TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

ANU VAARIO

FRAMEWORK FOR AVAILABILITY BASED MAINTENANCE CONTRACTS: MODEL FOR MANAGING AVAILABILITY AND CALCULATING THE EFFECTING FACTORS

Master of Science Thesis

Examiner: prof. Kari T. Koskinen
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ABSTRACT

ANU VAARIO: Framework for availability based maintenance contracts: a model for managing availability and calculating the effecting factors
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Customers and suppliers have started to prefer availability based maintenance contracts as maintenance contracts and using these kinds of contracts is becoming a trend in the industry. In availability based maintenance contracts the supplier does not sell maintenance, but for example availability of the operation in the customer plant. The main objective of this study is to enable for the target company to manage these kinds of contracts and to create tools to support those contracts.

This thesis is a study on what are the important factors in availability and how are those managed in the contract where equipment are not always manufactured by the supplier and equipment are not similar to one and other. The goal of the thesis is to examine availability based maintenance contract framework and availability costs with availability factors. To the research is selected a case study as a research method. It was grounded with literature review, benchmarking and interviews. Based on literature review, benchmarking and interviewing the framework was created for the target company to be used to manage availability based maintenance contracts.

Based on the framework, it was determined a suitable availability calculation model. With the calculation model it is possible to examine different factors and costs influences on availability. Also, effects of changes in availability to the company's total cost and profitability are investigated.

The research offers a methodology for adopting availability based maintenance contracts in target company. The emphasis is put on clarifying and focusing the availability factors and those affect to availability. While doing the research it was noticed that small changes in availability have a large impact on company's performance and profitability.

As a future measurement is presented that the company becomes more familiar with availability and that the company's management gives clearer instructions on where to invest in and what changes does it require from the company. This includes for example that the company start systematically design and manufacture equipment for availability purposes. This would make maintenance work faster and increase availability.

TIIVISTELMÄ

ANU VAARIO: Toimintamalli käytettävyyspohjaiselle huoltosopimustoiminnalle: Malli käytettävyyden hallinnasta ja laskentaan vaikuttavista tekijöistä
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Asiakkaat ja toimittajat suosivat yhä enemmän käytettävyyspohjaisia huoltosopimuksia perinteisten huoltosopimuksien sijasta, näiden käyttämisestä on tulossa trendi-ilmiö teollisuudessa. Käytettävyyspohjaisissa sopimuksissa toimittajat eivät myy enää huoltoja vaan muun muassa asiakkaan työmaan operoinnin käytettävyyttä. Tutkimuksen päätavoitteena oli mahdollistaa kohdeyrityksen kyseisten sopimuksien hallitseminen ja tuottaa työkaluja näiden tueksi.

Työ on tutkielma siitä, mitkä ovat tärkeimmät käytettävyystekijät ja kuinka niitä hallitaan sopimuksella, jossa koneet eivät aina ole toimittajan valmistamia eivätkä ole samanlaisia keskenään. Tavoitteena työssä on tutkia käytettävyyspohjaisten huoltosopimuksien toimintamallia sekä käytettävyyden kustannuksia ja tekijöitä. Tutkimusmenetelmäksi valittiin tapaustutkimus, jota tuettiin kirjallisuusselvityksellä, vertailuanalyysillä ja haastatteluilla. Kirjallisuusselvityksen, vertailuanalyysin ja haastatteluiden pohjalta suunniteltiin toimintamalli kohdeyritykseen, jota on mahdollista hyödyntää käytettävyyspohjaisissa huoltosopimuksissa.

Toimintamallin pohjalta pystyttiin määrittämään käytettävyys-laskentamalli. Laskentamallin avulla tarkasteltiin eri tekijöiden ja kustannuksien vaikutuksia käytettävyyteen. Myös käytettävyyden muutoksen vaikutuksia yrityksen kokonaiskustannuksiin ja kannattavuuteen tutkittiin.

Tutkimus tarjoaa metodologian käytettävyyspohjaisten huoltosopimuksien hyödyntämiselle kohdeyrityksessä. Pääpaino on asetettu selkeyttämään ja tarkentamaan käytettävyyden tekijöitä sekä näiden vaikutuksia käytettävyyteen. Tutkimuksissa huomattiin, että pienet muutokset käytettävyydessä vaikuttavan merkittävästi yrityksen tulokseen.

Jatkotoimenpiteinä esitetään yrityksen perehtymistä käytettävyyteen tarkemmin sekä yrityksen johdon selkeämpiä ohjeita, mihin yritys panostaa ja mitä muutoksia se yritykseltä vaatii. Tähän liittyy muun muassa se, että yritys alkaisi systemaattisesti suunnittelusta asti valmistamaan koneita käytettävyyttä ajatellen. Tällöin huoltotoiminnan tekeminen nopeutuisi ja käytettävyys kasvaisi.

PREFACE

I want to thank everyone who supported me during this thesis process. First, I want to thank the target company for giving me the chance to work on this thesis and for the engrossing topic. Special thanks to my mentor, supervisor and the rest of the PlusPlus team: “we got out of Mars!” in the target company. In addition, I want to thank my supervisor Jouko Laitinen at Tampere University of Technology for helping to find the red thread for the thesis. I also want to thank my examiner of the thesis, Professor Kari Koskinen for giving time and valuable advices. I also want to say thanks to my thesis buddy, who sacrificed her time reading this thesis and gave great tips for it.

The big thanks go to Aleksi, who supported me throughout this process and gave words of wisdom for the thesis.

“Non pudor est nil scire, pudor nil discere velle.”
- Unknown

Freely translated:
“There is no shame in not knowing, but it is a shame not to want anything to learn.”

In Tampere, Finland, on 11th May

Anu Vaario

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LIST OF SYMBOLS AND ABBREVIATIONS

ADL	Administrative Delay Time
AIDA	Advanced Inflight Data Analyzer
AR	Augmented Reality
BCM	Business Centered Maintenance
CBM	Condition Based Maintenance
DIKW pyramid	Data, Information, Knowledge and Wisdom pyramid
FEMA	Failure Mode and Effects Analysis
GM	Gross Margin
KPI	Key Performance Indicator
LDT	Logistic Delay Time
MDT	Mean Downtime
MLDT	Mean Logistic Downtime
MMT	Mean Maintenance Time
MSG-3	Maintenance Steering Group-3
MTBF	Mean Time between Failures
MTBM	Mean Time between Maintenance
MTTF	Mean Time to Failures
MTTR	Mean Time to Repair
NOWC	Net Operating Working Capital
OH	Operating Hours
OEE	Overall Equipment Effectiveness
ROCE	Return on Capital Employed
RCA	Root Cause Analysis
SLA	Service Level Agreement
SAE	Society of Automotive Engineer
TTF	Time to Failure
TTR	Time to Repair
TPM	Total Productive Maintenance
DoD	United States of America Department of Defence

A	Availability
A_O	Operational Availability
A_T	Technical Availability

1. INTRODUCTION

It has been noticed that no industry can manage poor functions that have many failures and additional stops in operations. Additional stops often lead to unexpected increase of costs. For the past years availability has become its own special field due to investigation of equipment usability and reliability. Maintenance can also be classified as availability work.

Dependability is seen as a key decision factor in global business environment. Dependability is affecting equipment processes and costs. To deliver high-value equipment managing dependability is essential. In a wider perspective dependability reflects to operators' confidence of use by achieving satisfaction from equipment performance capability, delivering availability against demand, and minimizing acquisition and ownership costs through equipment life cycle. [1]

Reliability and maintenance are the most important drivers for availability control. To improve availability, it takes more efficiency from maintenance and enhancement in reliability of operations. Availability is the main function in total productivity, and its maximizing and optimizing methods are key aspects in managing productivity. It is possible to see availability as a productivity factor which allows visibility for operational life time costs. Analytical review of availability and reliability gives a firm base for the whole maintenance management.

It must be mentioned that no maintenance program is able to prevent all faults even if tried. Well planned and scheduled maintenance program minimizes possible flaws and prevents occurrence of defects. Disadvantage is that excessive failure prevention adds maintenance costs.

A war cry of this thesis is: "It is not wise to stay still with a problem made in the past; it is wise to learn from that, look for the future with wisely eyes and push through to find new and improved ways." Welcome onboard to the world of pure possibilities!

1.1 Goals of the thesis

Roozenburg and Eekels [2] discuss empirical scientific inquiry and design cycles. Scientific inquiry in this thesis is used as a case study to find a flexible framework for availability based maintenance contract. The framework in this thesis is defined as a real structure which purpose is to serve as a guide on building a model around availability based maintenance contract. The framework is an outline linking functions together to support a particular approach to a specific target and it acts for example as a guide by identifying and categorizing process and steps establishing tasks in order to make a clear vision of the model. Framework is a model that is used to take over or manage already existing maintenance plant.

More specific goal is to make a model to manage availability based contracts. Goal of this thesis is to provide accurate framework for the target case company called Company A. This includes means and measurements for calculating and establishing a current status of availability in the area specified in maintenance contract. Company A provides goods handling solutions and services around the world with a mission to help customers improve their productivity. One of the goals is to create a method for calculating availability by using Key Performance Indicators, KPI, for making more cost efficient availability based maintenance contracts.

The subject of this study focuses on a data side of availability based contracts. Intending to find a correct data levels needed for calculating availability and to clarify proper information and data what is used to make calculations. Purpose for this is to make a statement on what data to collect for managing availability based maintenance contracts.

Data is used to make calculations about availability and its costs. One of the key factors of the thesis is to describe availability factors influence to costs. This is done by making a model of availability calculations based on gathered data and to translate those factors into cost.

In addition to scientific interest, this research should also serve other stakeholders. This research is done to also benefit Company A in capturing value from the resulting added knowledge. The research should motivate researcher to do research within a moderate time. Company A objective is to calculate new and current availability based maintenance contracts. Researcher's goals are to become a capable availability based maintenance contract specialist that is able to give a coherent picture of theory and practice that has a concrete advance for a listener.

1.2 Scope of the thesis

Maintenance contracts in Company A can contain all stages of equipment life cycle which is illustrated in Figure 1. It is not just an operation stage of life cycle but availability based maintenance contracts also means that equipment are planned and build for service. Even though whole life cycle should be taken into account in availability based maintenance contracts this thesis is limited only to the operational phase of equipment life cycle.

Figure 1. *A product life cycle phases [1]*

This thesis is only covering operational stage of the life cycle because maintenance contract can also include third party equipment and not only equipment made by Company A. In operation phase equipment's are maintained according to customer requirements with different maintenance operations. Different maintenance types and procedures are left out since maintenance technicians are professionals in their own field and procedures are not making a difference in availability based maintenance contracts. These will only be dealt with a conceptual level. In operation phase some performance is stored in reserve, passive stage of operation phase, and part is in use, active stage of operation phase. Operation phase takes as long as it is decided that performance is not needed anymore or it is been replaced with some other way [1].

Availability is created based on three factors: reliability, maintainability and maintenance support [1, 3]. This thesis is focusing on availability created by reliability and how framework around that could work; what is needed and what information should be gathered for calculating and guaranteeing availability in availability based maintenance contracts. This is why maintainability and maintenance support are viewed only on a conceptual level and only briefly in terms of availability.

This thesis focuses equipment availability and how to measure and ensure that with different methods. It is done by reviewing availability measuring methods from a customer and a supplier point of views. By reviewing needs from both perspectives, it is possible to make a framework that will benefit both the customer and the supplier. The framework will be then easily taken to the customer or to contract negotiations as a baseline to visually show: this is the model that is used to measure supplier's availability and that is what will be promised. Part of the framework is a preliminary root cause analysis, RCA, process model which is created to tackle failure root causes and to help catch needed development areas and issues.

This thesis is not done to make a generic model of the framework, a model that would be used in all different industries. It is making a framework based on theoretical research, benchmarking and interviews. Therefore, the thesis is fined down to be used in a Company A.

Thesis will not address warehouse locations, logistical matters, spare part availability or storing since the framework does not change if delivery time is changed. This also limits out the fact where technicians are located, the only thing that changes in a framework is the response time. That does not change the overall framework. Above limitations will be in a calculation model when calculating availability factors. Calculation will illustrate Company A what are the main factors to be considered and dealt with.

1.3 The five research questions guiding the thesis

Scientific research is defined as a research involving the systematic observation of and the experiment with an event. It includes the development of a theory subjected to a strict test. [4] The questions are meant to be the link between theory and practice.

Availability based maintenance contracts are often used in a specific equipment or in equipment that are standardized or similar to one and other [5-8], which raises a theoretical question: how does availability based maintenance contract respond to equipment that are not similar to each other? In Company A market, equipment are not always made by Company A, because there are a lot of third party equipment. Other side is that there are multiple different types of equipment in customer plant, so it is not possible to say that equipment are standardized. The base for this thesis is to compare theoretical views of a topic to different industries which are using this type of contracts. Creating a framework, that works for companies that are manufacturing and maintaining equipment, which are customized and all different from each other. This takes to a first research question:

Question 1: How is the framework created to serve company's and customers vision of availability where equipment are different from each other?

When framework is created to serve company's vision of availability it will make a model of how Company A sells itself to a customer and how it measures itself. Framework will also represent what is their vision of availability. Framework gives customer a view of how availability is handled. Customers in the target company's industry are only recently started asking about availability. There are thousands of customers and they all have different understanding on what availability is, what it offers and what it needs. This substantially increases the fact there are not standardized way or intent of managing availability.

When all the customers have their vision of availability and it falls into Company A to guide and instruct them to master availability [5, 9, 10]. With a desire to help and guide the customer, Company A must have its own definition of availability and to have standardized practice a managing availability. This factor is contributing to the need of a framework for availability based maintenance contracts. It can also make Company A, a more firm statement for a customer of the way it measures itself.

Discussion of availability based maintenance contracts with different types of equipment opens up a dialog on availability and to the factors that are influencing availability. This is a part that has been studied with small standardized equipment [5-8], but when thinking of small, medium and big equipment that are individually build with customer needs; this opens a door for a second research question:

Question 2: What are factors that affect availability of an equipment?

Thinking about factors in availability and especially availability based maintenance contract, it raises a question about a means: how to know whether the factor is influencing availability or not and how much is the factor influencing availability bases maintenance contract. It is a key to have the right way of calculating availability. If calculations are not standardized, how is availability calculated if it cannot rely on the findings and make a conclusion of a current state of availability. This leads to a third research question:

Question 3: What type of data is needed to manage availability?

In calculations the data is in an essential role. At the end, calculations cannot be performed without data and for the analysis data is a key. It is also the result of the analysis, it gives knowledge of the state of the availability. Without data the performance is more or less based on subjective informative for example experts estimate and experience. Besides from right calculation method is also important to know what calculations are done. This leads to a fourth research question of the thesis:

Question 4: How availability is measured with adequate information and with a sufficient accuracy in availability based maintenance contracts?

When information is accurate and correct level has been found next matter of wonder is what to do with this information and calculations. Calculation will give a percentage of availability and help to find a root cause of availability factors. The root cause will help to identify the development measures needed to improve equipment, design and maintenance. Calculations would also be translated into costs. Availability costs have been in Company A plans. If it is possible to calculate availability, these influencing factors of availability can be translated to illustrate cost of availability. This drives to a fifth research question:

Question 5: What are costs of availability and where do those come from?

Answering these questions will help to make a conclusion on the state of availability. These will also make a deduction on the condition of equipment in a current or in a new maintenance contract covered location. Knowing the current state of availability based maintenance contract area is making it easier for a supplier to promise something concrete to a customer. It will also help on finding ways of improving areas availability.

1.4 Review of methodology used in the thesis

Case study was implemented in the thesis to combine theory and practice together. Case study is linking experimental research with an exact temporary event by using several sources of evidence into the real-life context [4]. To ground and validate findings it was triangulated by other research methodologies: benchmarks, interviews and theoretical review of literature. Triangulation means that by using different data collecting techniques in one case study for the purpose of confirming that founded data is accurate [4].

Literature review considers the theoretical aspect of availability based maintenance contracts. Literature material for this thesis consists of reliability centered maintenance, availability based maintenance contracts and maintenance publications and books. Publications and books are both in English and in Finnish. By benchmarking companies, it is expected to find a level where companies generally are when dealing with availability based maintenance contracts. Benchmarking is viewed as a strategy in which actions are compared with major organizations in the market [11, 12]. Based on benchmarks it is found out a framework how availability based maintenance contracts are handled in industries.

Different types of interviews took part of gathering the information in the Company A. These interviews were semi-structured interviews, designed to collect data for qualitative analysis [4]. Interviews made it possible to create an image of a current framework on how Company A is working and what is the current framework for availability based maintenance contracts in the company. By gathering all these together, it is possible to find the framework for how availability based maintenance contracts should be treated with.

1.5 Theoretical framework

This thesis has been divided into four segments: theoretical review of availability and availability based maintenance contract, research methodology of the thesis with proposal of the next steps, practical segment where the framework is created and refined, availability factors and cost are simulated. To wrap up this thesis in the end is conclusions and discussion, more information can be found from appendixes.

First part of this thesis is a constructive approach to elaborate theoretical base to understand adequate amount of pertinent theoretical approaches to interfere with area of availability based maintenance contract and tools. Domain theory is a theoretical perspective of the steps on what are main aspect of availability, its factors and cost. Minor theory is on how to create a framework to take future steps with availability based maintenance contracts. It also bypasses a data aspect, part of this study focuses on the data analysis side of availability and locating the real influences behind that availability.

The research methodology part of this thesis first addresses a method used to answer five research questions. Second this part conducts a proposal on how to build and maintain availability based maintenance contracts based on theoretical framework created in a beginning of the thesis and by using benchmark organizations and interviews. This opens a door to a practical and result part of the thesis. The preliminary framework created is reflected to the current structure and validated in Company A. Then the case study is built to verify and refine availability factors influencing on availability and to illustrate factors' costs effects on availability percentage. After reviewing the results of the case study, the journey of availability based maintenance contracts goes on gathering conclusions and discussing of the work. The end of the journey is in the appendixes where it is possible to find more information about the thesis.

1.6 State of art in literature, organizations and target company

Availability and maintenance are widely investigated [6-8, 13-18] and there are lots of information from those. Because of enormous research the information is extensively spread, it is not easy to combine and gather all relevant information. This also gives an opportunity to make a research that is pounding all the information together in a certain scope. This thesis is giving a wide view on the availability, its factors and availability based maintenance contracts. This way all needed information is agglomerated under one topic and it is easier to manage all information included in availability based maintenance contracts.

Theory also leaves on opening of how these availability based maintenance contract are handled with one framework with several different types of availability. It is not clearly studied how the framework should be and is created to work in different fields. Theory takes a stand on different factors in availability, but it is not clearly presented how relevant those factors are. It is not mentioned if it is relevant to gather all the information available of the factors or is it possible to manage the availability sufficiently enough with less accuracy.

