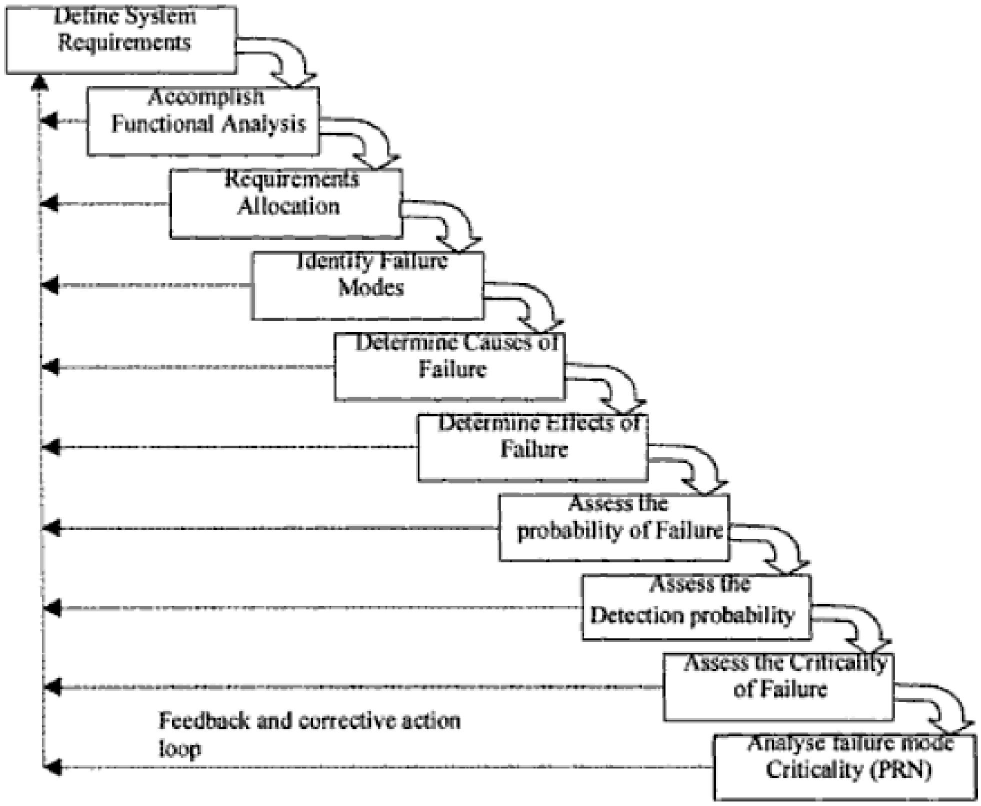


In the forming process, meat, fish or potatoes are formed into a specific shape. This is usually done in batches with specific characteristics. At the end of the forming, the shaped product is placed on transportation belts. The coating process entails that an outside layer, marinate or seasoning is applied to either a formed product or to a piece of poultry. This can take place in-line in a poultry processing process, or on transportation belts. Finally, before a product is cooled or frozen, the shaped products or pieces of meat are fried in oil, or the product is cooked in an oven.

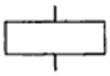
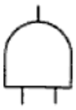
Because the equipment contains few parts that wear, process adjustments and fine-tuning of the process are of great importance and even more essential than the maintenance of the equipment. The speed of further processing is usually measured in kilograms per hour and is determined by the individual machines. The quality of the end product is mainly determined by the mix of input materials like seasoning and marinades and by temperature.

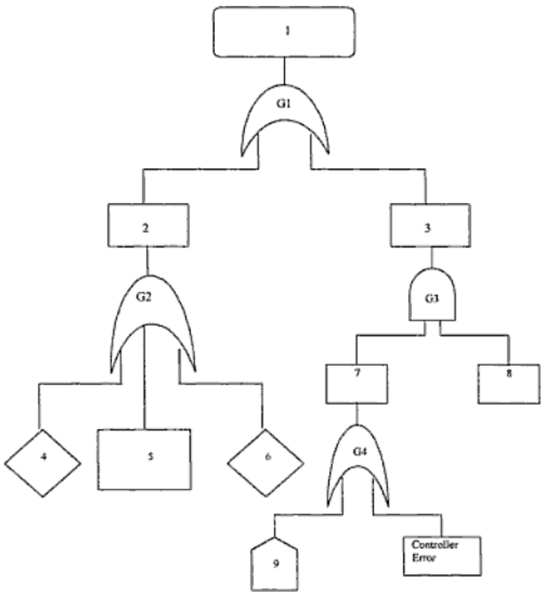
Appendix 2: Availability

Appendix 2.1.: FMECA and FTA



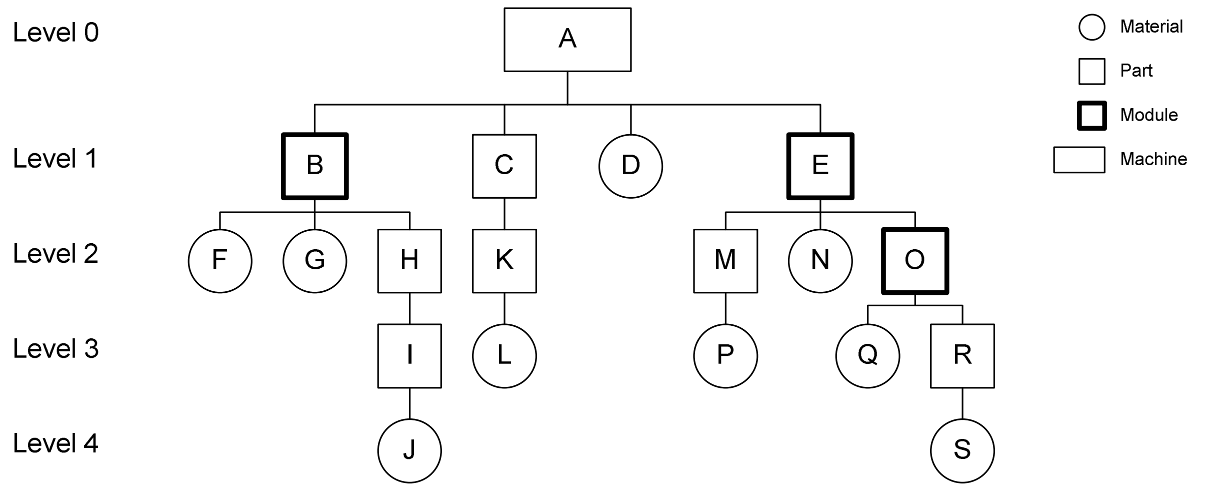
Sequence of Steps involved in FMECA (source: Kumar et al., 2000)