Efora Oy, later referred as Efora, is a service provider specialized in industrial maintenance and engineering [19, 20]. Efora is specialized for example in paper and board production lines and pulp mills [20]. Efora offers sustained maintenance contracts, engineering services and specialist services [19]. They maximize production capacity, manage the life cycle of industrial production lines and secure trouble-free operation with smarter maintenance solutions. Managing the production line information is a base for smarter maintenance. [20]

The information is gathered from systems and combined with expert's knowledge. Efora has knowledge on turning information into action [19]. Currently, Efora manage many maintenance contracts which are bound for example into Overall Equipment Effectiveness, OEE. They have a large knowledge on managing contracts with indicators. Efora keeps maintenance contracts similar to each other. [19]

Sataservice Oy, later referred as Sataservice, is a comprehensive maintenance company which helps its customers to maintain productivity and to develop operation and maintenance services [21]. Sataservice operates in different fields for example production plants and food industry. Company sees the co-operation with the customer as a life cycle, not as a length of the maintenance contract. [22] In Sataservices' operating model maintenance services are delivered in three different levels. First, 1.0, includes single maintenance operations and projects. Second, 2.0, contains service agreements which guarantee usability in one or many maintenance areas. Third, 3.0, promises productivity, development and performance for part or parts of customers' production. [21, 22]

Sataservice proceeds with a systematical way on taking customers into next levels. Their contracts are specified for customer needs and business, but four main indicators can be found from those: satisfied customers, well-being of staff, revenue and working environment safety. [22] Being an all maintenance company, they have a lot of awareness and information of maintenance and maintenance contracts.

The Finnish Defence Forces are responsible for the Finnish defence system as the name suggests. In the benchmarking the focus was more on the Air Force side than in the Army and the Navy side of The Finnish Defence Forces. This was due to the fact that the Army and the Navy have outsourced all of their maintenance, in contrast to the Air Force, where only aircraft of maintenance have been outsourced to Patria Plc [23].

Aviation also has very strict regulations on recording every fault into a paper or a system. These records need to be kept for years, even after the disposal of an equipment. Faults are expensive in aviation and affects availability of the aircraft fleet. These are few of the reasons why The Finnish Defence Forces are developing the maintenance and systems. They also have gathered an extensive amount of data from their aircraft. [23]

Wärtsilä Oy Abp, later referred as Wärtsilä, is a global manufacturing company consisting of three pillars: marine, power plant and maintenance [24, 25]. Maintenance is the one that combines all of these together. Wärtsilä customizes maintenance contracts for the customer needs and to fit the customers' business. In contracting it is important to know what the customer wants. [25]

In power side Wärtsilä often operates the plant for the customer and maintenance contracts can often be linked to availability, energy efficiency or cost/MW. In marine side the contract can often be linked to maintenance, revenue, availability or fuel consumption. [25] Wärtsilä has a large maintenance network and they ensure availability of services everywhere, where their customers are located [24]. Wärtsilä's field is different from other benchmarking companies and it being a manufacturing company gives them plenty of information and knowledge of availability and maintenance contracts.

Company A has done many exercises around the availability and availability based maintenance contracts, these exercises have taught Company A a lot and given insight on what is needed for conducting a full availability based maintenance contract [9, 26, 27]. Company A has been dancing around the topic for a few years and because exercises have been a hand full and Company A is already selling availability based maintenance contracts, it is time to take a firm grip on the topic [9, 26, 28]. Customers are asking for this type of service and there are no-one in the industry selling a solid guaranteed service for this need [9, 29]. Company A does not have a standardized framework for selling availability based maintenance contract and basically every contract is calculated differently and there is a need for steps to go forward from what is currently [9, 27, 30].

2. THE KEY THEORETICAL FACTORS IN AVAILABILITY BASED MAINTENANCE CONTRACTS

Theoretical overview paints a picture of availability; its influencing factors and the state of art of that theory. The overview is divided based on availability factors maintainability, maintenance support and reliability seen from availability based maintenance contracts viewpoint. It describes how these factors will influence to company and availability based maintenance contracts business side and gives a view of the costs incorporated in those. Second, this chapter also takes a stand on how availability can be calculated and measured, and what is the needed information to do that. Third part is illustrating availability based maintenance contract life cycle and its costs.

Fourth part reflect the theoretical review of the tools Reliability Centered Maintenance, RCM, and Root Cause Analysis, RCA. These tools are presented because those assist on enhancing availability. RCM has become a trend tool: it is widely known method in the industries [31-33] and which works very well as an analytical tool for predictive maintenance [31, 34]. Even though RCM is challenging for companies since industries are lacking information and data about its usage and it has not yet found its way to companies' processes, they are eager to take it in and use it as a part of their maintenance strategies [33]. Company A is also investigating the usage of RCM and would like to take steps towards exploiting RCM to meet the strategy goals [9, 26, 28]. RCA on the other hand is a strong tool when confronting unavailability.

2.1 Definitions for availability

Dependability is a general term describing availability of any simple to complex product [1] and it is only used for general descriptions and for non-quantitative terms [35]. In [36] Järviö describes that dependability is used to describe equipment availability and that emphasizes more measurable availability [36]. Availability has a paramount importance to organizations because downtime causes enormous costs to business. [37]

Dependability is formed from availability and its influencing factors: reliability, recoverability, maintainability and maintenance support. [38, 39] In [13] Avizienis et al. do not mention maintenance support as part of dependability which is clearly noted by SFS-EN 13306 and by Järviö [13, 36, 38]. However, they as include security just as SFS-EN 13306 [38]. Avizienis et al. discloses that dependence concept leads to trust which is conveniently defined as accepted dependence [13]. Dependability is integrating concept that encompasses terms:

- Availability: preparedness for corrective service
- reliability: stability of corrective service for example how quickly it fails
- safety: non-existing disastrous consequences for the environment and the users
- integrity: no improper system alterations
- maintainability: competency to go through repairs and modifications for example how quickly failure can be repaired when failure occurs [1, 3, 13, 14].

Availability is an ambiguous term, availability can quickly be determined from standards to have multiple definitions [1]. Availability according to SFS-EN 60300-1 is "*the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided"* [1]. Availability illustrates the time when equipment is available to perform with given conditions when user requires [3, 39].

According to standard SFS-EN 13306 external resources are affecting availability [38]. Availability can be determined as a probability of equipment operating sufficient where the considered total time includes active repair, administrative, operating and logistic times [14, 39]. Non-availability is a combination of how often the equipment becomes unusable and how long it takes to repair it back to service [40]. Availability according to Smith is determined by a proportion of time when system or equipment has not failed. Smith sees unavailability (1 – availability) more useful, because it describes a time period in which equipment has failed. Unavailability can be used to calculate costs of outage by multiplying it with the cost of outage per unit time. [38, 41] Smith sees availability as a parameter which is useful in describing a time proportion in which equipment has not failed [41]. Chiotellis *et al.* sees availability as a probability that in specific time and under certain conditions no relevant fault bring out inoperability of an equipment. Availability may be translated into a percentage of that when equipment is operational. [18]

Murthy and Jack states that with usage and age every item degrades and eventually fails. Designing, manufacturing, maintaining and operating are factors that influence failure occurrence in an uncertain manner. [42] Main aspect that needs to be recognized is that availability is constructed from reliability, maintainability and maintenance support [1, 3]. Availability can also be divided only into reliability and maintainability [43].

Misra does not share all the availability factors with SFS-EN 60300-1 and PSK 6201, his view of availability can be seen in Figure 2. As standards SFS-EN 60300-1 and PSK 6201 states above, Misra also combines reliability and maintainability as key factors in availability when establishing availability of equipment [1, 3, 14]. United States of America Department of Defense, DoD, on the other hand sees that availability can be divided into three categories based on its determining elements: reliability, maintainability and maintenance, and resources [44].

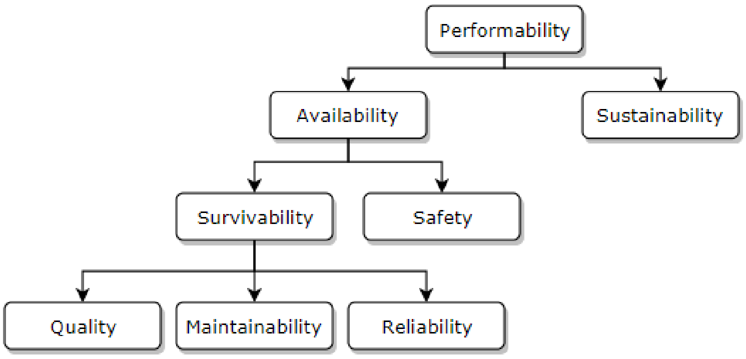

Figure 2. *Performability factors. Adapted from [40]*

Availability can be seen to have two separate events: failure and repair. This is why availability should be calculated based on estimated values, for example Time to Failure, TTF, and Time to Repair, TTR. [17] Defining a maximum level of availability which equipment can achieve, key factors are time to repair, need for repair, reliability and maintainability [45]. Those can be reviewed in a way that time period is not only a specific event in simulation but also a value of parameters [17].

In designing availability, reliability or maintainability data is not often available or it does not exist. Due to engineering complex systems and integrations of those it is almost impossible to gather significant data and information that could be used for objective analysis of probabilities. Therefore, the data used is a measurement and/or an estimation of numerous parameters relevant to each concept. [17]

Designing for availability is concerns optimizing the time period of usage for an equipment. This is directly related into equipment being able to execute a particular function within a schedule. It is possible to translate availability into equipment capability to be in use over a time period. Availability measure can be then translated into a period in which equipment is in a state to be used. [17] In operational use equipment have factors influencing availability. These are for example repair and spare parts, tools, support equipment, maintenance personnel skills, knowledge and performance capacity. [45]

According to Smith there are three key areas for achieving results for reliability, safety and maintainability:

- Design
    - reducing complexity
    - providing fault tolerance by duplication
    - reducing of stress factors
    - testing qualification and review of design
    - providing reliability growth by failure information feedback
- Manufacture
    - controlling materials, changes, methods
    - controlling work standards, methods

- Field of use
    - adequate instructions for maintenance and operating
    - field failure information feedback
    - reveal dormant failures by proof testing
    - strategies for replacement and spare parts. [46]

After a design stage it is more expensive and difficult to add reliability. It is important to add quantified parameters to design specification and it cannot be more reasonably specified retrospectively than for example weight, power consumption and signal-to-noise ratio. [46]

2.2 Availability time concepts and mathematical definition

For calculating availability there are plenty of different methods and options. A simple way is to present availability according to equipment operational condition time or up-time and failure time or downtime. Operational condition downtime or uptime is defined as a timeframe, in which equipment is in a working function or competent to perform required tasks or functions. [39] Inoperable time or downtime means a complement of operational capacity times. Total operating time is a sum of operation inactivity time and operational capacity time. [3]

Overall Equipment Effectiveness, OEE, is widely accepted nessessary quantitative tool for manufacturing operation productivity measurement. OEE is not only for monitoring and controlling, but also essential for formulating and executing Total Productive Maintenance, TPM, improvement strategy. [47] TPM is described as processes that make companies more competitive [48].

In key figure calculation, availability is a time concept and therefore does not include performance and quality rate. According to Nakajima and Ahuja goal of TPM is to improve OEE by reducing six categories of equipment losses:

1. equipment breakdown and failure
2. setup and adjustments
3. idling and minor stoppage
4. reduce speed
5. process defects and rework
6. reduce yield in startup [47, 49].

These losses conduct OEE indicator, which reveal the real efficiency level of scheduled production process. TPM is created to enhance OEE by structurally quantifying these losses and subsequently prioritizing the major ones. TPM provides notion and tools to reach long and short-term improvement. [45]

OEE provides a systematic way to stabilize production objectives and include management techniques and tools in order to obtain balanced view of availability, performance and quality [47]. These three terms give OEE a figure which according to Parida and Kumar is the most important and influential key performance indicator, KPI, when measuring performance. [50] As Juuti describes, availability of different equipment may vary in which case fixed assets might need to be divided into groups for examination. Juuti also argues that it is important to notice variability of availability when it comes to equipment that have been in operation in different time periods. They might have the same availability but one has been in operation for months and the other for year. [51] OEE can give a daily snapshot of an equipment and promote information openness and sharing equipment handling issues [47].

Ahuja argues that through observations it has been noticed that besides equipment related losses, it is necessary to investigate and address the losses with appropriate way to achieve world class performance. These other losses are the ones affecting human performance, energy and yield inefficiencies. [47] Ahuja depict McKellen's (2005) OEE calculation tool [47] based on 6 major losses presented earlier. Figure 3 illustrates the OEE calculation. Tool uses OEE metrics and is designed to help establish discipline reporting system to help organization focus on critical parameters for the success. OEE gives a starting point for companies who want to develop quantitative variables – relating maintenance measurements – into corporate strategy. [47]

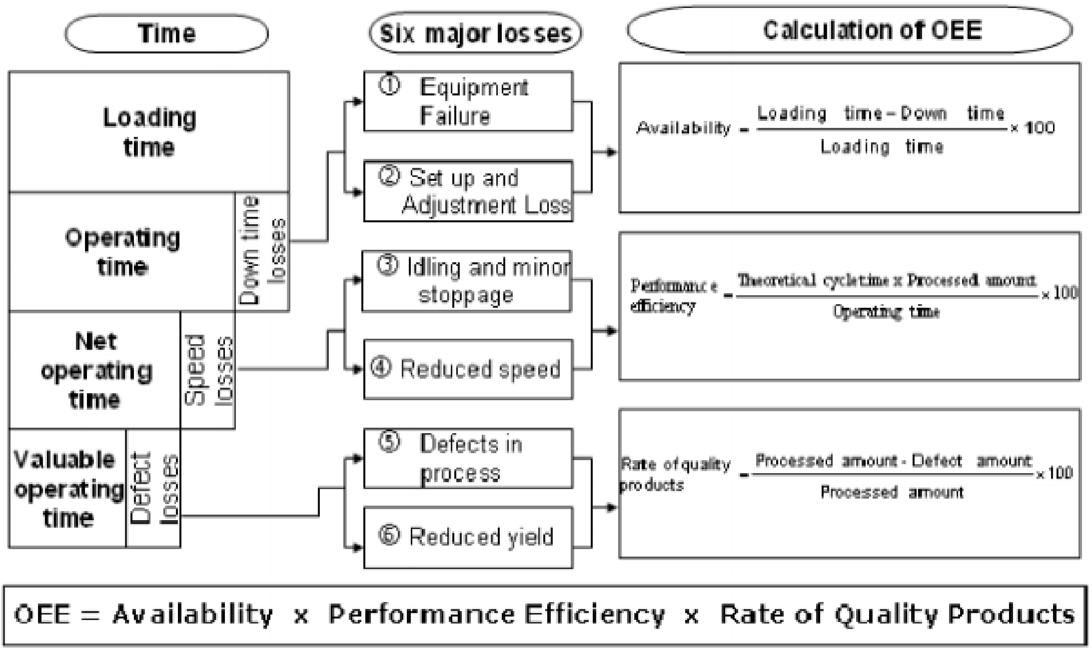

Figure 3. *Calculation for OEE according to 6 major losses [47].*

OEE can be seen as a productivity improvement process that gives management perception of TPM and commitment to focus on training workforces with liaison and cross-functional equipment problem determining. These kinds of teams which determine the root causes drive the biggest improvement and produce real bottom-line earnings. [47] 16 major losses can be calculated as illustrated in Table 1.

Table 1. *OEE calculation with 16 major losses [47].*

A	AVAILABILITY
1	Equipment failure loss
1A	Parts failure
1B	Parts adjustment
2	Setup and adjustment loss
3	Tool change loss
4	Startup loss
5	Minor Stoppage loss
6	Reduced speed loss
7	Defect and rework loss
8	Scheduled downtime
8A	Cleaning and checking
8B	Planned maintenance
8C	Meetings
9	Management loss
9A	Waiting for spares and tools
9B	Waiting for instruction
9C	Waiting for material
9D	Waiting for menpower
9E	Waiting for power
9F	Waiting for inspection
Total non-utilized hours (a)	
Hours available (b)	
Availability = (b-a)/b	

B	PERFORMANCE FFICIENCY
Output achieved for *(b-a)=c*	
Standard output for *(b-a)=d*	
Performance efficiency = *c/d*	

C	QUALITY
Quality produced (e)	
Quality under RT (f)	
Quality scrapped (g)	
Rate of good components produced = *{e-(f-g)}/e*	

OEE = A x B x C

Ahuja describes down and repair time in which downtime and repair time consist of 7 phases: realization, access, diagnosis, spares, replace, check and align. Phases can be influenced by logistic, administrative time and access at any given time and in no specific sequence. [47] Downtime means the total time taken to repair equipment. With this determination, Misra and Ahuja describe uptime as a time period when equipment or system is available or operating. [16, 47] Equipment goes through several cycles of down and operating states during a lifetime before disposal. [16]

Mirghani argues that organization can gain uptime with effectively planned maintenance management. In Mirghani's case uptime is linked to the capacity of consistently produce and provide service for satisfactor the customer. Heavy investment for serving customers – when capital assets are needed – make it critical for capital intensive organizations. [48] Both down and uptimes are random variables which are characterized by repair and failure time distributions [45]. Total time is calculated from adding uptime to downtime [44, 46].

DoD sees that in practice downtime has at least two parts. First is logistic downtime, the time when waiting the spare parts to come through the supply chain. Second one is the time when the repair is done. This can include maintenance time and the time spend in queue waiting for maintenance personnel to start the work [44]. This can be described as:

$$Downtime = Active\ repair\ time \\ +Administrative\ delay\ time \\ +Logistical\ delay\ time \quad (1)$$

Definition of availability, A, depends on the viewpoint and intended use. The review subject can be a single equipment or production system. [36] Performance variables link availability into reliability and maintainability and are included with time measures which are target to equipment failure. Measures mentioned are Mean Time between Failures, MTBF, Mean Downtime, MDT, and Mean Time to Repair, MTTR. [17] Riane *et al.* describe that in practice, ratio between mean time equipment operated, Mean Time to Failure, MTTF, [15, 52] and MTBF equals to asymptotic availability [15].

According to Ben-Daya *et al.* MTTF is average uptime, which is independent and identically distributed with distribution function. MTTR on the other hand is the average downtime which is similarly distributed than uptimes. [45] Ben-Daya *et al.* extrapolate an insight that it is possible to improve equipment availability by either decreasing MTTR by improving maintainability or by increasing MTTF by improving reliability [45].