Symbol	Description
	The Ellipse represents the top-level event (thus always appears at the very top of the fault tree).
	The rectangle represents an intermediate fault event. A rectangle can appear anywhere in a fault tree except at the lowest level in the hierarchy.
	A circle represents the lowest level failure event, also called a basic event.
	The diamond represents an undeveloped event, which can be further broken. Very often, undeveloped events have a substantial amount of complexity below and can be analysed through a separate fault tree.
	This symbol represents the AND logic gate. In this case, the output is realised only after all the associated inputs have been received.
	This symbol represents the OR logic gate. In this case, any one or more of the inputs need to be received for the output to be realised.



Legend of FTA and example (source: Kumar et al., 2000)

Appendix 2.2.: Bill of Material



Appendix 3: SWOT-analysis regarding Availability

Appendix 3.1.: Methodology to gather company-specific information

Most of the data used to explore and explain the availability components comes from specified literature. Yet, it is possible that the exploration is modified later on. These modifications are than based on information coming from the first set of interviews with employees of SFS which were originally organized to gather company details concerning availability. The first set of interviews was person to person, taking about one hour, and the setting of the meeting can be best described as being informal and interactive. The table below shows the date and subject of the meetings, and the name and occupation of the respondent.

Date	Subject	Respondent	Occupation
November 28, 2008	Product Development Process	Bert Teurlinx	Senior Product Specialist
November 28, 2008	PLM	Steef Laurijs Jan Melssen Bart Weerts	Structural Group Service members
November 28, 2008	Product Development Process and Manuals	Arendien Vrieling	Coach Technical Information
December 9, 2008	Reliability-centered Maintenance	Marco Vos	Coach Structural Group Service
December 19, 2009	Reliability an POR	Ruud Deckers	Coach Mechanical Design Engineering
December 20, 2009	Customer Support Process and Installed-Based Management	Steef Laurijs	Structural Group Service members
January 16, 2009	Feedback and Communication	Gerrit den Bok	Service Manager
January 23, 2009	Service Area Managers and Customer Support Process	Marcel Linders	Service Coordinator
February 3, 2009	Product Development Process, Reliability and POR	Wim Beeftink	Engineering and Development Manager
February 4, 2009	Assembly and TCO	Erik Peters	Coach Innovation Engineering
-	Spare Parts' Inventory Management	Joep Croonen	Structural Group Service member
February 16, 2009	Validate Information	Gerrit den Bok	Service Manager

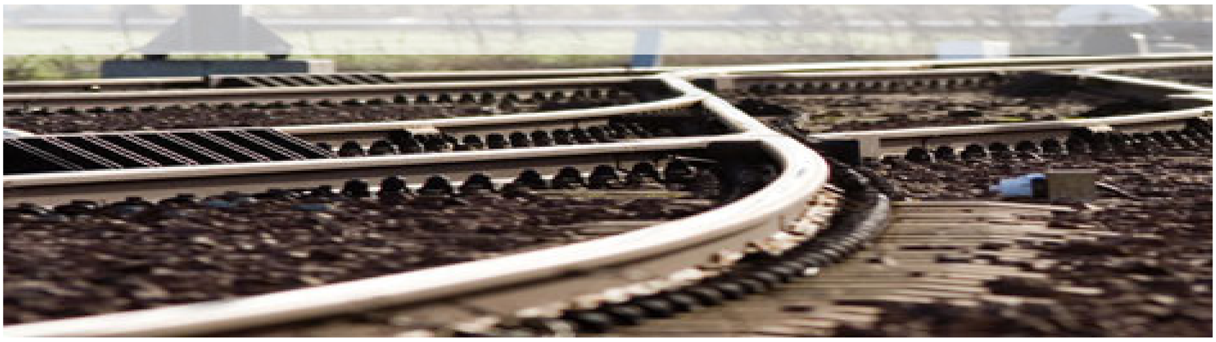
For each interviewee, more or less the same process of meeting is obeyed. First, general information about the purpose of this research was given to the respondent. Next, the specific subject of the meeting, covering one or more components of availability, was explained into more details, followed by a discussion about this subject. During the interview, little predetermined questions were asked as the intention was to discover the interviewee's familiarity and experience with the subject. The discussion was mainly carried on by the interest and critical attitude of the researcher, constantly causing questions towards the respondent about what was just told. Valuable information is recorded constantly throughout the meeting. Finally, the rounding up of each interview was initiated by a review of the listed records, and the question whether any further information needed to be added to the list. Note that the information obtained from these interviews contributed to the exploratory research but is not necessarily of scientific nature. For that reason, each bit of information is subjected to verification by Gerrit den Bok, a member of SFS' management team, and Jan Melssen, Senior Business Consultant, and only then written down in this research.

Subsequently to the first set of interviews, a second set was organized in order to clarify ambiguity in company details. The table below shows the date and subject of the meetings, and the name and occupation of each respondent.

Date	Subject	Respondent	Occupation
April 9, 2009	POR and suppliers	Ruud Deckers	Coach Mechanical Design Engineering
April 9, 2009	Customer Support Process	Bert Schippers JP Raaijmakers	Service Area Managers
April 14, 2009	Trainings	Jan Knijnenburg	Technical Trainer
April 14, 2009	Spare/repair packages and Reliability-centered maintenance	Steef Laurijs	Structural Group Service members
April 21, 2009	Testing and Manipulating failure causes	Erik Peters	Coach Innovation Engineering
April 22, 2009	Condition-monitoring and POR	Wim Beeftink	Engineering and Development Manager
April 27, 2009	Validate Information	Gerrit den Bok	Service Manager

Again, the interviews were held person to person, taking about 30 minutes to one hour, and the setting was informal and interactive. On every occasion, the interviewing process was comparable. First, the specific subject of the meeting was announced to the interviewee. Next, predetermined questions were asked as the intention was to ask for clarification of knowledge gained from the first set of interviews. Helpful facts are recorded actively throughout the meeting. The rounding up of the meeting was initiated by a review of the listed records, and ended with the question whether any further information needed to be added to the list. Finally, the data written down in this research was verified by Gerrit den Bok and Jan Melssen.

Appendix 3.2.: Optimizer+



Optimizer+ is the primary tool of every maintenance & reliability engineer and is ideal for implementing criticality analyses and preparing maintenance plans. It complements your own maintenance management system. It also provides excellent support for the import of your Asset Register into Optimizer+ and the export of the maintenance plan prepared in Optimizer+ to your own maintenance management system (e.g. into Maximo, SAP PM, Infor EAM and Ultimo). It offers you the unique functionality of simulating your maintenance plans and evaluating what the results of these plans will be in terms of uptime, safety, number of malfunctions, and associated costs.

Optimizer+ consists of various modules:

- **Asset library**
- **Business goals**
- **Quick FMECA**
- **FMECA**
- **Maintenance concepts**
- **Inventory management**
- **Simulation / optimization**
- **RASCI**
- **Linking module to maintenance management system**
- **Report module**

In addition, modules for Root Cause Analysis and Risk Based Inspection will be developed in the near future. Optimizer+ is available in English, Dutch, French and German.

Source: www. Maxgrip.nl/services/maintenance-software-optimizer+.html

Appendix 3.3.: Parts Coding

Stork Food Systems
Standardization & Coding

CONTENTS:

SPARE PARTS CODING

Allocating a code to a spare part or assembly indicating the service character of that spare part or assembly within a structure.

1. DEFINITION OF ABCDE PARTS

There are five codes, for example:

A - parts

A-parts are consumables. These are parts that make contact with the product to be processed and have a direct effect on the technological action of the machine. So these parts should be replaced or repaired (ground) frequently. By definition A-parts must be easily accessible. For example:

- Knives, Drills, Plucking Fingers.
  PUR strips: PGI, HLS and gizzard harvester.

B - parts

B-parts are "breakdown" parts. These are parts or assemblies of parts, which, if defective, make it difficult or impossible for production to continue. For example:

- Entire processing units of rotary machines.
- Motor reductors, three-phase motors, motor variators
- Springs.
- Special chains such as point chains, plastic chains, etc.
- Chain links and offset chain links.
- Gearbox (angular gearbox, etc. forming part of a drive section)
- Geared belts and V-belts.
- Sensors, speed monitors, photocells and micro switches.
- Pneumatic parts, example given: valves
- Frequency converters + filters.
- Critical hydraulic parts
- Printed circuit boards
- Pumps, blowers, etc.
- Belts, of transport system CAS and GP system.

C - parts

C-parts are small overhaul parts. These are parts that are subject to wear and tear. As a rule these parts should be replaced at least 1x per 2 years and at most 4x per year* in order to ensure that the machine works properly. For example:

- Bearings, bearing bushes and bearing rollers
- Internal/external retaining rings, O-rings, gaskets.
- Springs, geared belts and V-belts
- Bearing rod end; on unit and module (AMF BX / PLH = continuous action)
- Plastic rings. (Units rotary machines)
- Chain, chain links and offset chain links
- Pneumatic parts
- Pinch-off pinions, skinning pinions and peeler rolls
- Screw hexagonal head < M8, Screw Countersunk head < M10, Adjusting screw. < M12
- Grooved pins, Split pins, Clamping pins, etc.

ALWAYS IN RELATION TO THE C,D OR E PARTS MENTIONED IN THIS LEGEND

Techn. Drawings Service parts coding	T 0111 Page 1 of 11	
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Stork Food Systems
Standardization & Coding

D - parts

D-parts are major overhaul parts. See C-parts, but with a time interval of 1 to 3 years*. For example;

- Bearings (at main shaft level)
- Internal/external retaining rings. Sealing rings and O–rings. (At main shaft level)
- SKF nut + retaining ring
- Special chains such as point chains, plastic chains and suchlike, with corresponding chain links and offset chain links.
- Timing belt pulleys, pinions, gear wheels and sprocket wheels.
- Spring-loaded tensioner elements.
- Keys.
- Spray nozzles.
- Bearing rod end. At main shaft level
- Grease nipples
- Screw hexagonal head < M8, Screw countersunk head < M10, Adjusting screw. < M12
- Grooved pins, Split pins, Clamping pins, etc.

ALWAYS IN RELATION TO THE C,D OR E PARTS MENTIONED IN THIS LEGEND

* => All time intervals mentioned for C and D-parts are indicative, as the definite intervals will be laid down in the various overhaul prognosis schemes.

E - parts

E-parts are condition-dependent overhaul parts. These E-parts are subject to wear and tear and will be added to an overhaul package depending on their condition at the time of inspection. They are usually replaced during a total overhaul.