According to Smith, difference in MTTF and MTBF is in their usage. MTTF links to items that are not repaired, for example transistors and bearings. MTBF links to items that are repaired. It is important to remember that the time between failures exclude downtime [46]. It is imperative that there is a relationship between MTBF, cost and MTTR versus cost before any transaction takes place. From practical considerations upper and lower limits of MTTF and MTBF and the state of available technology should be recognized. For MTTF and MTBF this will help to strengthen feasibility. [16]

Speaking statistically uptimes and downtimes are random variables which distribute in their own ways [16, 44]. Based on distribution it is possible to calculate MTTF and MDT. Misra argues that MTTF projects on how good the inherent design or built-in reliability is. For example, MDT projects on how good maintainability is. Misra also emphasises that designing for high availability and maintaining equipment life cycle costs should always be remembered. [16]

MDT includes following time sensitive matters:

- maintenance instruction consulation
- preparing platform, for example external power for connecting safety devices to conduct maintenance
- maintenance during performance
- waiting equipment, parts or personnel during maintenance task
- diagnostic; when failure is detected and isolated

- position removal or repair and replacement of the failed part for repair
- repair validation requires for example sunctional check
- administrative and other logistic delays [44].

MTTR is a function of maintainability including:

- diagnostic time
- time to repair
- required time to validate a repair [44].

As earlier stated, availability is depended to a viewpoint. There are different types of availability [3, 18, 39, 42, 46, 48, 51]. For example point availability, inherent or steady state availability and interval availability. Point availability is a probability that at given time equipment is available. Inherent availability is average of long period of time when it is possible to asses performance of a maintaned or repaired equipment. Interval availability is expected fraction of a specific length interval that equipment is running. [19] On the other hand classifying availability with downtime incorporates:

- operational availability
- preventive and corrective maintenance determined by achieved availability
- corrective maintenance determined by inherent availability [14].

Equipment availability can be separated to theoretical, technical and practical availability. Theoretical availability can be formed with a simulation of production system. Technical availability can be handeled with intelligent control in which execution can be centralized or distributed by coordination of handling equipment. Defining practical availability requires evaluating all system states by their usage, service time or idle. This is easily done with real time capture and using real time data. Real time data requires capture of all incoming data according to generation time. [18]

If intent is to retain high inherent availability designing for high MTTF and low MDT is a key factor [16]. According to Amari *et al.* inherent availability and steady state failure frequency are important measures of repairable equipment. Steady state failure frequency is in a long period a number of failures per unit time. [52]

Inherent availability describes all difficulties interpretation described about dangers of MTBF. It is important to remember that availability cannot tell a difference between 10 outages of 5 minutes each or 50 minute outage. [37] DoD see that inherent availability is appropriate measure only when designing is considered in availability [44]. From these, it is seen that MTTF and MTBF serves the same purpose.

Operational availability due to maintenance works as a key indicator which can be used to evaluate maintenance [36]. Allowances from a broader set of availability sources are included in operational availability downtime [14]. Operational availability A_O is calculated as follows:

$$A_O = \frac{Uptime}{Total\ time} = \frac{Uptime}{Uptime+Downtime}$$

$$= \frac{Average\ uptime}{Average\ uptime+Average\ downtime} \quad (2)$$

where average up time is mean time between maintenance actions comprising corrective and preventive maintenance [14, 44], it is then equipment uptime. [14] Combination of equations (1) and (2) can be used to describe operation availability factors which are presented in Figure 4.

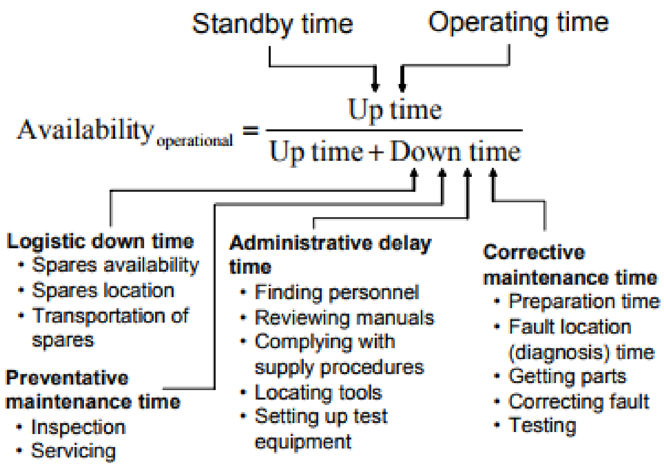

Figure 4. *Factors to be calculated into operational availability [14, 47].*

DoD argues that operational availability does not give a truthful indicator of achieved availability if measurement point is brief compared to reliability and maintainability parameters [44]. From 0 it is possible to see that downtime is formed from Mean Maintenance Time, MMT (preventative and corrective maintenance time), and from Mean Logistic Downtime, MLDT, which include Logistic Delay Time, LDT (or logistic downtime) and Administrative Delay Time, ADL. With this information it is possible to translate operational availability as follows:

$$A_O = \frac{MTBM}{MTBM+MDT} = \frac{MTBM}{MTBM+MMT+MLDT} = \frac{MTBM}{MTBM+MMT+LDT+ADT} \quad (3)$$

Availability time is dependent on a waiting or repair time, on maintenance effectiveness. Management objective is to minimize inventory levels, enhance availability time, quality rate and production. [50] Availability can be estimated by using a weighted average of usability figures for parallel equipment or lines. For more complex production system availability can be calculated by applying above calculation methods at the same time. [36]

As availability is formed from reliability, maintainability and maintenance support, Table 2 illustrates how reliability and maintainability factors effect operational availability. It illustrates how increase and decrease in reliability and/or maintainability changes operational availability. It also present underlying issues for operational availability chiftment.

Table 2. *Reliability and maintainability impact on operational availability. Adapted from [44]*

Reliability parameter	Maintainability parameter	Impact on Ao	Reliability and maintainability considerations (reason for Ao change)

↗	=	↗	• Improved design reliability
			• More efficient screening tests in OEM
			• Reducting number of
			  ○ induced failures
			  ○ incidents where failure can not be verified
			• Increased time between PM actions

↙	=	↙	• Negative impact on reliability due to design modifications
			• Screening test efficiency reduced
			• Increased:
			  ○ maintenance induced failures
			  ○ number of unverified failures
			• Shorter time between PM actions

=	↗	↙	• Lower-skilled maintenance personnel
			• Increased delay
			  ○ paperwork
			  ○ repair pasts unavailability
			• Product performance limits and test equipment measurement limit improper correlation
			• mishandling of the product during repair induced failure causes

=	↙	↗	• Increased maintenance personnel training and learning • Repair parts readily available and paperwork reduction • Efficiency increased with correctly verifying and isolating failures • Equipment proper handling during maintenance • Product performance limits and test equipment measurement limits correlation improved

Some of the interruptions that affect plant's effectivenes are machine breakdowns, over time degradation of performance and accidents. The plant's maintenance policy and safety performance is in a significant role on achieving the operational effectiveness in the plant. Management has to depend on plants predicted capacity in order to meet the delivery schedules, quality, quantity and cost. Maintenance productivity needs to be defined specific and according to organization. According to Parida and Kumar this is a must in order to achieve a uniformity and transparency between all the employees and stakeholders. [50]

2.3 Maintainability and maintenance support in availability

Currently production breakdowns cost companies millions of euros [53]. This chapter will address maintainability and maintenance support roles in availability. It will present the factors influencing those and what kind of possible changes those might create when designing availability.

2.3.1 The definition of maintainability

One of the contributors for equipment availability is maintainability. Maintainability is a combination of repair and failure rate or downtime which defines unavailability. [46] Maintainability is equipment ability to be kept or restored into the state where it can perform needed actions under specified operating conditions [1, 3]. Maintainability can be seen as a probability where within a given time failed item restores its operational effectiveness when actions to repair are performed according to prescribed procedures [14, 16, 41, 46, 54]. Järviö has gathered and combined PSK 6201 factors into three key drivers [36]. Maintainability factors are presented in Table 3. Designers should consider following factors when designing complex equipment maintenance task. [36]

Table 3. *Factors in designing complex equipment. Adapted from [36, 54]*

Factor	Factor includes
Serviceability	Equipment standardization, modularity, accessibility and amount of testability built in
Detectability of the fault	Detecting the fault, tests, instrumentation and automatic condition monitoring, and productive work
Reparability	Availability and usability of documentation, availability of spare parts and materials, accessibility to an object, human resources, assembly, testing, adjusting, work safety, reporting, updating documentations and developing actions

Maintainability is dependent on all downtime factors, including administrative, logistic and active repair times [14, 16]. Maintainability is equal to reparability; the difference is that maintainability consists of total downtime [14]. Equipment easy maintenance and reparability are the factors that indicate whether high maintainability performance is obtained. [54]

Traditionally it has been a maintenance people problem to know equipment characteristics and not the designer's. This has been changing, since customers have recognized the significance of the information and have made it as needed as for example power, weight and speed. Equipment characteristics have become more important as they are considered to contribute to the reducing maintenance cost during operational life. Maintainability objective is to deliver stability to corrective and preventive maintenance, at least in overall cost. [55]

Designing equipment properly and implementing budget and cost have an important role in improving a maintenance function efficiency and effectiveness [48]. Key maintainability measure is mean duration of maintenance task. This measurement provides useful information for design, operation and maintenance engineering related to planning logistic support resources, regulation for an impact of operational availability and logistic delay time of equipment. [55] Maintainability is generally measured with

MTTR which incorporates total time of finding a failure and the actual time repair is carried out [54].

2.3.2 Depiction of maintenance support

SFS-EN 60300-1 defines maintenance support as following "*the ability of a maintenance organization, under given conditions, to provide upon demand, the resources required to maintain an item, under a given maintenance policy*" [1]. Maintenance support describes maintenance organization's ability to perform needed functions effectively in a required time or time period [36]. Factors effecting maintenance support are described in Table 4.

Table 4. *Components included in maintenance support factors. Adapted from [36]*

Factor	Factor includes
Management	Key individual in organization, control systems and computerized maintenance management system
Routines, systems	Action instructions, communication between operation and maintenance, cooperation and working cooperation with a supplier
Documentation	Instructions, maintenance instructions, content quality and relevant fault histories. Correctly done documentation is one of key elements in efficient maintenance
Repairing equipment	Tools availability
Spare parts, materials	Storage, availability and acquisition are expensive and labor-intensive activities
Maintenance workers	Enough skilled and capable maintenance workers in the right place and at the right time, keeping and developing their knowledge and skills must be taken care of constantly. Also, motivation and customer service need to be taken into account.

Knezevic describes that logistic factors need to be specified, measured and controlled to fulfill system's ultimate mission. Maintainability is tightly related to area of system support. Maintenance requirements are directly affected by the maintainability results. System supports qualitative and quantitative requirements which need to be addressed when specifying maintainability factors. This way it is possible to determine impacts between different areas. [55]

2.4 Reliability: The "R" in RCM

Reliability according to SFS-EN 60300-1 is "*the ability of an item to perform a required function under given conditions for a given time interval*" [1]. Reliability is a probability that system or equipment performs needed action under specific conditions for a stated period of time. Therefore it can be said that reliability is prolongation of quality into time range and may be translated as a probability of non-failure in a stated time. [36, 46, 56]

According to O'Connor methods of statistic for example measuring, analyzing and predicting reliability have been developed and taught so widely that engineers view it as a special topic based on statistics. This is a reason why most articles, books and conference papers related to reliability consider statistical aspects [57] Availability and maintainability are often assessed for repairable systems, not for example reliability which is assessed for non-repairable system with no regard whether system is repaired or restored to service after failure or not. [17]

Reliability does not take into consideration backup for failed item in forms of replacement, restoration or multiple failures with standby reliability for example redundancy. [17] Main factors influencing reliability are presented in a following Table 5.

Table 5. *Components included in reliability factors. Adapted from [36]*

Factor	**Factor includes**
Construction	Equipment design data, material and their dimensions and design principles
Structural maintenance	Accessibility, easy troubleshooting and repair such as technical difficulty, safety and use of special tools
Installation	Installations technical performance, delivery and use guidance, maintenance plans and documentation, documentations need to be machine-specific
Maintenance	Proactive maintenance and maintenance implementation
Utilization	Physical ability, training and motivation
Confirmation	Availability and selection method

Ability of equipment to work over its expected time in use without failure is descripted as reliability in the engineering context. This gives dependence for equipment reliability on how good the design is to withstand using conditions, how good is the manufacturing quality and how well it is maintained and used. [57] Reliability is therefore objects capability – a feature. Drawing a line between reliability and maintainability factors can be difficult at times, some concepts even are overlapping. [36] Important factors to equipment reliability are usage period and environment of use [54].

Equipment's reliability is a popular approach to complex systems maintenance. Time to failure distribution is seen as a correct way to estimate reliability. [58] Restricting factors in making equipment and system reliable are effort, skill and knowledge. It is possible to create equipment as reliable as needed or wanted, then it is possible to say that reliability as a measurement is a statement of history. As the history data is used in creating a reliable equipment. [57] Reliability may be used as an alternative to enhance maintenance performance [59]. Reliability indicator is MTBF [36]. Duffuaa and Haroun argue that it is essential to maintain major and critical equipment history and to estimate calculations of MTBF [59]. Mean Time between Maintenance, MTBM, according to

Knezevic is an average time between maintenance tasks, preventive and corrective. Determining system or equipment achieved and operational availability MTBM as a maintenance frequency factor is a substantial parameter. [55]

2.4.1 Finding a business side of maintenance

Business Centered Maintenance, BCM, consists of a framework based on identification of objectives in business. BMC needs excessive amount of data, because business objectives are translated into maintenance objectives as seen in Figure 5. The main thrust towards BCM is to maximize maintenance contribution to profitability. Fundamental difference between Reliability Centered Maintenance, RCM, and BCM is that BCM is more focused on maximizing technical performance. [60]

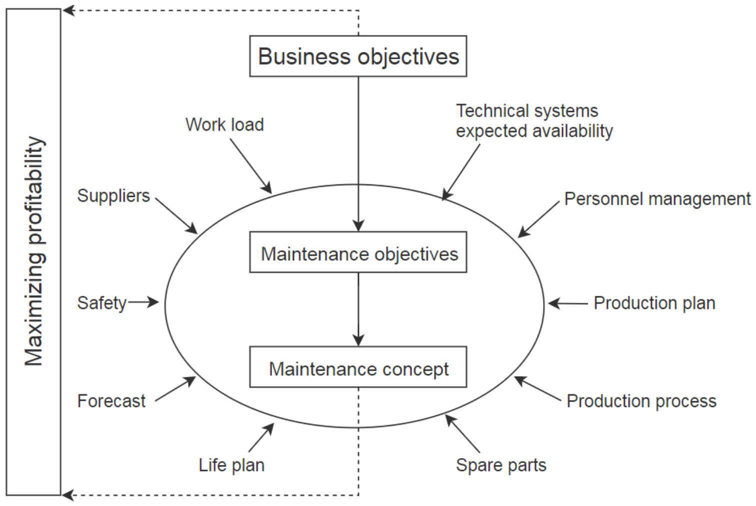

Figure 5. *Maximizing profitability with BCM. Adapted from [60]*

Operating load is affecting equipment just as maintenance actions. Production plans and decisions effected by commercial needs and marked consideration are included in operating load. This is why maintenance planning is an important factor in maintenance decisions, production planning, inherent reliability and in requirements of commercial and marketing. [49] The biggest influencer is business objectives [49, 61], but also other factors are influencing the maintenance objective [61].

Al-Turki emphasizes that it is important for major maintenance function to have strategic plan, objectives and goals which are align with a whole organizations objectives and goals. Maintenance strategies should be selected from alternatives to achieve these objectives. In Al-Turki’s vision corporation strategy is influencing maintenance strategy plan [62]. He adds factors to Figure 5, which are imported from maintenance strategies and presented in Figure 6.

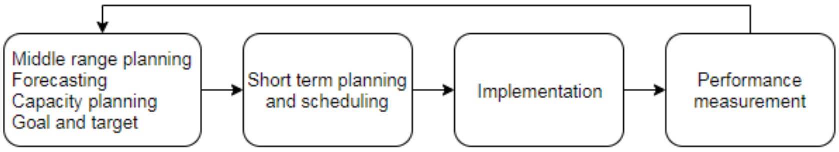

Figure 6. *Planning process of maintenance [62].*

Various companies with manufacturing and service excellence are starting to see maintenance as a source of revenue by investing to relationships between maintenance units and engineering [48]. Maintenance objectives and strategy are integrating different organization levels involving employees in every level [50]. This change in objective has given companies a push to outsource their in-house maintenance. Internal pressure serves as an incentive for equipment to be more competitive and profitable. [48]

In maintenance management, planning and scheduling are the most important things to consider. When done effectively it will have significant effects on reducing maintenance costs, delays and interruption. Adopting best methodologies and procedures will improve quality of maintenance work. [62]

Maintenance can be presented as an unsophisticated input/output organism as seen in Figure 7. An efficient maintenance control organization furbishes equipment reliability and supports in the resources optimum utilization. Maintenance management reference to a set of tools, activities and procedures utilized to organize and allocate maintenance resources to achieve maintenance organization targets that are indispensable for the following quality, cost, process and work control and an effective feedback and reporting organization. [59]

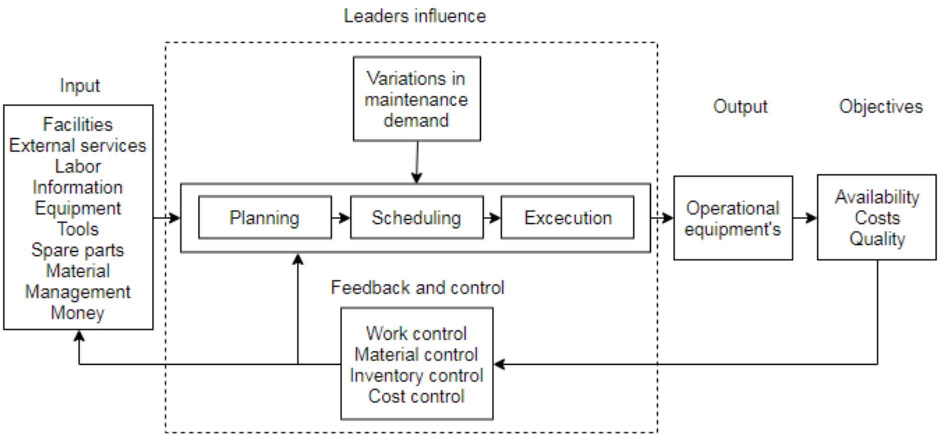

Figure 7. *Enterprise control in maintenance. Adapted from [59, 62]*

Planning part of maintenance control develops achieving goals and targets. In maintenance these can be measures of availability, quality rates and production. Management provides resources, organizes and drives to perform actions and obtain targets. Plans are implemented to achieve prospective goals like measuring performance and estimating which objectives have been achieve and what are needed for corrective measures. [59] In Figure 7 dashed line illustrates management action, its subactions and interactions.

Planning and forecasting maintenance load as one of the key factors in maintenance. It is important to plan maintenance load so that it is possible to do predictive maintenance. Al-Turki sees that it is necessary to have at least 80 % of the maintenance load planned. [62]

Unplanned maintenance is a key factor which reduces uncertainties when planning maintenance resources and coordinating maintenance accomplishment. Second key factor in maintenance is work order planning and scheduling, which are dealing with planning and allocating resources available. Executing the work and monitoring functions, function is a phase when data is collected for assessments of work quality and recourse utilization. After analysis, information is understandable for decision makers and they can do corrective actions to achieve goals and objectives set earlier. [62]

According to Al-Turki, managers might make historical comperison by using past performance to assess current performance. Relative comparison compares other person's performance achievings, work units or organizations as a benchmarking evaluation. In maintenance comparison scientifical standards are set based on time and motion studies. [62]

One main step in maintenance control is to take essential actions to correct problems, make improvements or discrepancies. Management need to give attention to show need for actions in a situations. This will save energy, time and resources when attention is focused on critical and priritized areas. Al-Turki sees two different types of exceptions that needs special attention: problem and opportunity situations. Cause for this is, with a goal of existence, organizations need to find a way for achieving high level productivity. [62]

2.4.2 Maintenance as a starting point for availability

Ahuja agrees with Misra and Kumar maintenance has undergone a transformation in the last three decades [16, 47, 54]. Maintenance expectations have raised the bar with cost effectiveness [16]. Ahuja divides maintenance progress into nine significant strategy influencers [47] described in Table 6 starting from the oldest strategy.

Table 6. *Maintenance types and strategies. Adapted from [16, 36, 39, 47, 48]*

Maintenance type	Maintenance strategy
Breakdown maintenance, BM	Repair and restoration starts after equipment failure/stoppage and equipment's are served only when repair is required [47].
Preventive maintenance, PM or scheduled maintenance	Check-ups are done physically to prevent breakdowns and prolong equipment lifetime, it is done after specific period of time or amount of usage [47, 48]. Goal is to reduce failure possibility or deterioration of functional capacity [36, 39, 48].
Predictive	Launched as a response to equipment condition or deterioration of

maintenance, PdM or condition based maintenance	performance based on monitoring and analysis [36, 39, 47]. Carried out when enough physical data has been collected and evaluated [16] for example: noise, lubrication and corrosion [16, 47].
Corrective maintenance, CM	CM is done after detecting the fault [36, 39]. CM eliminates failures (improving reliability) and improves maintainability [47].
Maintenance prevention, MP	Piece of equipment is designed maintenance-free and ultimate ideal condition is achieved. Goal is to ensure reliability and easy to care user friendly equipment. MP is done based on the earlier experience from failures and other factors. [47]
Reliability centered maintenance, RCM	Logical and structured process for optimization and developing maintenance requirements to comprehend "inherent reliability" [16].
Productive mainte-nance, PrM	Raising equipment productivity with the most economic maintenance. Goal is to increase productivity by reducing equipment total cost over the life cycle. Focus on reliability and maintainability. [47]
Computerized maintenance management system, CMMS	Goal is to manage information on spare part inventories, maintenance workforce, repair schedules and equipment history. Created to auto-mate PM function and control purchase of materials and maintenance inventories. [47]
Total productive maintenance, TPM	Innovative approach to optimize equipment effectiveness, breakdown elimination and promote autonomous maintenance. [47]

Järviö and SFS-EN 13306 also describe four other maintenance strategies which are presented next. Deferred maintenance, in which maintenance action is deferred for example due to costs and done later on. Immediate maintenance, where delayed maitnenance is executed after detection of fault. Remote maintenance, where maintenance is done without maintenance grew directly dealing with the equipment. Run to failure or operate to failure, which is reactive maintenance where equipment is not in PM and only normal maintenance actions are done. This is used only in low value equipments where failure does not hinder production. [36, 39]

Maintenance strategies are currently seen as a part of maintenance [47]. Links between strategies are illustrated in Figure 8. Maintenance is often referred as preventive and corrective maintenance or planned and unplanned maintenance [3, 39, 61]. Subcategories are formed based on facts how much information is already available and existing, and whether maintenance is done in a rush or not. Pintelon and Muchiri divide preventive maintenance into two categories: use-based and condition-based, which are very much similar with SFS-EN 13306 and PSK 6201 [3, 39, 61]. SFS-EN 13306 sees deferred corrective maintenance as a part of corrective maintenance but it is possible to see it as part of preventive maintenance [39]. Predictive maintenance can also be divided into RCM and Condition Based Maintenance, CBM [58].

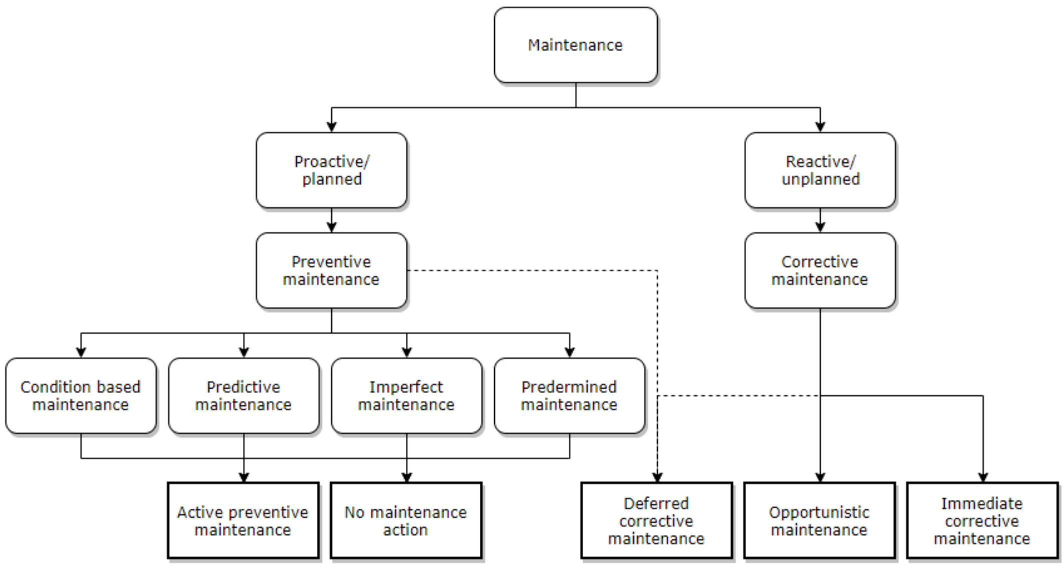

Figure 8. *Maintenance overview. Adapted from [3, 38, 39, 58, 61]*

Standards SFS-EN 13306 and PSK 6201 depict equipment time states [3, 39] which are described in Figure 9. State is a time when equipment is not in down state, during this time equipment can either be in operation, standby, idle or external disable state [39]. As stated earlier, up state can be referred as uptime [16].

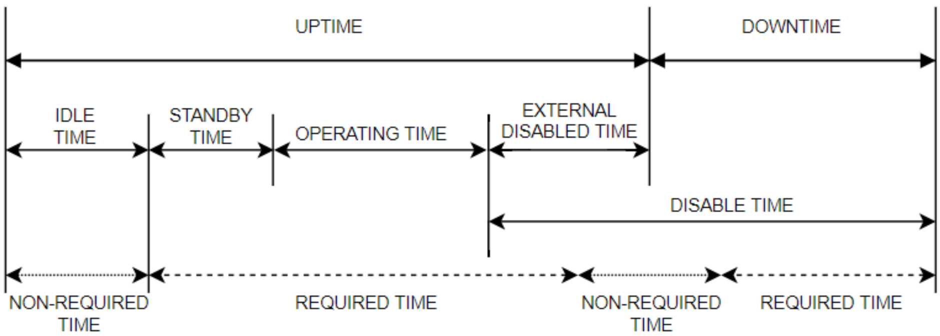

Figure 9. *Stages of equipment or system. Adapted from [39]*

According to Järviö corporations are emphasizing maintenance efficiency. Part of functional reliability is based on equipment being in perfect condition. This is one way to reduce probability of a domino-effect. If maintenance is inefficient faults are accelerating emergence of failures and in a moment whole system falls apart. Breakdowns are often a result of poor maintenance, inferior materials and spare parts that are rather breaking than fixing a problem. [36]

DoD argues that equipment will always be available for use if zero preventive and corrective maintenance is performed, then it becomes a matter of acceptable mission reliability. In these cases, availability is 100 %. In practice availability is never perfect since failures occur and take more than zero amount of time to prevent repair or do them. [44]

By combining previous theory, it is noticeable that data rises to more essential role. Being able to follow, calculate, develop and evaluate data is a key for doing maintenance more efficiently. Kumar describes a process of collecting raw data and transforming it into valuable knowledge and information. Data can be turned into information, and information can become knowledge, either by manual process or by use of artificial intelligent. Information can then be processed for the companies knowledge. [54]

2.5 What does availability based maintenance contract incorporate?

Availability has a paramount importance to organizations because of the massive costs downtime makes to enterprise [37]. One of the main differences in availability based maintenance contract and spare part type or original maintenance contract is that in availability based maintenance contract vendor provides planned predictive and preventive maintenance within a fixed schedule. In maintenance contract customer takes care of the responsibility of maintenance and repair tasks of equipment. In maintenance contract customer pays for replace parts in contrast to availability based maintenance contracts where vendor often provides the replaced parts. [63]

2.5.1 Maintenance contract life cycle

Due to fast technological developments, management might want to focus the attention and resources to companies core business. The preferable way seems to be to outsource maintenance or services. This is to allocate the business liabilities with eather original equipment manufacturer or with supplier. [54]

Cullen sees life cycle of contract being divided into 4 different phases: architect, engage, operate and regenerate, as shown in Figure 10. Last block in architect phase is design, which goal is to create a future state as detailed as possible. In this phase the Service Level Agreement, SLA, and other caracteristics and measurements are defined to be able to follow the contracts stage and to create a possibility to be able to make improvements needed for the better. [64]

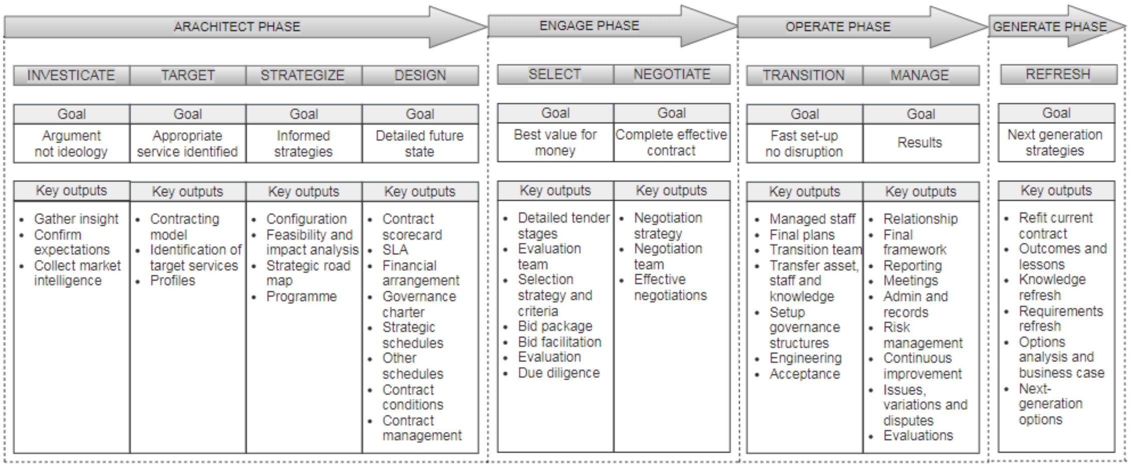

Figure 10. *The contract life cycle. Adapted from [64]*

Operating phase starts with transition which should be done fast. In operating phase contract is taking its first steps in customer plant. This phase is about setting staff into contract suppliers path and it is about managing, teaching people and earning acceptance. In this phase it is nessesary to make needed decisions fast and contract supplier to act fast to make transition go as smooth as possible. Second stage of operating phase is about managing the plant and creating results. This stage attempts to gather reports, manage risk and evaluate status of a contract. [64]

2.5.2 Key Performance Indicator factors influencing availability

Ahuja writes about how important performance metrics are within a physical resources management process [47]. The selection of a set of Key Performance Indicators, KPIs, is a key on defining the performance evaluation of functions in delivering service [65]. These metrics assist management and plant personnel to comprehend business and mission requirement and also to identify opportunities which could increase effectiveness and to measure performance objectives. According to Ahuja organizations need to establish KPIs, to measure parametric through all metric system classes. [47] In a fixed price contract KPIs define how the pain and gain share mechanisms work. [65]

To demonstrate contributions to manufacturing effectiveness equipment management indicators need to be brief and connected straight to company or mission goals. If too many regions are focused at once, it can lead to information overload and increase difficulty for controlling limited resources for major value activities. KPIs are essential for establishing targets, measuring performance and reinforcing favorable behavior for realizing world class maintenance. [47]

2.6 Factors to consider in availability based maintenance contract costs

Improving reliability, maintainability and safety will clearly reduce life cycle costs, but this will increase activities to achieve them. It is important to figure out an optimum balance which minimizes the total cost. Life cycle costs including unavailability can be greater than a typical project cost. Hence, even small enhancements in MTBF or availability easily lead to additional costs. [41] O'Connor describes that traditionally cost of quality and reliability are seen as a progressive curve when quality or reliability increases and comes closer to 100 % costs of those increases exponentially. A modern way of thinking sees that when quality and reliability are approaching 100 %, costs of quality and reliability are decreasing with total costs [57]. Differences can be seen in Figure 11.

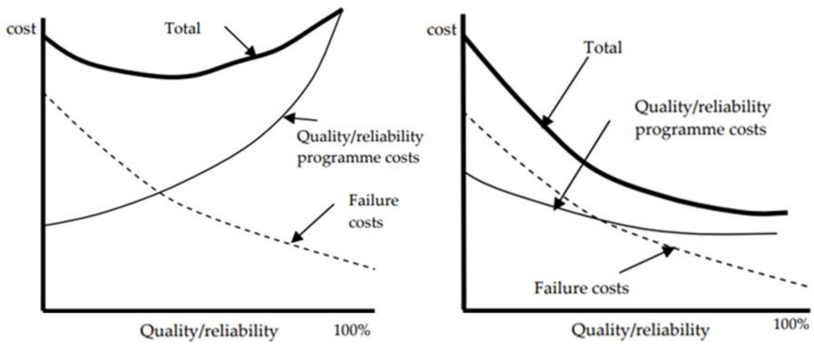

Figure 11. *Traditional and modern views of quality and reliability costs [57]*

O'Connor states that reliability is frequently described as probability but it is an attraction for statisticians too. Reliability can be displayed as MTBF for a repairable system or as MTTF for non-repairable item. It is also possible to display reliability as inverse of failure or hazard rate. [57] Lad *et al.* sees failure free operation as a probability of reliability which is for not maintained equipment normally chosen criteria of design No matter what the performance assessment index be, it should be able to create mathematical model that fits into the present techniques of solution for the problem of the system design. [66]

Maintaining competitiveness is a key to reduce maintenance costs in finished product. This means that when total costs increase, it is possible to get more done with a same amount of money. [36] After capital and raw material, maintenance is one of the biggest an uncontrollable cost in companies. It is made as a priority to manage maintenance and control costs. Maintenance is indirect cost to a company result. Looking at the maintenance effect (Figure 12) to profitability, it is important for the maintenance technicians to follow the costs and profit of maintenance so that technicians can be more profitable for the company. [36]

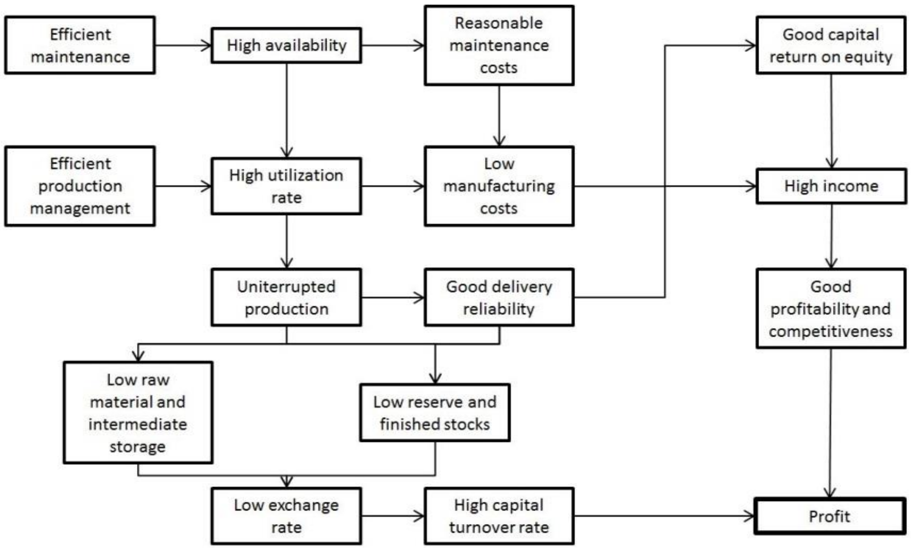

Figure 12. *The impact of maintenance on profitability. Adapted from [36]*

Sandborn and Myers see that availability comes with potentially significant life cycle costs, including the following:

- loss of sales or point-of-sale system
- loss of manufacturing operation capacity
- loss of customer confidence
- loss of mission or assets [14].

According to Pintelon and Muchiri, modifications are more expensive to make when going further in equipment design or construction cycle. This is one of reasons why maintenance needs to be considered in a first moment of design phase. Pintelon and Muchiri states that equipment which has the lowers price is not always the cheapest when comparing maintenance and operation cost. It is well known that equipment with minimal life cycle cost are not the safest. [61]

Riane *et al.* sees that from costing viewpoint, determinating an optimal preventive maintenance scheduled by periods criteria demands a cost model. It has been established that with corrective and preventive maintenance losses and costs in maintenance are different. [15] Figure 13 illustrats availability in a function of maintenance periodicity, it also represent a visualization of preventive maintenance period with a function of maintenance costs.

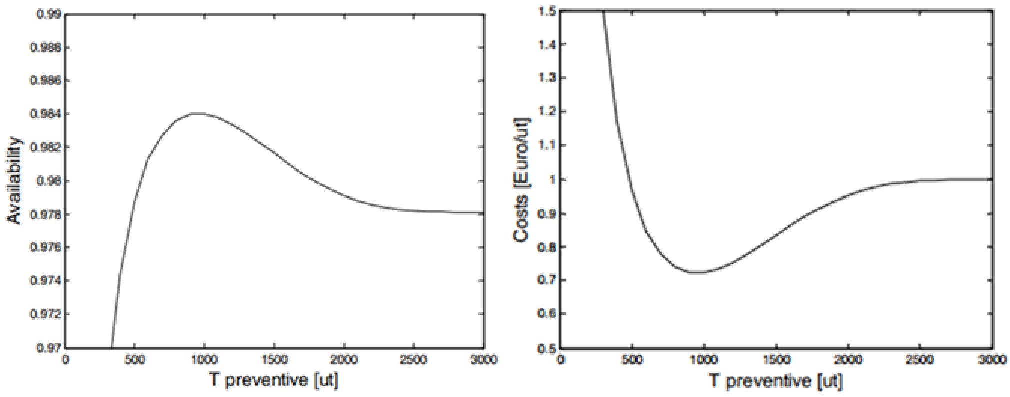

Figure 13. *Availability and maintenance costs as a function of maintenance periodicity. Adapted from [15]*

From the curve it can be seen that equipment hazard function increases with time. Minimum point can be seen to be depending on costs and interventions time on maintenance. [15] It is also visible that availability is growing when costs are decreasing and vice versa.