Application 1 => Depending on their condition, these parts will be added to an overhaul kit. For example:

- Cams
- Cam insert pieces
- Gearboxes.
- Teeth for conveyor wheel machine (replace according to chain pitch).
- Plastic guides.
- Plastic product holders

Application 2 => Parts which are supplied with an overhaul as a precaution. The value in the column "piece" stands for the quantity of this part that is supplied with the overhaul. (See chapter 3)

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Source: T1 Standards Stork Food Systems, T0111

Appendix 3.4.: Stork Food Systems' Program of Requirements

STORK® Stork Food Systems

Maintenance / COO (whole machine)

Frame:
- Double shift operation: 16 h per day
- 255 production days per year
- Capacity according POR

Uptime: > 99,9 % (99% for a whole line)

Minimal technical life cycle 10 year

<u>A-parts:</u>
- L+M costs per year <= 1% of total machine L+M
- Time needed for replacement, including adjustment: < 15 min
- Frequency max 1 time per production day.

<u>B-parts:</u>
- L+M costs per year: <= 5% of total machine L+M
- Time needed for replacement, including adjustment: <1/2 hour

<u>Overhauls:</u>
- Time frame interval:
  - Small: (=C parts): ≥ 9 production months
  - Large: (=C+D parts): ≥ 18 production months
  - Total: (C+D+E parts): ≥ 36 production months
  - Duration of all overhauls <12 hours non-production time.
- Costs:
  - Average L+M costs C+D+E parts measured over a period of 3 year: <5% average per year. (15% maximum in 3 years)
  - Total overhaul L+M costs C+D+E parts < 25% of total machine L+M

Break down costs in years

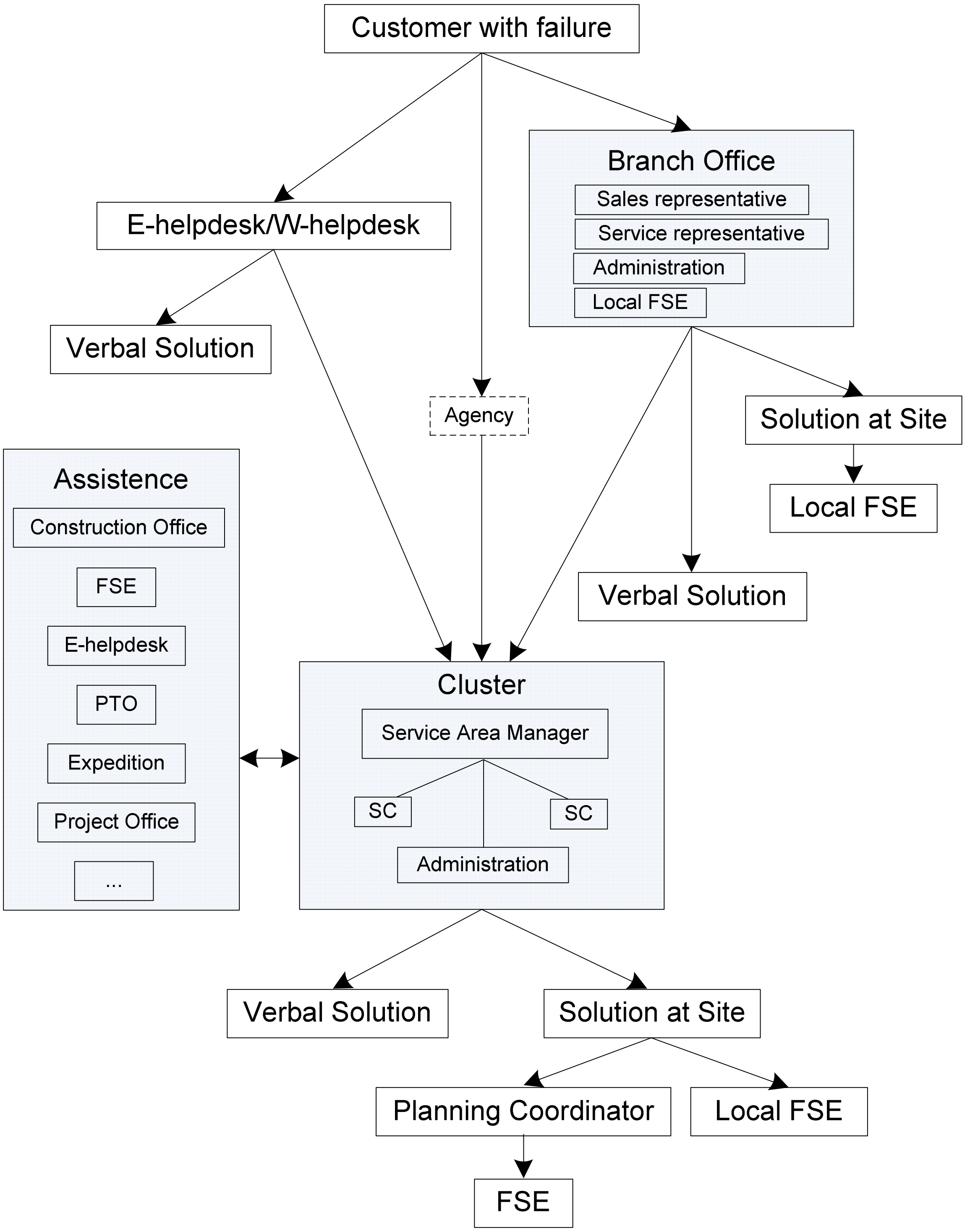
Year 1	Year 2	Year 3	Year 4
Average 5%	Average 5%	Average 5%	
Total over 3 years 15%			Total overhaul <25%

Commissioning

Total overhaul moment = reset and start new period

Source: Manual PDP Stork Food Systems

Appendix 3.5.: Maintenance Support Process at Stork Food Systems



Appendix 3.6.: Offices from Stork Food Systems

USA (production)
The Netherlands (production)
Costa Rica
Mexico
Brazil
Argentina
Venezuela
Peru
Russia
Austria
Bulgaria
Croatia
Slovakia
Denmark
Finland
France
Greece

Hungary
Ireland
Italy
Sweden
Poland
Portugal
Romania
Spain
Switzerland
Turkey
Ukraine
UK
Serbia
Iran
Israel
Pakistan
Egypt

Republic of South Africa
Nigeria
Tunisia
Australia
Bangladesh
Philippines
China
Indonesia
Japan
South Korea
Malaysia
Singapore
Sri Lanka
Taiwan
Thailand
Vietnam
Canada

The offices in bold are the branch offices of SFS, the other offices are agencies.

Source: www.Storkfoodsystems.com

Appendix 3.7.: Service Kits

STORK® Stork Food Systems

Standardization & Coding

7. SERVICE KITS

The service parts coding allows composing a spare parts kit by means of a selection of one or several codes. We distinguish the following five kits:

1. THE START-UP KIT — A
2. THE RECOMMENDED SPARE KIT — A + B
3. THE SMALL OVERHAUL KIT — A + C + E – "piece"
4. THE MAJOR OVERHAUL KIT — A + C + D + E – "piece"
5. THE TOTAL OVERHAUL KIT — A + C + D + E

It is possible to automatically generate these kits for any coded structure through the built-in functionality in EDB-PLM.

1. A
2. A + B

SPARES KITS GENERATED FROM EDB-PLM

3. A + C + E – "PIECE" — POSSIBLY SUPPLEMENTED BY E PARTS AFTER INSPECTION — E
4. A + C + D + E – "PIECE" — POSSIBLY SUPPLEMENTED BY E PARTS AFTER INSPECTION — E
5. A + C + D + E — MINUS E PARTS JUDGE OK AFTER INSPECTION.

OVERHAUL KITS GENERATED FROM EDB-PLM

OVERHAUL KITS AS A RESULT OF THE ACTUAL INSPECTION

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STORK®

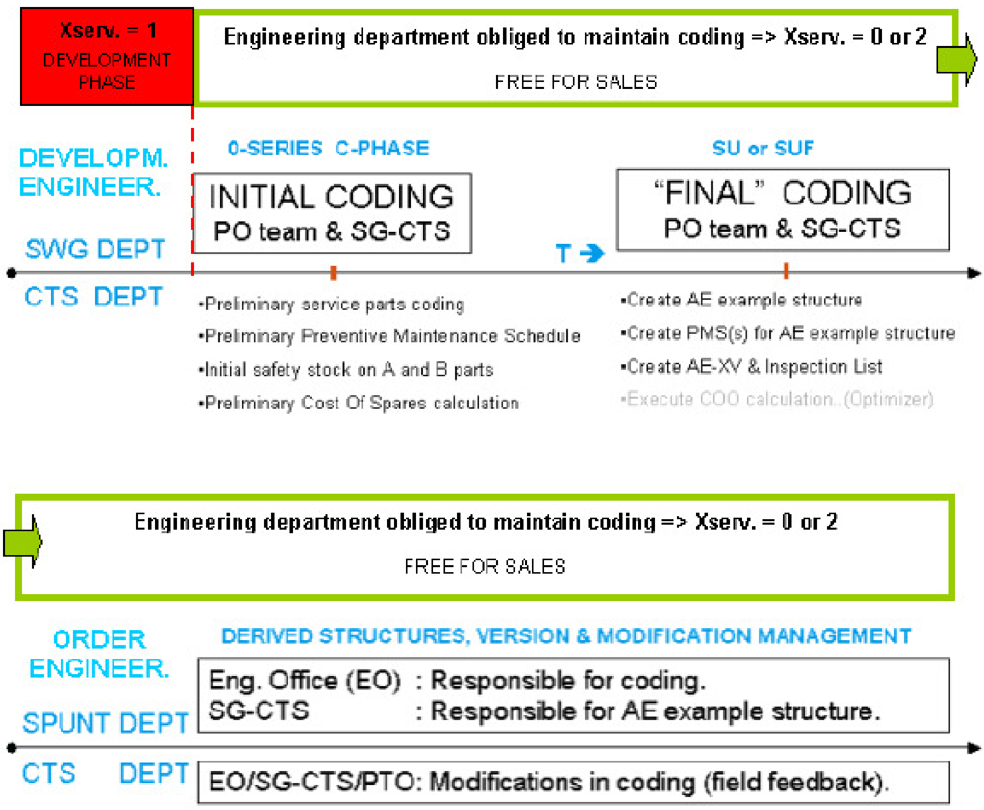
Stork Food Systems
Standardization & Coding

8. PREVENTIVE MAINTENANCE SCHEDULE

Besides the available spare parts kits and overhaul kits, so-called preventive maintenance schedules (PMS) are made for all AE example structures (see chapter 6 = Fill-in instruction structures).
The preventive maintenance schedule shows what overhaul work to expect for a specific machine structure in order to keep it in good mechanical condition.
Per assembly, a prognosis is made concerning the overhaul operations within a certain period of time.
A number of process parameters set beforehand are taken into account when determining the PMS.
The preventive maintenance schedules available, serve as a basis for an initial Cost Of Spares calculation.
The PMS is laid down in consultation with the PO team, often during the coding session in the C-phase.

P.M.S. nr. : B271I.00 P		Year :	1				2				3				4				5			
Ref.nr. : 1I435I3AE I TRANSFER SYSTEM,TR-DE R KE		Quarter :	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Pos	**Part Name**	**PMP :**	1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	4,3	4,4	5,1	5,2	5,3	5,4
	TRANSFER SYSTEM,TR-DE R KE																					
1	TROLLEY				S			M			S			T			S			M		
2	MAINSHAFT EV													M								
3	MAINSHAFT DF													M								
4	CHAIN				S			M			S			T			S			M		
5	GUIDE BRACKET/TRACK													T								
7	GUIDE (contra & product)				M			M			M			M			M			M		
8	BRACKET (pushover release)													T								
9	UNIT PUSHOVER-				S			M			S			T			S			M		
10	BLADE				S			S			S			M			S			S		
12	BRACKET (shackle DF)													T								
18	SAFETY													T								
20	PNEU PIPING DIAGRAM																					
21	BRACKET UNLOADING							S						M						S		
22	ELECTRICAL ACCESOIR.																			T		
24	LUG													T								

9. Tasks and management workflow



Source: T1 Standards Stork Food Systems, T0111

Appendix 3.8.: The adoption of Slim4 at Stork Food Systems

Door: joost boers | Industrie Magazine | 24 september 2002

...