For total life cycle cost a major segment comes from maintenance cost. It is also studied that early design decisions contributes to maintenance costs significantly. [55] Two factors influencing maintenance cost are efficiency improvement and new maintenance techniques [36]. Knezevic emphasizes that it is essential to consider total life cycle cost as an important parameter in design starting from equipment requirements. Maintainability affects design which is a result in achievement of maintenance at minimum overall cost. [55]

Knezevic states that according to Lowery and Blanchard cost related indices can be adequate criteria in design:

1. cost per maintenance action, euros/month
2. maintenance cost per system Operating Hours, euros/OH
3. maintenance cost per month, euros/month
4. maintenance cost per mission or mission segment, euros/mission
5. ratio of maintenance cost to total life cycle cost [55].

From cost escalator in Figure 14 it can be seen that there are three different stages in incorrect path. First one is in the architect phase of contract life cycle. Usually in this stage there are unrealistic expectations, over simplification of life cycle and no guiding strategy for future model. Second stage is in engage phase of the contract life cycle. In this stage there are invalid assumptions, uncalculated expectations and protracted negotiations. This usually is the one that turns contract costs in to steep increase. Third stage, is done in operating and generating phase where the contract loses all control, service becomes inadequte and there are constant renegotiations and disputes. This leads almost always to full or partial termination of contract. [64]

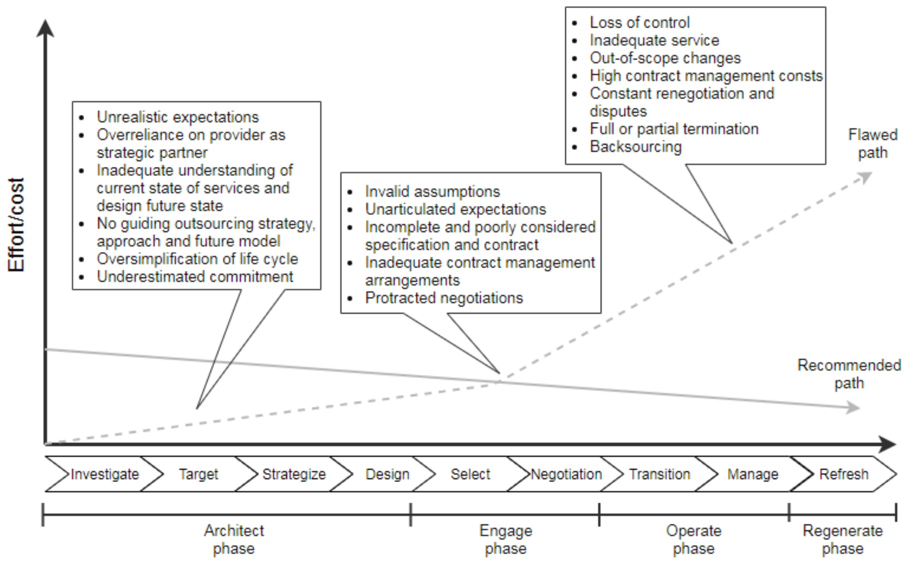

Figure 14. *Life cycle cost escalation. Adapted from [64]*

If these stages are tackled correctly contract supplier might be able to take recommended path in Figure 14. In this path effort and cost are constantly decreasing and contract is easier to manage. [64] Misra sees that many contracts are written with availability clauses, this means that part of the price paid in the contract is a function of the products availability that cusomer truly experiences [14].

New aspect in availability based contracting is a fact that traditional service acquisition is replaced. Availability based contracts measure service delivery and available use of products. These contracts are often compulsory where availability can be measured. This is often a case in product centric services for example support and maintenance, but it is not easily measured purely for services. [67]

Availability can be seen as a business performance measure turning maintenance operations and reliability into main performance drivers. Different cost estimation techniques combinations for example parametric techniques and analogy-based methodology with additional simulation models use cost maintenance offerings. Further used techniques are data and information intensive and rely much on available historical maintenance data. [67]

2.7 Introducing key tools: reliability centered maintenance, RCM, and root cause analysis, RCA

Reliability Centered Maintenance, RCM, can be considered as a tool to enhance maintenance policies and improve reliability of equipment. Rather than bringing equipment into ideal condition, maintenance program tackles basic concepts of restoring equipment function. [59] With RCM, it is possible to develop design priorities to effectively facilitate preventive maintenance. It is a useful tool for achieving reliability and availability goals with minimal total cost. [34]

Solving troubleshooting and failure key aspects of enhancing availability, they are important for developing equipment availability [36]. To improve availability with correct action, it is essential to find the root causes of a failure [34, 36]. Troubleshooting and failure can be located by:

- fault analysis
- finding faults, simulation
- reconstruction
- root cause failure analysis
- analysis of material
- design analysis
- failure mapping potential, risk management. [36]

2.7.1 RCM: a tool for availability / Reliability centered maintenance as a base for availability

By identifying asset functions, failure causes and failure effects, RCM process determine maintenance requirements for the physical asset. [16, 61] RCM studies are often limited to focus on one specific subsystem or pilot [31]. The meaning of RCM, as an approach to utilize estimates of reliability of equipment, forms a cost-effective maintenance schedule. It was previously developed for aircraft industry for safety related applications. Kothamasu *et al.* see RCM as a two-task union [58]. First task is to analyze and categorize failure modes based on failure effects. Second task is to assess maintenance schedules impact on reliability. Failure analysis starts by identifying all failure modes and continues with categorizing these based on each failure consequences. [47, 58]

RCM determines specific maintenance tasks to be performed with influencing equipment reliability and maintainability when designing. RCM should be taken into account during design and development. [34] RCM is a methodology of 7 steps [34, 56, 68], it guarantees documentation which records how and why maintenance tasks were selected [56]. These steps are presented in Figure 15.

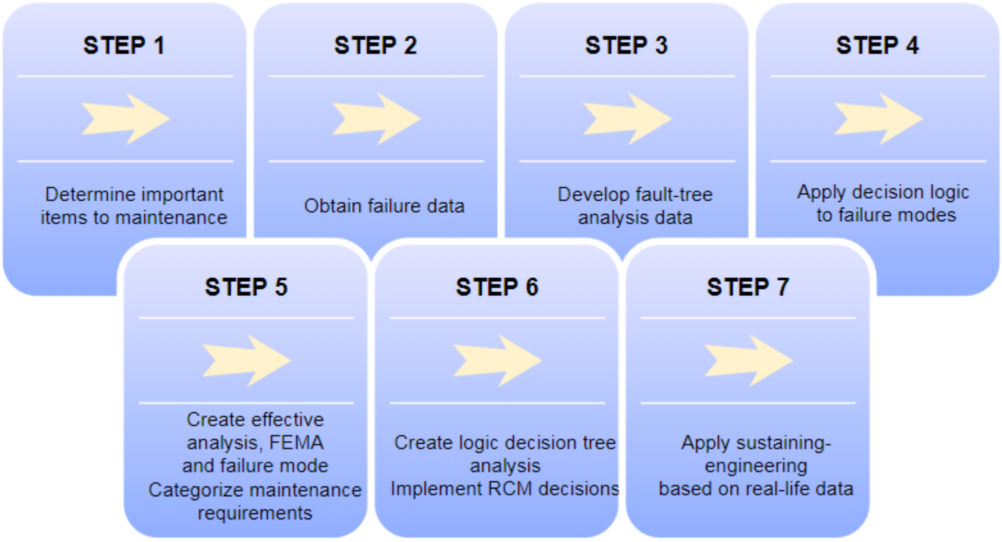

Figure 15. *RCM process steps. Adapted from [34, 56, 68]*

Fault-tree analysis is a graphical description of multiple parallel and sequential faults resulting in an undesirable event to be reviewed. The failures in this content can be related to actual component failures but these can also be human error or other incidents which leads to undesirable event. The fault-tree depicts using events logical interactions to describe leading event chains as top-down deductive presentation. [69, 70] In the upper level of the tree structure the undesirable event is called top event. The lowest level causes, primary events, can have different effects into the creation of top events. These basic failure combinations causing top failure rates are gathered as a fault-tree. Primary events in gate events are described by using logical gate conditions. [69-71] Operators OR, AND, k/n, PriorityAND, XOR and NOT are used as gate condition. [69, 70] These gate conditions help to depict how many and in what order basic events will happen to create a top event. After the gate event is created the event transfers to the next level in a tree structure either to the next gate event or to a cause of top event. [71] Example of the fault-tree is depict in Figure 16.

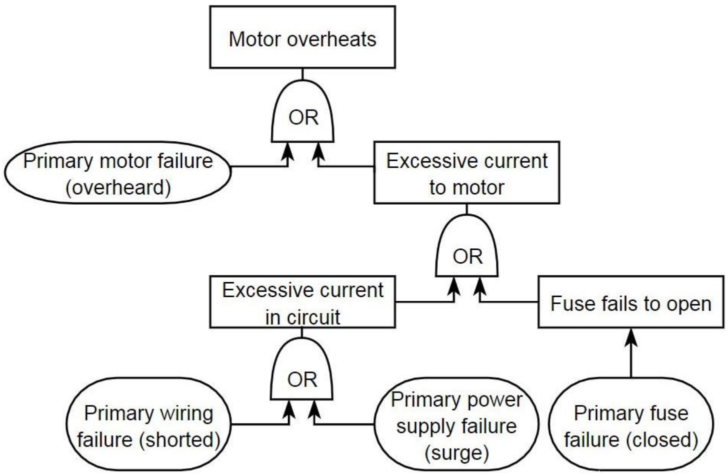

Figure 16. *Example of fault-tree logic diagram. Adapted from [71]*

RCM is generally acceptably defined by Society of Automotive Engineer, SAE which defines the RCM based on 7 questions. If one or more of those are left out it is not acceptable to call it as RCM. A definite step-by-step procedure exists, its forms and decision charts are available to answer following questions:

1. In assets present operating context, what are the associated performance standards and functions?
2. How can its failure fulfill its mission, what are functional faults?
3. What are the each fault causes, what is fault mode?
4. What happen when fault occurs, what are fault effects?
5. How does each fault matter, what are fault consequences?
6. What needs be done to prevent or predict each fault, what are proactive tasks and those intervals?
7. What needs to be done when appropriate proactive task is not found, what are default actions? [61]

As a maintenance concept RCM is undisputedly valuable, it notices system functionality and not just the equipment [61]. RCM can improve equipment availability and reliability, reduce corrective and preventive maintenance and increase safety [31]. RCM increases lifetime and can achieve more effective and efficient maintenance. It is suitable for management philosophy for example more and better historical data and analysis, reduce human error and exploit expert knowledge. [61]

2.7.2 RCA: finding the real causes for non-availability and reducing its repeatability

Ben-Daya defines Root Cause Analysis, RCA, as a tool to find real cause for a problem in a repeated fashion. RCA deals with the problem and does not deal with symptoms. RCA is a method which is used to analyze problems and failures to their roots. Equipment failure can happen for many reasons, there is a clear progress of tasks and consequences leading to failure. RCA tracks the cause and effect path from failure to root cause, determining what happened and why, and more essentially what to do to decrease the probability of it happening again. Process of analyzing failure root causes and operating to eliminate those causes is the most effective tool when enhancing reliability and performance. [72] The RCA process is illustrated in Figure 17.

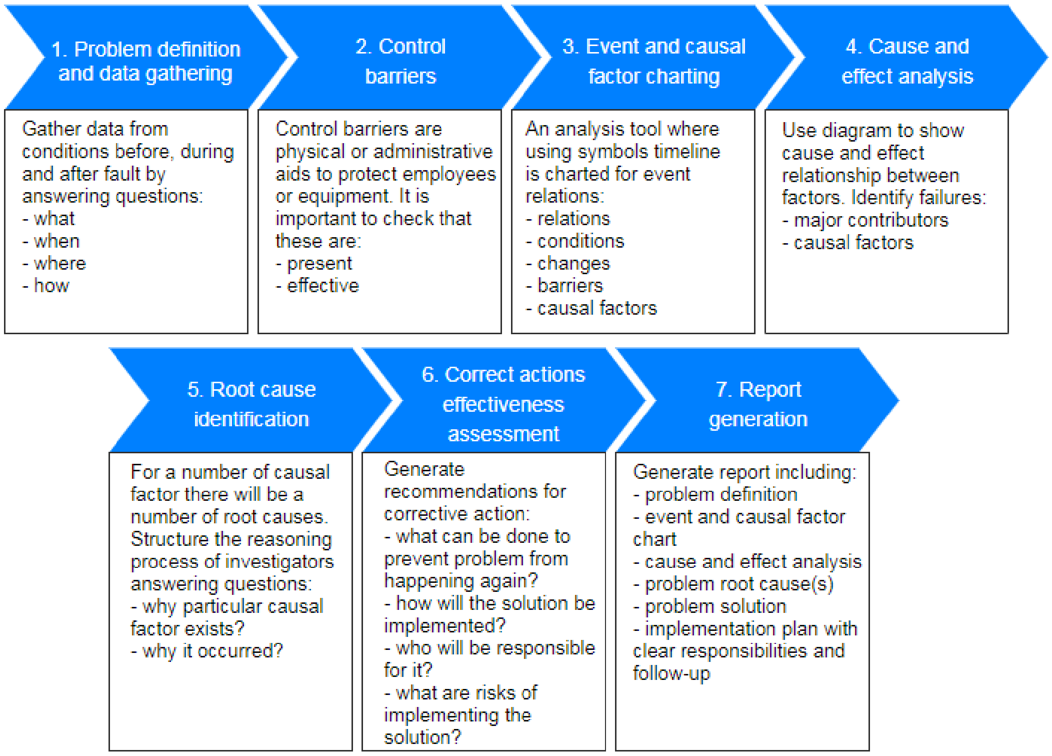

Figure 17. *Framework for RCA. Adapted from [72]*

There are several starting questions for first step to gather data and to define the problem [72] these can be seen in Appendix A. Using standard symbols in step three is essential for systematic way of presenting the timeline [72] they are shown in Appendix B. All failure signs should be analyzed, and the root cause should be determined. Informed decision need to be made as to whether it is technically, economically and necessary. The root cause is analyzed thoroughly from the fault to identify of the failure and determine the necessary corrective action. [44] All of the different approaches for root cause analysis are valuable in order to gain a broader comprehending of the recurring challenges in the system-level [73].

3. THE RESEARCH STRATEGY AND MATERIAL IN THE THESIS

Research strategy is implemented to create a possibility to answer research questions. Research is aiming to generate a framework on availability based maintenance contracts for Company A and to illustrate how availability factors are affecting availability costs. The major objective of this chapter is to present the research strategy as shown in Figure 18. The process starts with the first section including benchmarking, literature review and interviews, which will then create a preliminary framework for availability based maintenance contracts. First section is about gathering information and material from which it is possible to construct results for the second section.

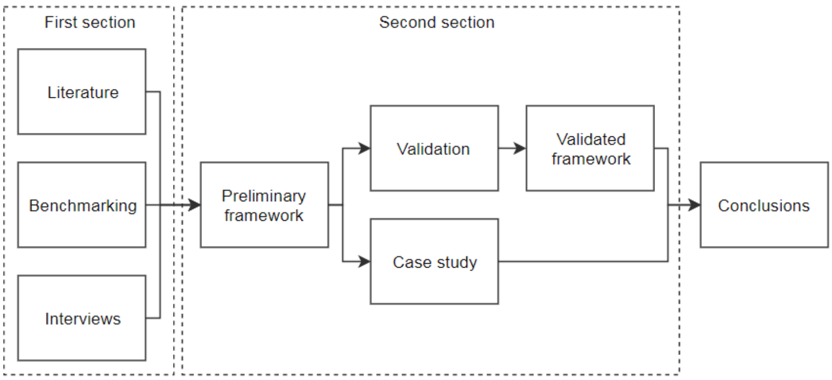

Figure 18. *The research strategy process.*

In the second section, preliminary results are formed based on the first section. The preliminary framework leads to two simultaneous processes. In the first process the preliminary framework will be validated and modified into its final version. In second process a case study is created and its results are viewed. In the end, results from both processes are gathered and final conclusions are presented.

This chapter will explain how these two sections are conducted and how they are linked together. The main purpose of this chapter is to clarify what strategies are used in this thesis and why. In the end this will make a proposal on how will it go forward with the implementation and how conclusions are formed.

3.1 Overview of methodology and material in the thesis

The methodology which started and compiled the topic for this thesis is a preliminary study. The idea behind preliminary study was to refine new ways for the research in order to turn those into a research project [4]. Preliminary study gathered the needs of the Company A and defined the topic and the subject to this thesis. In this thesis the preliminary study was conducted by interviews.

In this thesis a case study was conducted, which is a research strategy linking experimental research with a precise temporary instance by using multiple sources of evidence into the real-life context [4]. In a case study one or a small number of instances in a real-life context are selected, and results obtained from these cases are analyzed in a qualitative manner [74]. A case study, as a research method, presents a possibility to study a problem in a defined situation in large detail. The key is to understand a matter in depth and comprehensively. [75] What makes a case study so unique is the fact that it gives a possibility to explore and understand context in a real-life situation and that collected data is limited by the number of variables [4]. The case study strategy was chosen because it gives more in-depth and concrete understanding of the framework studied.

The case study is grounded with other research methods. It is done to make sure that the findings are valid and to ensure that collected information is what it should be, this case study is triangulated into other studies. In this thesis this is done by using interviews, literature review and benchmarking to secure that information is correctly analyzed.

Different typologies are overlapping and used in the interviews. Those can be divided into two main typologies: standardized and non-standardized interviews. Non-standardized interview, also called as semi-structured interview, is designed to collect data that is analyzed qualitatively [4]. Non-standardized interview is usually used with a case study strategy [4] which is why it was selected as one of the research methods.

Benchmarking was used as one of the research methodologies to get new viewpoints and more perspective on how availability and maintenance contracts are seen in different fields [11]. It is a tool based on voluntary and active cooperation between organizations to apply best practices [12]. Benchmarking is defined as a method in which activities are compared with leading organizations in the market sector [11, 12]. Benchmarking can be external or internal [76]. Benchmarking is a process including following phases shown in Figure 19.

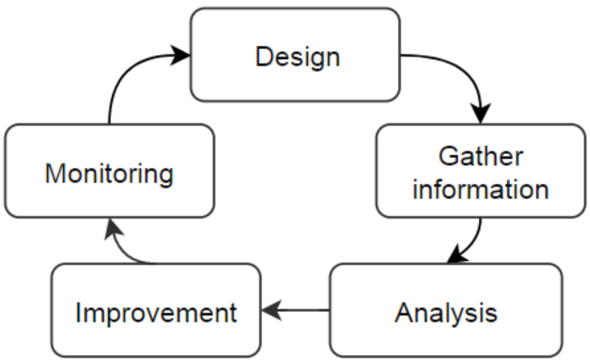

Figure 19. *Benchmarking process. Adapted from [11, 77]*

In the first phase, it is designed how knowledge is gathered and to which organizations are relevant in a field. In the second phase, indicators and analysis are defined to help in comparing the results with own organization. When differences are spotted the best practices are selected to achieve new ways of doing. [11]

A mathematical review is used in the case study. The method makes it possible to quickly screen a large domain. It also helps to understand interaction between different several independent factors in order to create a mathematical result. [78] It helps to clarify what are the figures needed for calculations. The review is important part of this thesis because it is necessary to know the correct factors inputting the availability based maintenance contract. It is also important to do correct calculations to find out the influencing costs in availability.

In addition to above methods, brainstorming was used as one of the research methods. Brainstorming method has a problem-solving attitude, which is also used for creating new viewpoints and notions. [4] In this thesis, brainstorming was done with researchers' co-workers and manager to get new prospect and to help to focus and find own path. Brainstorming was also used with another researcher in Company A to clarify and to throw different thoughts around. This was done with the purpose on when the researcher says the idea or thought out loud it might get a new meaning or it might sound more rational that way. Of course, this also gave some needed breaks and laughs while helping the other researcher.

Additional research material was conducted from Company A. The source for additional materials in practical part was existing contracts, current framework for contracts, documentations and data collected in Company A. These materials were quantitatively analyzed to gain more information on the current state and the possibilities of the future. Company A has extensive data base, where information about maintenance actions and times were compound. These materials are essential for creating the case study with real information and connecting it to the company.

3.2 The next steps in the thesis

This section is designed to introduce the proposals on how research questions, introduced on chapter 1.3, are planned to be answered. This will present the way of how materials gathered will be used. This chapter first explains the implementation of the benchmarking and the interviews in Company A.

The following sections present how the processes were planned, what kind of information these sought to find and which research questions they aimed to answer. Next, the proposal for the framework created is introduced. Finally, in the last section, the proposal for the case study is presented.

3.2.1 The contemplation for benchmarking

Benchmarking was chosen to streamline availability based maintenance contract and identify ways of delivering a better service for the customers in Company A. The benchmarking were carried out during spring 2018. The process began with a search of suitable organizations that have knowledge on maintenance, availability and maintenance contracts. The aim was to find organizations that are leaders in their field and that have different kind of know-how. The next phase was to find suitable people to interview. This phase was done with in co-operation with colleagues in Company A and with the thesis supervisor in Tampere University of Technology. The four different organizations, with these requirements, were found: Efora, Sataservice, The Finnish Defence Forces and Wärtsilä. Organizations were approached via emails. All of the four organizations returned that they would like to participate. It was decided that benchmarking will be done face-to-face, because that was seen the best way to communicate, collect information and networking. If needed, personal contact makes it easier to ask follow up questions.

The benchmarking questions were created to find out answers for the following research questions:

1. How is the framework created to serve company's and customers vision of availability where equipment are different from each other?
2. What are the factors that affect availability?
3. What type of data is needed to manage availability?
4. How availability is measured with adequate information and with a sufficient accuracy in availability based maintenance contracts?

The literature review was used in the base of the benchmarking. The questions were also created with an aim to find out how organizations see availability, data gathering, maintenance contracts and how they manage these. The issue of how to manage maintenance contracts and the framework around those were discussed toughly. Another important factor was new customers and the implementation of a new plant. It was also discussed how maintenance is seen in the future, how it will develop and how availability suites in that picture.

The questions were designed to support a semi-structured interview to leave room for the interviews to talk about their perspective and follow-up questions were asked which were not in the question transcript to get better view on matters. It is important to notice that in benchmarking it is allowed for the organizations to choose what information to share. The questions were design in a way that enough information is collected if the organizations decide not to share that much.

3.2.2 The contemplation for interviews

The interviews were conducted during fall 2017 and spring 2018. They were planned in a way that those could give an insight of how maintenance contracts and availability based maintenance contract are managed currently in Company A. The vision was to get an image of what kind of challenges might arise when designing framework for availability based maintenance contracts and how a created a framework could better serve Company A's needs. The interview questions were created to get Company A's views for research question 1. One goal of the interviews is to get the idea on interviewees' vision of what concrete information is needed. Multiple interviews were also held if new ideas or sides to availability based maintenance contracts were raised during other interviews which needed clarification from someone else in the organization who had already been interviewed.

All interviews were a mix of structured and semi-structured. Some questions were asked to get the interviewee to stay on topic, but the interviewee was given a chance to talk freely [4]. The interviews were also done this way to avoid giving the interviewee the possibility to get fixated on something the interviewer said or leading the interviewee to think outside his or hers point of view. Interviewees were selected from Company A in the way that all parts of organization have its say in a matter. Also the key personnel were interviewed to get the real-life view of managing maintenance contracts and what are the current steps in maintenance contracts framework.

3.2.3 The contemplation for framework

As shown in Figure 18, framework model is conducted based on the results of literature review, benchmarking and interviews. First, preliminary hypothesis of framework is formed based on above factors and its goal is to gather all the information obtained from availability based maintenance contracts. When creating the preliminary framework accentuation was on literature review and benchmarking. Interviews were utilized more as a guide for the framework to fit in Company A's agenda.

The preliminary framework was aiming for being an initial model, in which all key aspects are taken into account. Key aspects are chosen based on the issues emphasized in the benchmarking. The purpose of making the preliminary framework was to get a genuine illustration of how availability based maintenance contracts are handled in other fields and to get the most out of literature review and benchmarking.

Secondly, created preliminary framework was validated by Company A's key people. Validation was done by semi-structured interviews where preliminary framework was presented to individuals in one-to-one sessions. After presentation, the interviewee had a possibility to elaborate, change and improve the framework as he or she saw suitable.

Validation was done to get the framework better suited into Company A. One intention in validation process was to give better knowledge for the Company A of how others in different fields see the framework for availability based maintenance contracts. Validation also gave insights on what is seen as a main issue and what are the cornerstones in organizations when it comes to availability. The final framework was conducted based on validations.

The framework aims to answer the research question 1. It is created to give Company A a vision on how availability based maintenance contracts should be managed, and what are the main aspects to be considered when dealing with those. One goal is to bring a different and possibly even a new way of looking at availability based maintenance contracts into Company A. One isolated target is to gather knowledge of managing maintenance contracts in a fresh way.

3.2.4 The contemplation for a case study

As visible in Figure 18, based on the preliminary framework the case study can be formed to give more insight information of how availability acts when its factors and different costs change. The case study will give a clearer and easier way of showing Company A, what are the factors seen in availability and what kind of differences are there when changing a factor. The study will illustrate the information needed to measure availability. It is created also to give Company A a tool to describe and illustrate to a customer how the availability is seen in Company A and how it is measured.

One of the objectives in this case study is to conduct a calculation model to give more explanatory view of the topics needed to be investigated and to answer research questions:

2. What are the factors that affect availability of an equipment?
3. What type of data is needed to manage availability?
4. How availability is measured with adequate information and with a sufficient accuracy in availability based maintenance contracts?
5. What are the costs of availability and where do those come from?

In this thesis the case study is a mixture of single and embedded case, which is explained earlier by Saunders [4]. This thesis is only covering one single case studied. The case comes from the fact that the framework covers more than one organization in the Company A. Framework also covers outside of the Company A which means that there are more than one unit that needs to be analyzed.

Creating the case study starts with identifying the factors influencing availability. Benchmarking and literature review give the division for downtime. Calculating downtime it is important to have data. That data is gathered from Company A's material, it is later divided into different sections similar to 0 presented earlier. In the computation it is necessary to have correct data and adequate information about the times it takes to perform each factor. Without exact data it is not possible to do precise calculation and make accurate decisions and operations base on those calculations. Data's interference and poor quality is quite similar to generating decisions based on experience and estimates. Incorrect data can also lead to interior conclusions.

When data is set, availability is calculated for each equipment type per equipment separately. Then the fleet availability per equipment type has been calculated after that, it is possible to get availability for the entire plant. The customers are interested in technical availability because it takes into account the human error factor of availability. Company A on the other hand is interested in operational availability because that only considers the failures the equipment has which can be possibly prevented. It is possible to prevent human errors for example with training. Those can be added into technical availability calculation. Therefore the calculation model has a human error factor included so it is possible to calculate technical and operational availability within the case study.

After identifying all the factors in availability, those have been given times on how long each of the factors take. Choosing the country changes the costs of availability, but it does not make change the availability itself. Company A has a lot of maintenance people around the world which is noticed in the case study calculation.

Next the calculation will notice how availability percentage can be transformed into availability cost. Those are calculated based on the maintenance people wage costs. Besides that the calculation notices the possibility for small equipment to be replaced with other same types of equipment and what are the costs of that included extra equipment on the plant.

One of the biggest factors in the calculation model is the OEE calculation done based on Figure 3 and Table 1. It is possible to separately simulate different factors influencing availability and OEE based on Figure 3, which is added to the calculation model. OEE is then included into Return on Capital Employed, ROCE, value calculation. ROCE is a profitability ratio measuring efficiency and profitability of a company to generate profit. ROCE gives more weight on how availability factors influence the whole company. As calculating ROCE the profit is visible in the calculations. In addition, some customers have a clause on bonus and penalty side in their contracts [30]. For this reason, the penalty is calculated in the calculation model.

The calculation model demonstrates the factors and gives a realistic view on what is needed for availability calculations. In the end, the case study calculation will give an accurate manifest on how modifications in different availability factors translate into costs. These costs can then be rewritten into availability based maintenance contract cost and later to organizations costs.

4. AVAILABILITY BASED MAINTENANCE CONTRACT FRAMEWORK AND CALCULATION MODEL OF AVAILABILITY FACTORS AND COSTS

First on this chapter is the results got out of benchmarking and interviews. These benchmarking give a base for preliminary framework with a small influence of interviews done in Company A. Interviews give a low impact to help tie the framework to the company, but it is desired to create the framework based on benchmarking and literature review to get new perspective. Preliminary framework is then disclosed and later validated with managers who have knowledge on contracts Company A. Based on the validation, the final framework is created and presented.

Second this chapter presents a proposal of KPIs for the Company A's contracts. Third this chapter presents the calculation model case study created. Case study is conducted based on materials, interviews and benchmarking. Case study is visually showing different availability factors and how their costs changes availability.

4.1 Review of results from benchmarking and interviews in target company

This chapter presents benchmarking results from selected organizations Efora, Sataservice, Wärtsilä and the Finnish Defence Forces. The results are gathered and presented in different categories that had the most value in benchmarking sessions. The benchmarking was done to get more information on how availability, data and availability based maintenance contracts are managed in different companies. Main goal for benchmarking was to gather new point of views for Company A to control and model availability based maintenance contracts. As discussed earlier in chapter 3.5, benchmarking also tried to find out what data is needed for control availability and adequate performance calculations. It was noticed in benchmarking that some were careful on how to answer in some questions and some answered more freely and in more detailed. The chapter also introduces the future prospects the benchmarking organizations see in the field of maintenance.

Second the results gathered from interviews in Company A are introduced. These results are about how Company A is currently managing its maintenance and maintenance contracts and how does availability fit in those. The chapter also takes a stand on what kind of future studies and thoughts came up in the interviews.

4.1.1 Benchmarking results and findings

For a customer, it should be shown what the price includes and brings to the customer. [19] Sataservice sees important to go through with a customer what the terms and indicators mean in maintenance contract to make sure both parties understand them the same way [22]. In Efora, contracts are often based on fixed price including for example materials, maintenance personnel, planned preventive maintenance, subcontractors and work. A customer sees from price change or from OEE indicator if there has been a development in maintenance. In Efora, fixed price is seen – not only beneficial for the customer – but also for vendor. Fixed price gives vendor a possibility to improve its profit margin by changing and developing its internal functions. [19]

Wärtsilä sees availability more complex than just tracking fuel and lubrication consumptions because customer should be able to tell how the machine is being used [25]. Maintenance contracts and service process are measured with indicators and contract is managed with key figures. This way it is possible to see bottle necks in contract or maintenance. According to Efora, to do and exceed in these it is important to invest in building a maintenance system over a control system. It will help to model business processes and to install indicators in those. This will be useful for opening processes to get better process control. [19]

Efora uses same indicators in its contracts, which give them a great opportunity to compare different contracts [19]. In Wärtsilä, contracts are done for each customer individually. This means that same kind of contracts do not exist with different customers. [25] Sataservice's contracts have variable forms from which the actual one is gathered to fit the customer's needs. Similar to Wärtsilä, it is possible to customize contracts to meet customer's needs. [22]

Wärtsilä's contracts have two domains: marine and power side. In Wärtsilä the marine can make maintenance a bit harder, because ships often have tight schedules and maintenance personnel is not onboard but for example in a terminal. This means that maintenance needs to be carefully planned and communication plays a crucial role if maintenance actions need to be divided between different maintenance plants. If this is necessary, it is important to make sure it is cost-effective for the customer. [25] Sataservice can utilize its knowledge in different companies for example with best practice model, with a respect of customers' privacy and trade secrets [22].

Maintenance actions

It is common for the maintenance that customers' maintenance systems, indicators and management methods can be very different and in various levels [22]. In Efora planning and dependability adds vendors' profit margin. They know in advance what is production turnaround time, when are the planned maintenances and what is the spent time on maintenance. They also know what the machine resources are, what the triggers in a long term are and prognostic workloads weeks ahead. [19]

The Finnish Defence Forces has an analysis form in use, to get all maintenance actions analyzed and reported in a standardized way. In the form, it is told what is done in which maintenance. The Aircraft fleet also have A and B inspections where planes are checked in the flight line. [23]

Maintenance actions are written out with repairs into reliability card for everyone in the organization to see. This is one of the factors which influence on maintenance personnel's training. Efora also teaches for quick reaction, how to handle the palette and what are the correct measures and indicators. [19]

The maintenance can be based on several different things. For example, failure can be detected while inspection is carried out before the operation. [23] Maintenance can be based on operation hours, equipment condition or a change over a specific time period of time [23, 25]. These are so called hard philosophy elements. Inconvenience of these is often configuring the lengths of the periods. [23]

Customer needs

It is important to discover what the customer asks and what are the reasons behind outsourcing or why customer wants to change maintenance vendor [19, 22, 25]. It is also important to know how factors mentioned above affect vendor organization operation [19]. It is hard to offer something if it is not visible what the customer desires [25]. For Efora and Wärtsilä it is important to find their place in customer's ecosystem or value chain in order to bring as much value as possible for the customer. They also see that division of responsibilities with the customer is one of the key factors in maintenance contracts. [19, 25] Wärtsilä emphasized that it is important to remember that the reason in maintenance contracts is not to charge one and other, but to have a partnership with the customer and gain common win-win situations. This can incorporate bonus and penalty side in maintenance contracts. [25]

Everything starts with what interest a customer. It might be availability or it is something else [25]. For Wärtsilä and Efora it is also important to know what challenges the customer might have and what factors are not going so well in customers' opinion [19, 25]. The organizations see transparency to the customer important and they try to maximize it [19, 22, 25]. Sataservice also emphasizes that honesty is one of the key factors what comes for cooperation with a customer [22]. Efora see that the key factor for customers to work with them is the open book model which is often used with customers [19].

In Wärtsilä's marine, contract can be done for a long period of time. The marine side customers want to do a lot by themselves and a lot of things are dependent on the customer. Wärtsilä can be seen as an expert, giving recommendations, as they do not operate the ships. In the marine side the contract can be bound to for example fuel consumption or availability. Power side is simpler as producing electricity is in a key position for the customers. Knowledge of when and how much electricity is needed and if it is a peaking plant (meaning a value which is exceeded to get Wärtsilä involved) is essential for Wärtsilä. In power side Wärtsilä operates on behalf of the customer and contract can be measured for example with energy efficiency or cost/MW. [25]

The startup of a new maintenance contract

With assessment tool in Sataservice, picture of the current state can be created to help customer decide whether to outsource or not. If customer decides to outsource, the next step is contract preparation phase where all tools, ICT (information and communications technology) -systems, safety, personnel resources and supervisors are set for the first day the contract is activated. [22]

Wärtsilä first conducts an audit where experts estimate the machine's condition. This phase has a lot to do with technologies as all equipment and systems should be looked over to see what kind of maintenance and changes need to be carried out. It is important to find out what kind of usage or life cycle a customer has planned for the machines for example if the customer wants to operate the machine for the next 20 years. [25]

Efora is doing implementation to customer plant with a large measure to get implementation done fast in order to get the plant up and running as soon as possible [19]. In Sataservice's integration phase includes driving organization's way and culture of doing maintenance into the customer's production [22]. Implementation usually brings in a new plant manager, outside the previous maintenance organization, to bring organization way of working into the customer plant [19, 22]. To make faster decisions, Sataservice can include the organization's deciding managers into the team meetings [22]. Efora brings new matters into maintenance constantly to keep the saturation curve from falling. According to Efora, in implementation phase the important factor is to ensure dependability process. [19] According to Wärtsilä, implementation depends a lot from the customer as each case is different [25].

Usually Wärtsilä's maintenance contracts include competences, right tools and work instructions. Wärtsilä have thought of doing a competence analysis for customer's maintenance personnel which would create a base for the personnel skills. Based on the competence analysis, it would be possible to customize training program for the personnel. [25] Efora often has a training period when the baseline is set. It is set to acknowledge what is promised. It gives a starting point for maintenance contract and crossing it will decrease business and staying under the baseline means that performance is well planned. [19]

As mentioned earlier, customers have different levels of maintenance. In Sataservice, developing maintenance starts from doing maintenance in customer's plant for one to three years depending on the function of the service maturity. At this time, systems, indicators, for example TPM, OEE, technical availability and possibility of operator maintenance are investigated. [22] Efora sees that when machine is in uptime state installed base need to be in condition and machines cannot fail all the time. One of the main indicators for Efora is performance KPI, which are set so that they are not too strict, but not too ambitions either. [19] To achieve this it is necessary that activities are systematic and going forward one step at the time [22].