Om een nog grotere klantentevredenheid te bereiken wil Stork PMT zijn voorraadposities van onderdelen minstens verdubbelen, zonder hierbij de totale waarde van zijn voorraad substantieel te verhogen. Dit is het gevolg van een goed concept met de juiste tools.

Tot midden vorig jaar hield Stork een voorraad aan van de 3500 meest gevraagde wisselstukken in Boxmeer. Veel onderdelen werden echter slechts geproduceerd na bestelling van een klant, omdat men er geen idee van had welke van de tienduizenden onderdelen wel besteld zouden kunnen worden. De nodige IT-tools ontbraken, want een goed voorraadbeheersysteem van dergelijke onderdelen was in het ERP systeem SAP/R3 niet beschikbaar. Van een ondefinieerbare servicegraad heeft Stork als streefdoel te komen tot een servicegraad van 98%: onmiddellijke levering uit voorraad van zodra de klant bestelt in 98% van de gevallen. Jan Melssen, Service Support Manager en verantwoordelijk voor deze doelstelling, legt uit waarom: "Wij zijn een zeer klantgedreven organisatie en doen bijna het onmogelijke om aan klantenwensen te voldoen. Gezien we marktleider zijn verwacht de veeleisende klant van ons vandaag gewoon dat we zijn onderdelen onmiddellijk leveren". Men kan alle bestaande reservestukken in voorraad houden natuurlijk om de klant op zijn wenken te bedienen, en aansluitend de boeken neerleggen. Stork koos voor een programma als aanvulling op SAP dat helpt een hoge servicegraad te bereiken om dubbel zoveel onderdelen te beheren met zelfde voorraadwaarde.

De keuze viel op het operationele voorraadbeheersysteem Slim4 van InfoLog, in België geleverd door Möbius. Periodiek worden de bewegingen van de onderdelen uit ERP gehaald en met Slim4 bekeken. De resultaten van de analyse gaan dan weer naar SAP/R3 als voorstellen voor bestellingen en voorraadniveau. Slim4 deelt de onderdelen in verschillende klassen in, afhankelijk van hun afzetpatroon. Het houdt hierbij rekening met vorige perioden, en kan een onderdeel van klasse veranderen, met een gewijzigd voorstel voor een ijzeren voorraad en een andere bestelfrequentie van andere aantallen. Met Slim4 kreeg Jan Melssen ook kijk op alle leveringen van de laatste jaren. Daaruit bleek dat de laatste twee jaar bijna 18000 verschillende onderdelen waren uitgeleverd, terwijl de voorraad slechts 3500 posities bevatte. Het was onbegonnen werk exact rekening te houden met een wijziging in het bestelpatroon. Vaak kwam dus een onderdeel in de voorraad na een probleem met een klant.

Door de analyses met Slim4 werd sinds de invoering in september 2001 het aantal voorraadposities verhoogd tot meer dan 5500, zonder dat de totale voorraadwaarde noemenswaardig steeg. Posities in voorraad bleken volgens Slim4 met minder stuks te kunnen. De administratiekosten zijn gedaald. Voor de meeste klassen en per onderdelengroep kan Slim4 een simulatie maken van de hoeveelheid voorraad voor een bepaalde servicegraad en wat de kosten hiervan zijn.

Slim4 wordt niet gebruikt voor de allertraagste roteerders met minder dan twee bewegingen per jaar en de onderdelen die geen enkele keer in een jaar werden besteld. Melssen: "In de laatste drie jaar hebben we zo'n 25.000 verschillende onderdelen pas geproduceerd na bestelling. Die kunnen we niet allemaal in voorraad nemen, maar om aan de klantenverwachtingen te voldoen en onze servicegraad te verhogen moeten we die onderdelen in simulaties betrekken. Wellicht moeten we er af en toe van bestellen voor de voorraad, zonder er permanent een ijzeren voorraad op na te houden. Dit zou op zijn minst de leveringstermijn voor de klant sterk verkorten, of met wat geluk ligt het onderdeel net op voorraad als hij bestelt. Dat zou een grotere klantentevredenheid opleveren."

InfoLog ontwikkelt Slim4 nu verder op vraag van o.a. Stork PMT om ook hiervoor voorstellen te kunnen doen.

…

Appendix 3.9.: Availability (components) at Stork Food Systems

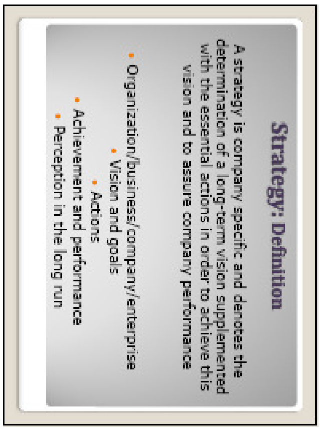
This Figure illustrates for which aspects of availability SFS scores sufficiently (green) or inadequately (red). The Figure also demonstrates that certain availability controlling actions refer to the design phase of the product development process while availability can also be influenced once the machines are already in use.

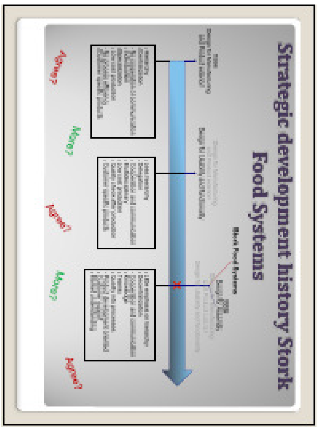
Appendix 4: SWOT-analysis regarding "Design for Availability"

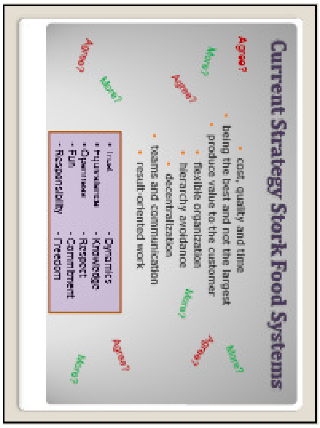
Appendix 4.1.: Methodology to assess the strategy of Stork Food Systems

To conclude whether DfA is achievable in the suggested time span of 5 years it is essential to be familiar with the current business strategy of SFS. To get acquainted with the current strategy of the company, an interview and brainstorm session is organized on the 11th and 24th of March respectively. The interview was person to person, taking about one hour, and the setting of the meeting can be best described as being informal and interactive. The interviewee was Gerrit den Bok, employee of the company since 1989, and member of SFS' current management team. Obviously, the subject of the meeting was about the strategy of SFS. First, the respondent was informed about the purpose of this meeting a propos the research. Next, the definition of strategy, as adopted in this study, was given to Gerrit den Bok. Subsequently, the only predetermined question was asked, i.e. how can the strategy of SFS be best described? Valuable information is recorded constantly throughout the meeting. Finally, the rounding up of the interview was initiated by a review of the listed records, and the question whether any further information needed to be added to the list. To verify the information obtained from this meeting, a brainstorm session of about 1 hour followed. This brainstorm session included five persons, i.e. the researcher to steer the sitting in the right direction, Gerard Hutting (Coach Mechanical Engineering), Erik Peters (Coach Innovation Engineering), Gerrit den Bok (Service Manager), and Jan Melssen (Senior Business Consultant). To keep the employees' attention, a power point presentation was set up, as shown at the end of this Appendix 3.1. The topic of the session was evidently the strategy of SFS. First, those present were informed of the discussion points of the meeting. Next, the definition of strategy, as adopted in this research, was specified. Then, the employees were confronted with the information that was obtained from the individual interview with Gerrit de Bok. A discussion of about 15 minutes took place. The conclusion was that the current strategy of SFS could be established with the available information together with one extra point, being the fact that the company can and strives to be full line supplier. Afterward, a conversation of more than 30 minutes went on about the strategic history of the company. Knowledge that was gained at that moment was verified with the written down strategic history of SFS in the company's handbook of their product development process. The end of the brainstorm session was initiated by a short clarification of the business strategy that suits DfA and the match between that strategy and the current one of the company.


Strategy sought-after Design for Availability
Lydie Smets
March 2009
TU/e
STORK®


Strategy: Definition
A strategy is company specific and denotes the determination of a long-term vision supplemented with the essential actions in order to achieve this vision and to assure company performance
Organization/business/company/enterprise
Vision and goals
Actions
Achievement and performance
Perception in the long run

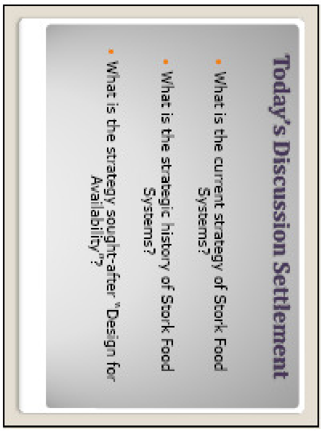

Strategic development history Stork Food Systems
Agree?
More?
Agree?
More?
Agree?

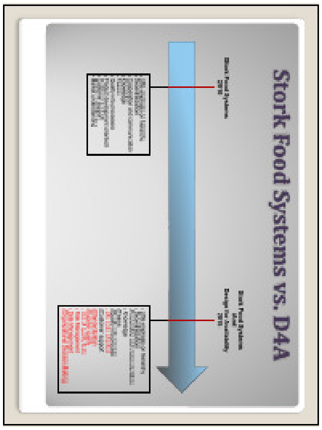

Current Strategy Stork Food Systems
Agree?
cost, quality and time
being the best and not the largest
produce value to the customer
flexible organization
hierarchy avoidance
decentralization
teams and communication
result oriented work
More?
Agree?
More?
Agree?
More?
Agree?
More?
Agree?
More?
- Trust - Dynamics
- Perseverance - Knowledge
- Openness - Respect
- Fun - Commitment
- Responsibility - Freedom

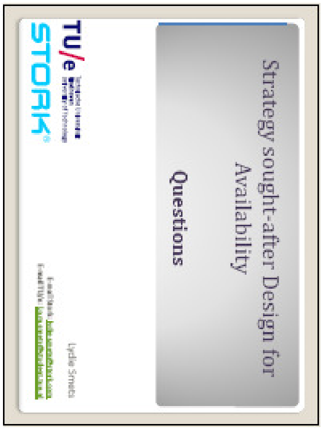

To Design for Availability
Organization: Stork Food Systems
Vision: "Design for Availability" (goals)
Actions
Market Leadership
Perception: 5 Years
A missing element in the strategy formulation is the actions that need to be taken within the following 5 years to achieve, insofar as possible, "Design for Availability"


Discussion Points Today
What is the current strategy of Stork Food Systems?
What is the strategic development history of Stork Food Systems?
Does Stork Food Systems fit with the strategy sought-after "Design for Availability"?


Strategy: Design for Availability
The idea behind "Design for Availability" is the opportunity to offer equipment to customers with high availability against minimized LCC. Consequently, "Design for Availability" requires good management of availability and costs
Availability management:
- emphasis on reliability of equipment
- reliability-centered maintenance
- efficient and effective customer support
- involve maintenance in design
- monitor maintenance actions
- product lifecycle management
Cost management:
- lifecycle costing
Design for Availability:
- mix products and services
- innovation
- define a decision-making process
- deal with uncertainty


Today's Discussion Settlement
What is the current strategy of Stork Food Systems?
What is the strategic history of Stork Food Systems?
What is the strategy sought-after "Design for Availability"?