Data in maintenance contracts

Data is seen in a crucial role, as it can help with new equipment purchases. It is used to show what the maintenance costs are and how much labor it takes to do maintenance. When offering new equipment it is possible to compare its maintenance. In order to use data for example for analyzes the organization need to have the data in systems. [23]

Efora practices open book methodology in which the data can be owned by the customer or Efora, but data can be openly used by both parties [19]. In Wärtsilä marine side data is often in customer's systems and they own it, because Wärtsilä has only provided the engine and propellers and not the whole ship. Wärtsilä asks for a permission to use data in development projects. Power side is different from marine side when it comes to data. In power side Wärtsilä has technical documentation and data is managed by Wärtsilä. This is because Wärtsilä has provided and constructed the power plant. [25]

Wärtsilä's goal with the data is to make improvement suggestions for the customer and to do maintenance planning. Wärtsilä uses data to further develop maintenance and processes. It helps Wärtsilä to see machines real condition and prevent accidents from occurring. In Wärtsilä power side if customer could tell when electricity is needed, how much and for how long time the optimization would be easier. [25]

In order to study failures, failure data needs to be adequate. Data should be allocated to the right categories. Failure codes needs to be accurate and clearly indicating where the failure occurred, what was the fault detection, what is the fault severity, its cause and what are corrective actions and further measures. It is also essential to know after how many operating hours the failure took place. Also, valuable information is how soon after the maintenance is the equipment failed. [23]

For Sataservice, data is important for controlling operations, but it is not necessary to have that in the system delivered by them. Data can also be located in the customer's system. [22] Wärtsilä does not see data ownership as a priority. Owning the raw data itself can be overrated and data analysis is the real deal. It is not essential who owns it, the access to data is in a key role, the one who can analyze data is in a key role. [25]

The Finnish Defence Forces have plenty of data in the Air Force because of aviation standards. In the Navy and the Army, the data is often not in the same level with the Air Force and the knowledge is often in the experts. This is one of the biggest challenge for the maintenance action optimization projects because data is not available for everyone. The Navy and the Army have started to fix their data. They have a lot of information from warranty period but after that there are not much data. Data is essential for the analyses. [23]

The Army and the Navy use RCM and the Air Forces uses Maintenance Steering Group-3, MSG-3, which is the aircraft version of RCM. Originally RCM was developed from MSG-3 which is a customized maintenance optimization tool for airplanes. It gives the needed maintenance tasks with needed accuracy. It also performs reliability analysis, which gives task intervals. MSG-3 has been taken into account when designing F18 Hornet aircraft. MSG-3 and RCM are based on failure analysis and the fact on how to manage predictive maintenance and reduce corrective maintenance. To do this it is essential to have good failure statistics. [23]

Wärtsilä finds root causes for all faults with customer permission. Repeating faults are taken seriously and are taken into product development and also future measures are informed to the customer. Failure information is transferred to key personnel, this information includes failures, conclusions and response methods. Maintainability information can be translated into product development and design to be redesign for maintenance and tracking. [25] In Sataservice, failure investigation is customer specific. In some customer cases precise root cause analysis is done but in other cases those are not necessary considered as important. As some customers do not see root cause analysis necessary in their field. Root cause analysis can be carried out for example for product and quality tracking. [22]

Future prospects

The Finnish Defence Forces studied early warning system to detect when the failure is about to happen. They did a research with a neural network, to test if it is possible to compare field bus data's failure situation to normal situation and get a failure indicator signals. The Finnish Defence Forces gets about 10 gigabits of field bus data from each flight which is then registered. Even when the data is preprocessed to get the irrelevant information for the failure analysis out, it still leaves data to be analyzed. [23]

The aim is to get early warning from upcoming failures. With this information it would be possible to make condition based maintenance in order to avoid mission interruptions. The idea is that data sample is later compared to a failure-free neuron network sample. In case of deviation the alert is given. Some failures are developed fast which is the reason it is not yet possible to get the information of system failures in advance. Often electronics failures are on-off failures which are not possible to detect them early enough, meaning that those do not give a notice before the failure. [23]

The research has develop the Finnish Deferce Forces AIDA, Advanced Inflight Data Analyzer which automatically does the analyses. In the future, AIDA will be installed into a data hotel where all information from the flights is stored. AIDA could automatically tell if there are any coming faults. Challenge with this is, the time from fault indication to the fault is short. Second, algorithms must be built for every equipment separately, which is extremely laborious. Time is saved if the field bus data is possible to analyze as soon as possible and correctly. Without this data, the equipment needs to be taken into the workshop, put into uprights and systems are looked through. This will take much more time than getting failure analysis from field bus data. [23]

Wärtsilä has many development projects going on which are related to digitalization, data movement, analyzation and understanding. Wärtsilä is constantly working towards finding new solutions to help customers. Wärtsilä wishes that maintenance would go more to condition based maintenance and for example propellers would not have to be maintained every year if they have not been used. In a distant future, Wärtsilä sees that it is possible to sell marine terminal slots for ships for example with half a price if the booking is done early. For Wärtsilä, it would also be interesting to have an open ecosystem to see ships real terminal arrival time. This could for example give terminals a possibility to suggest ship to arrive few hours later to get the terminal operation flow better. [25]

The future of maintenance is seen bright in Sataservice, all fields are going into more productive based operation away from hourly sales. For example, digitalization, AR, Augmented Reality, and 3D printing are changing the world during the next 5 to 10 years. The world is dependent on the experts and their knowledge is needed. Currently a person can walk and find the right way and machines on the plant, this can be seen as non-refining competence. When digitalization still evolves, putting on a AR safety glasses in the plant, it will tell the safety instructions, where to walk and the machine tells what equipment under observation. The glasses can also tell safety knowledge at the same time when the issue, for example changing light pulps in buildings room X, is being fixed. In the industrial world that kind of technology is still far away from this. [22]

4.1.2 Findings from the interviews

Company A has some communication issues that need to be solved. During the interviews few inconsistent statements were given. For example how the contract is determined, is it the one signed or the one in the system [79]. One suggestion made based on the interviews is that communication methods need to be gone through to make sure everyone on Company A sees the things the same way and that everyone has the same knowledge. In Company A all different departments have their own need for the maintenance contract information and different way of seeing maintenance contracts, for example finance, contract team, frontlines and different contributors [30].

In Company A there are 4 different viewpoints on what availability is. It would be useful to get everyone on the company see availability the same way. One of essential thing is to determine what availability is in Company A. For example, contracts can sell technical, general, operational and fleet availability but those are all customer specific. [30] Company A does not have its own availability model which to present for the customer. Giving the customer a standard way of measuring Company A’s availability and measure the company’s most important availability in every customer. [30, 80] Creating a possibility to compare different plants and Company A’s maintenance contracts. [30]

Currently Company A sells availability contracts which include penalty side if that availability is not reached [30]. Availability is measured usually in the customer system because Company A does not necessary have the information for contract measurements in its own system [27, 30]. Also, not every country has implemented the same system which is used widely in Company A [30].

KPIs in contacts are measured manually and data is worked in multiple different files. In the future it is possible to show to the customer when creating contracts how Company A is measuring its KPIs. This way it is clearly visible for the customer what is Company A’s way of calculating KPIs. [30, 80] Company A is more interested in operational availability because it takes into account only equipment failures. Customers on the other hand are the most interested in technical availability when there is also included the operators caused failures. [30]

OEE concept promotes a holistic approach; it ties various interrelated factors to your operations’ financial performance. Carefully studied OEE is widely and easy to use so makes no sense to optimize equipment availability without connecting this to Company A’s operational needs. It makes no sense to focus only on operational activities without paying attention to the outcomes. It does not matter if company is able to lift a box ten times really fast, safely and reliably, if in the end you have lifted the wrong boxes. [81]

In Company A one specific need is the data [30, 79]. When someone enters data into the system there should be a tool which is measuring it. These measures should be then recorded for everyone with a right access to see. [30] Company A has a lot of data in its system. Especially from the equipment warranty time, after that data is not as high quality and extensive. Hard part comes when the data should be used. Data is not always valid and quality of the data varies in different departments. [79]

Company A also gathers data directly from the equipment. [79] Variety of sensors has been inputted into equipment to measure conditions for example temperature and vibration. Putting on sensors could be expensive these costs are more especially visual in a smaller equipment. [27] This data is used after analysis to measure for example fuel consumption. Collected data could be later used for failure prediction and locating failure trends. [79] Data makes it easier to find root causes of the problem and find reasons why something is going well or poorly [30].

To get access to the costs, it is essential to have data. In the future when a lot of clearly presented and high-quality availability and downtime data is in the system it is possible to make different analyses. These analyses can for example be used to build a performance based contracts and move more into predictive maintenance. [82]

In current maintenance contracts it is presented that availability is concreted into things like equipment cannot have unexpected failures and if those occur those have to be dealt fast. In contrast to corrective maintenance, preventive maintenance needs to be fast and scheduled in the customers operation. [83] Keeping in mind, that some equipment are critical for customer plant and some can be easily changed and replaced [84-86].

Even though RCM has been tested and noticed of being heavy method it is also seen that it has a future in Company A. Fixing the data side and start working with RCM by small steps and then creating a solid base for it. [9, 26, 27] It is also important to find the correct level of doing RCM and it is not by singling out every screw and nut [27].

One opportunity for the future is to use digital twin which have the aim in investigating the equipment condition without the history data. First determine how the equipment should work and under which conditions and simulate all the time the current operation condition against the calculation model of the so called perfect operating condition. [26]

In the future one of possibilities is to create a table where it is visible how the contract is doing. For example, the maintenance personnel can see whether the contract is doing very well and they can do some extra work for the equipment or whether the contract is not performing as hoped. If the contract needs improvement the maintenance personnel can start doing corrections to get the contracts’ performance to increase. [30]

4.2 Preliminary availability framework; created based on research overview

The object was to develop a framework, a model, for Company A on availability based maintenance contracts. The framework that could be used to present Company A's way of managing availability based maintenance contracts. The framework gives a process model on how the availability contracts could be managed. In addition to that, how to monitor and manage factors of availability and availability based maintenance contracts. The preliminary framework is created based on benchmarking and literature review, it also has some aspects from the interviews in Company A. The framework is limited to match general overview of managing availability contacts. It is not intended to tell every small step and task included in each phase.

The key hurdle in standardized framework is its heterogeneous nature in a company which was earlier focused on product business. The framework is supposed to give the company a vision of service business and the factors included in that. This framework encompasses different parameters which certainly determine few standards for Company A's core business.

The structure of the framework needs to be straightforward and simple in order to achieve the objectives stated earlier. The framework applicability needs to be compatible with a big product centric company which products vary with sizes and technologically. It also needs to be compatible with a company that has different service offerings that are extending its wide region.

As illustrated in Figure 5 business need to be bound to maintenance strategy [60]. This gives a starting point for the preliminary framework. To be able to maximize maintenance contribution to profitability the framework should be created to drive this goal. As Al-Turki's vision illustrated in Figure 6, business strategy is influencing maintenance strategy plan [62], this process should be taken into account in the framework of availability based maintenance contracts. Controlling maintenance and to get the most out of it, it is important to add maintenance planning process into the framework to get all needed information from maintenance for availability calculations.

Cullens [64] contract life cycle was depict in Figure 10. This gives an great base for the framework. Cullens contract life cycle illustrates the factors needed to be consider and presents the different phases of the contract. When aspects mentioned above are linked with life cycle cost escalation [64] (Figure 14), benchmarking and interviews the framework can be created. The preliminary framework is presented in Figure 20.

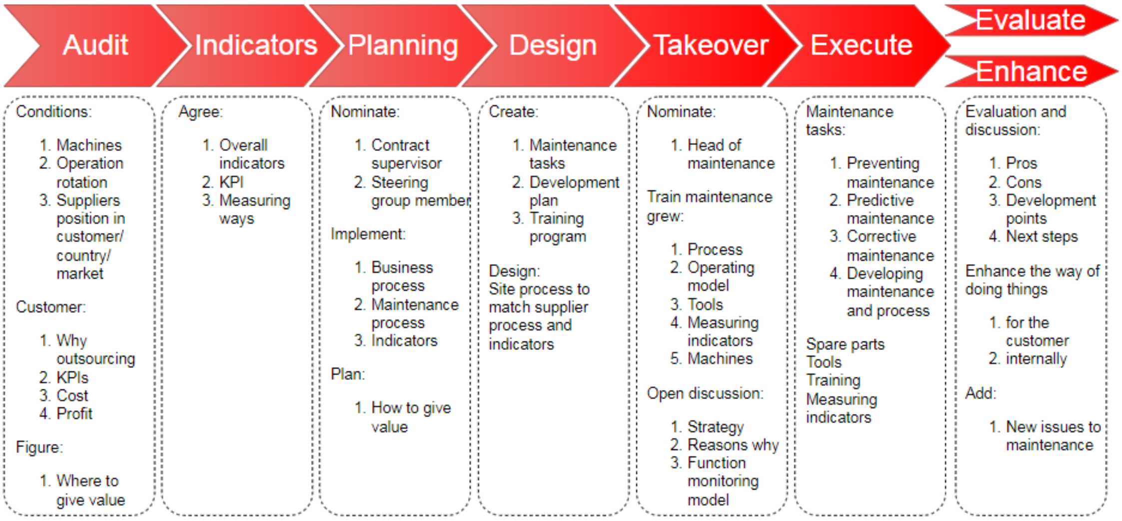

Figure 20. *The preliminary framework for availability contract.*

First of all, it is essential to discover what the customer wants [19, 22, 25] and what are the reasons behind outsourcing or why customer changes the maintenance supplier [19, 25]. Everything starts with the customer interest [25] in this case availability. It is also important to know the challenges the customer have and to know the things going poorly [19, 25].

Contracting starts with an audit in a customer plant [19, 22, 25]. This phase has a lot to do with techniques, all equipment and systems should be looked over to see what kind of maintenance and changes need to be done [25]. It is important to find a place in the customers' value chain to give as much value as possible for the customer [19, 25].

Defining indicators in contracts give an opportunity to compare different contracts [19]. Indicators are in a vital role when creating contracts. KPIs are a key on defining the performance assessment of functions in service delivery. [65] It is important to have indicators to define responsibilities in business relationships between a supplier and a customer [34]. Terms guaranteeing availability have a main role in availability based maintenance contracts [35, 64]. Indicators measure vendors work quality for the customer [64].

Maintenance contracts include competences, right tools and work instructions. A competence analysis should be done for customers' maintenance personnel to create a base for the personnel skills. Based on the competence analysis it would be possible to tailor training program for maintenance personnel. [25] Contract preparation phase in which all for example tools, ICT -system, work environment safety aspects, maintenance workers resources, maintenance supervisors and the whole baggage are prepared for the first of day the contract. [22]

Implementation to customer plant should be done with a large measure to get it done fast to get the plant up and running [19]. One of the aspects in a new plant is to get manager outside maintenance organization to make sure organization way of working is taken to the plant correctly [19, 22]. One of the important factors in implementation phase is to ensure dependability process [19].

The maintenance needs to be exactly planned and information transference is in a crucial role [25]. Information transference is one of the main strength company can have, utilization of knowledge is an essential thing to get better performance for the contracts [22]. Constantly bringing new things into the maintenance keep saturation curve from falling [19].

4.3 The availability framework; created after internal iteration round

Data, Information, Knowledge and Wisdom, DIKW, pyramid in Figure 21 illustrates how the experience and data transforms into a knowledge and wisdom. This figure creates a good vision on how parts of the final framework were generated. Data was gathered early on January, but the understanding of that information was formed and increased throughout the benchmarking process. Gathered knowledge was analyzed after the last benchmarking and mirrored into the created preliminary framework.

Figure 21. *DIKW pyramid. Adapted from [87]*

Visually presented preliminary framework was the taken into the different managers for validation. The preliminary framework was introduced to decision makers in the Company A to hear their opinion on the matter. Based on the inputs obtained from the Company A the preliminary framework was modified based on interviews conducted. The final framework was created based on validation round.

The preliminary framework was welcomed quite openly [82, 84, 88, 89] It was noticed that the preliminary framework had some issues regarding its comprehensibility. It was clear that the presented form was not as transparent as the process model should be. [82, 88] The framework needs to be presented in the way that it is pellucid for the reader to understand it straight away [82]. For this reason, the framework presentation was changed for the more understandable form.

The validation raised an issue of what phases of the process were done before getting and signing the contract with the customer [82]. Offer and negotiation phases had been left out from the preliminary framework because it was taken for a granted that the contract is won. This made it difficult to understand when the offer and negotiation phases are done in a real-life situation [82, 88].

Other factor which is often used in a process models is the turning points and milestones. These help on making decisions whether to go forward to the next phase stay on the same phase or go backwards. Turning points also indicates the factors on go/no-go decisions. It is possible that in one phase it is noticed that information gathered might present that the process needs to be stopped for example in order to wait new technology or the project might be overly expensive compared to the profits. [90] These are not necessary for the process model, but those help on simplifying the framework. Few of the most important turning points and milestones were added to the final framework based on this feedback.

In addition to these it was mentioned that the preliminary framework does not quite start anywhere. There are not presented the initial starting point, a point where is presented what factor launches the process. It was considered important to present a reasons and actions that kick off the process. [82, 90]

After an iteration round the final framework was created, it is presented in Figure 22. The framework starts with identifying possible prospects and based on those an audit can be made in a customer plant. After ground work the indicators need to be defined so that those show the project team what is the aim of the contract. These indicators are the key aspect on a potential availability based maintenance contract. Defining the precise KPIs and measuring ways is a main issue and important for the future process of the potential contract.

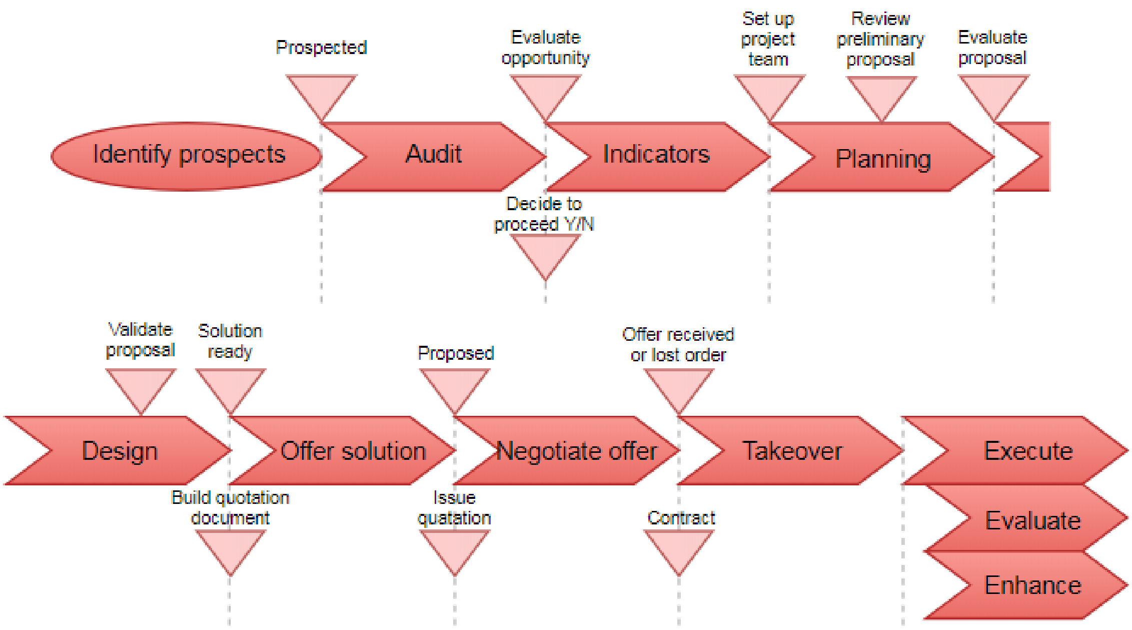

Figure 22. *The final framework.*

Creating a proposal of the contract base will help to view possibilities and ways of how Company A will fit in the customers' value chain and operation. In the designing phase, the proposal is reviewed and quotation for the customer from the contract is build. Next steps are one of the hardest steps on availability based maintenance contract framework, offering solution and negotiating the offer. These phases are crucial for the future of the contract period where the takeover and implementation of the customer plant happens and the execution of the contract starts. While executing the maintenance it is essential to do evaluations of the work and enhance it at the same time when execution is in progress. If every part if pleased with the process it is important not to forget to add new factors and develop the maintenance itself step by step.