Stork Food Systems vs. D4A


Strategy sought-after Design for Availability
Questions
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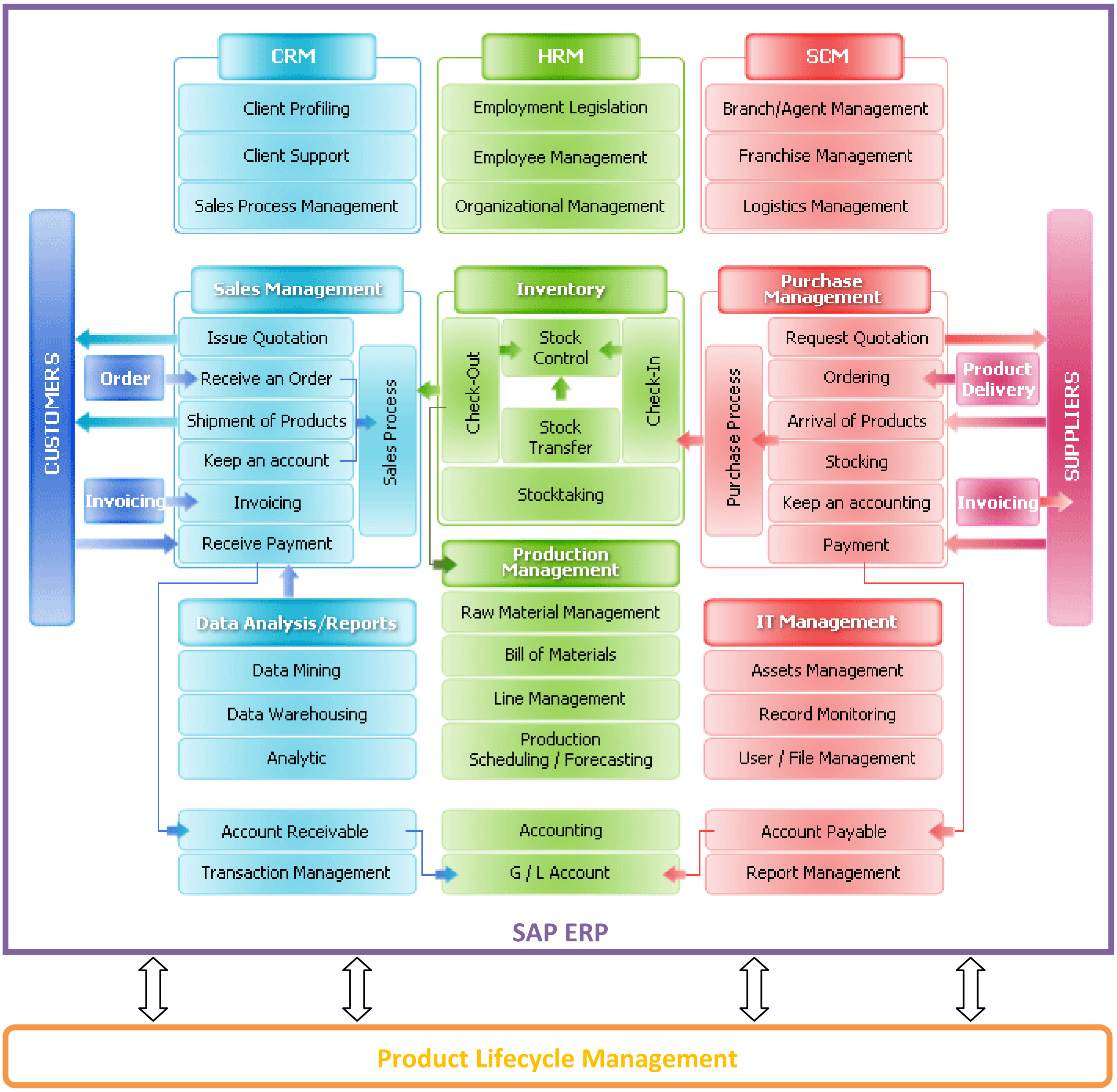
Appendix 4.2.: SAP ERP and Product Lifecycle Management



Source: www.bluedzine.com/solutions/ofcx/erp/

Appendix 5: Improvement Potential

Appendix 5.1.: Operation, service and maintenance cost

Operating, service and maintenance cost

Fixed operating cost

- O_{sc}: Space capture [square meters]
- ~~depreciation~~
- ~~Interest~~
- ~~2nd hand value~~
- ~~transport efficiency~~
- O_{tr}: *training [hours]*

Variable operating cost

- O_u: utilities
- - water [m3/h]
- - electricity [kWh]
- - compressed air [m3/h]
- - steam [m3/h]
- - ice-water [m3/h]
- - vacuum [m3/h]
- O_w: waste disposal [m3/h]
- O_c: Cleaning [hours]
- O_{lc}: labor cost [# operators/h]
- O_{ic}: ingredients consumption [kg]
- ~~availability of (skilled) labor~~

Service cost

- S_{ic}: *Installation cost*
- S_{lc}: *customer support labor cost [# employees/service]*
- S_{dt}: *downtime [lost production/service]*
- S_{ic}: *inventory cost [spare parts/year]*
- S_{tc}: *transportation cost [# spare part packages]*
- S_{sc}: *sale cost*

Maintenance cost

- M_{cp}: consumable part consumption [# parts]
- M_{sp}: spare part consumption [# parts]
- M_{lc}: maintenance labor cost [# servicemen/h]
- M_{tr}: *training [hours]*
- M_{dt}: *downtime [lost production]*
- M_s: *supervision [# supervisors]*