After discussing about the preliminary framework in validation round one new aspect was raised, there is a need for root cause analysis process model in Company A. As presented in the final framework evaluating and enhancing phases of executing the contract are important for getting the contract payoff for all parties. Customers of Company A have been asking for a common systematical way of investigating causes for non-availability [82].

The model should present Company A's way of examining failures. The systematic model would be the base of improving operation. This model could also help investigate and analyze operation and situations which causes non-availability. The availability percentage can be anything, but it is analyzed with the simple model. [82]

4.4 Steps with RCA and KPI

This chapter presents the root cause analysis process model created for Company A as a possible tool to identify non-availability factors in availability based maintenance contracts. It is done based on literature review and benchmarking. The model will assist on finding the real reasons and causes behind the failure and downtime. By investigating the root causes it is possible to find development areas and make corrective actions to improve availability.

Chapter also describes the key performance indicators proposed to the Company A as a result of investigating availability. The result is gathered based on benchmarking, interviews and literature review. Proposed KPIs are selected specially to fit Company A's business and strategy. Selected KPIs are giving the company standardized measuring indicators for managing availability based maintenance contracts. These selected KPIs are later in chapter 4.5 be used in calcumation case study to measure availability factors and costs to find the most influencing factors.

4.4.1 RCA framework to tackle non-availability

The process model for root cause analysis would be Company A's clear concept and operating model in examining different aspects in the customer plant. With the root cause process model the situation and reasons causing non-availability are researched and systematically start improving those. The framework will help on determining what are the tools and measures raising availability percentages for example from 85 % to 90 %. The model gives added value if Company A can tell its customers that this is the company's template on tackling non-availability. [89]

RCA finds the real cause of the problem. It is used to analyze failures and to find the root causes of those. [72] RCA clears the cause and effect path [72] to identify real reasons for unavailability. With RCA it is possible to make a change on availability and to enhance it. The RCA framework needs to be created according to Figure 17 starting from defining and verifying the failure.

After verifying the problem, its impact should be evaluated; all failures need to be categorized based on its impact. In Company A the failure or situation occurred can have significant impact on customers operation or even stop the operation. It can also cause major damages to the equipment. Therefore, the severity of the failure should be determined. The fault can have high, medium or low impact on the operation and on the equipment. Determining the impact severity can be done with Figure 23.

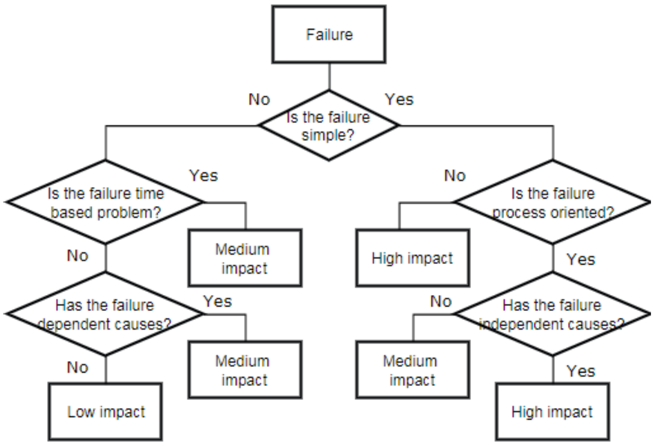

Figure 23. *The process for determining the failure impact.*

High impact has major distributions to the customer operation or to the equipment. In high impact equipment loses the possibility of working, in Company A case the equipment that can have high impact failures are the one that often cannot be replaced with other equipment. These equipment also usually have a high value to the customer operation. High impact also concerns “Y” amount of people.

Medium impact causes minor distribution and is impacting “X” to “Y” amount of people. In medium impact the customer operation can be partly operated with other equipment and changing the time table. The customer operation and equipment can be operated in medium impact, but it still causes conveniences.

Low impact causes minor distribution and it influences less than “X” amount of people. These can be noticed by some customers, but others might not even notice these because the operation can work the same way without stoppage. In Company A’s case these are often the failures that happen to small equipment which are relatively low priced and easily replaced.

The RCA process model started with a base of literature review depict in chapter 2.4.2. It was decided that the process itself needs to be simple and easy to follow which is why the model is depict with flow chart method. The model was introduced to two people in the Company A but not real validation and testing round could not have been done because of the time frame the thesis presented. In short validation round the model was described and then the person gave feedback on the models. The proposed preliminary RCA process model is presented in Figure 24.

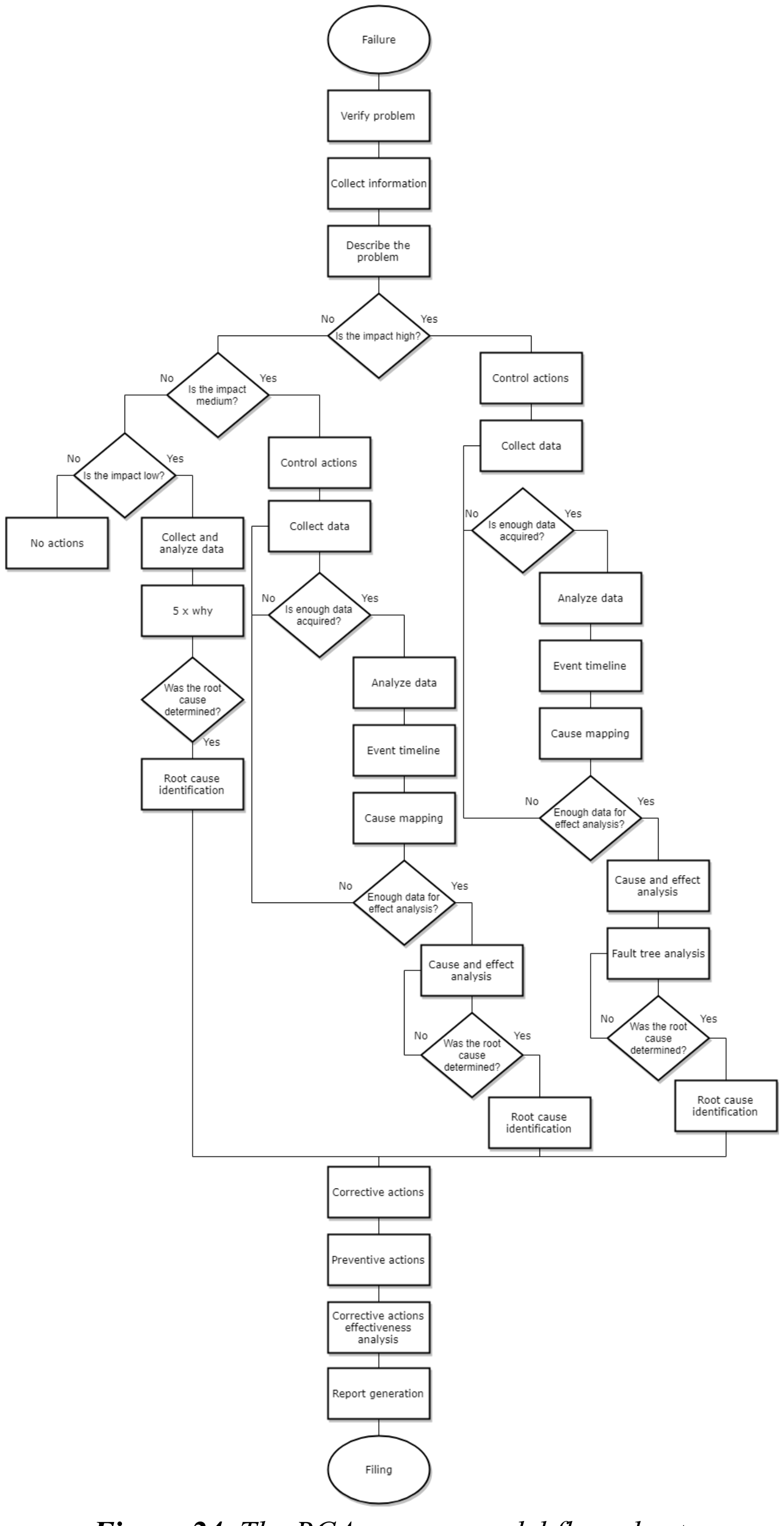

Figure 24. *The RCA process model flow chart.*

As seen from the figure above the RCA process starts with a failure. This failure can be just occurred, or it can be a situation that has happened in the past. As presented earlier everything starts with problem definition and leads to collecting information. These steps are done with a help of questions presented in Appendix A. It is important to gather all failure related information for example the equipment individual tracking number, is there other similar failures and what the affected parts.

After determining the value of impact, the controlling actions need to be taken. This means that all barriers should be checked in order to prevent the same failure occurring again in a small-time period. Also, the failure is stopped from impeding other parts of equipment and operation. When this is done it is time to analyze the data collected and to create cause and affect analysis to identify the root cause. All different levels of impact have different way of doing the analysis. The higher the impact is the closer it is looked at.

After identifying the root cause or causes it is important to take corrective actions and to create ways of preventing those happening again. When these steps have been taken the RCA should be reported and filed for every key person to see. Reporting and filing are very important aspects because it can help others in the organization how might be dealing with that same issue. This also created a data base which can later be used for example to design new equipment.

4.4.2 KPI advances

One key aspect of this thesis is maintenance contracts and especially the contracts based on availability. Availability types of contracts are selling service that supports customers' daily work and processes [9]. The focus company is selling availability on its contracts and just a physical maintenance which identifies these contracts as service contracts.

Thinking about the Company A, all their customers might have slightly different specifications for the availability, which is one of the reasons why it is important to define a clear definition for the terms to be able to illustrate to the customer what is Company A definition and measurement for availability. This and the fact that dependability is collective term of availability [1] this thesis is following SFS-EN 60300-1 and PSK 6201 definitions of dependability management. Availability is a combination of maintenance support, reliability and maintainability [1, 3].

For this thesis, availability is defined according to standards mentioned above emphasizing the standard point of view: "*as a probability that system is functional when needed in required conditions*". This means the percentage in which the equipment is available for use when needed and in required conditions. Equipment does not have faults that affect machines operations and it does not cause safety or environment risks. This includes resources and spare parts for maintaining machines availability so that machine is able to start its mission and complete tasks required.

It is proposed that Company A uses operational availability in its own inner calculations. The reason for this is that Company A will get more insight on how the equipment works under the required conditions. It will present the real conditions and gives knowledge of the equipment life cycle. It will also create real information on how preventive, productive and corrective maintenance are changing availability. One other reason for operational availability is to get a vision of the other operational availability factors. What are the real reasons behind downtime and giving Company A a possibility to change its methods and processes to enhance availability as was suggested from Efora. Efora told in a benchmarking session that giving a fixed price the profit will become better when developing own processes and operation [19].

The customers for Company A might be interested in technical availability, because it takes into account not only the operational availability factors but also human errors. Human errors increase downtime, which decreases plants operation. From the Company A side, the human errors are not something that can be predicted. Amount of human errors need to be evaluated using history data and it is not possible to get accurate information for the future. Company A does not have a way of controlling these kinds of errors which make it reasonable not to use that information on company's own calculations. Preventing human errors can be done by training the operators and giving them information on what operating unevenly causes. To illustrate the difference of availability in these two cases both operational and technical availability are included in the calculation case study.

4.5 Case study: a calculation model of availability factors and costs

This chapter shows how the case study has been created and what kind of results has been found from the study. The case study is a calculation created with the Microsoft office Excel. The case study has an objective on helping to identify the fruitful combinations of availability factors and to show capabilities that could result in a new innovative view in a company. The case study also identifies the resources needed for availability and the capabilities that Company A could possible leverage to extend beyond its capacity.

Few defining factors set for the calculation model comes from the Company A's business. Company A manufactures equipment for goods handling, the calculation model needs to be able to count availability for a fleet based on equipment type and based on all equipment in the customer plant. This is, because equipment can only be substitutable with the same type, this is due to fact that customer logistic system is often quite simple and changes cannot be handled easily in that [91]. The calculation model does not take into account the different maintenance tasks the same type third party equipment might have compared to Company A equipment.

4.5.1 The calculation model itself

The calculation model was conducted to create a calculation tool for availability factors. The calculation model is visual presentation of how availability factors are influencing availability and availability cost. With the calculation it is possible to increase and decrease factors to see how availability is the changes. The data is essential for the calculation and it is important to have adequate information, without correct data the results are irrelevant and does not support the decision-making process.

Appendix C is a streamlined picture of the calculation model, green squares illustrate the parts needed to be filled by the user and blue ones are calculated based on the added information. The calculations are done for single equipment type, fleet of one equipment type and for the plant availability for two different availability: technical and operational. Human error can be calculated from history data or it can be calculated based on a customer or Company A estimate. It is evaluated that usually human error is approximately 5 to 10 % of corrective maintenance. This evaluation is used in the calculation model.

Technical and operative availability is calculated from logistic downtime, preventative maintenance, preventive maintenance, administrative delay and corrective maintenance time as shown in Figure 4. The downtime is created from these times. The downtime is reduced from the total time to get the total uptime. Reason for These information is needed for the availability calculations. To calculate accurate availability this data needs to be accurate.

The calculation has OEE calculation, which was presented in chapter 2.1.1, done based on Figure 3 and Table 1. OEE calculation is implemented with a purpose to demonstrate how availability and availability factors affect OEE. OEE is one of the most known calculation tool as presented in the literature review. It was implemented into the calculations because it was one of the most mentioned tools in the benchmarking. In Company A baggage handling field OEE need to be modified because the field is unique, and the handling process is not continuous. This is the reason why it is assumed in the calculation model's OEE calculations that quality and performance are stated to be 100 % because those where not under review in this thesis.

The calculation model also calculates availability costs and depicts the return on capital employed, ROCE. ROCE is a financial ratio of measuring company's efficiency and profitability with which its capital is employed. ROCE is calculated as follows:

$$ROCE\ \% = \frac{Earnings\ before\ interest\ and\ tax\ (EBIT)}{Capitan\ Employed} \tag{4}$$

Needed information for calculating ROCE is received from Company A's material. This is calculated to illustrate how changes in availability affect the ROCE percentage. OEE is used in ROCE a calculation which is how the availability factors are affecting ROCE. ROCE calculation is presented in more detailed in Figure 25.

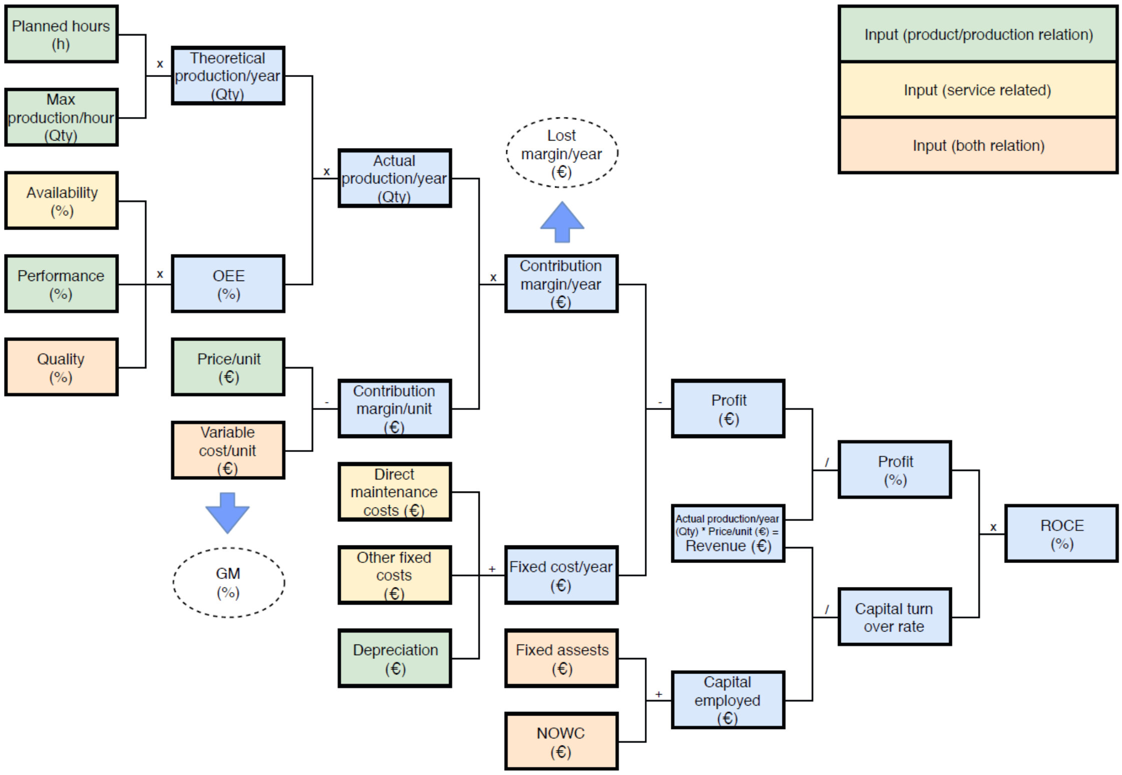

Figure 25. *Service activity improvement calculation model calculating ROCE. Adapted from [92].*

In above model (Figure 25) NOWC is Net Operating Working Capital. NOWC stands for the excess of operating current assets over operating current liabilities, it is a measure of company's operational liquidity of a business [93]. Gross Margin, GM, is calculated as follows:

$$GM\ \% = \frac{Price/Unit(€)\ - Variable\ Cost/Unit(€)}{Price/Unit(€)} \tag{5}$$

and Lost Margin/Year is calculated as:

$$\begin{aligned} Lost\ Margin/Year\ (€) = [\ &Theoretical\ Production/Year\ (Qty) \\ &- Actual\ Production/Year\ (Qty)\ ] \\ &*\ Contribution\ Margin/Unit\ (€) \end{aligned} \tag{6}$$

Revenue is calculated in Figure 25 as follows:

$$Revenue\ (€) = Actual\ Production/Year(Qty)\ * Price/Unit(€) \tag{7}$$

The calculation model also takes notice on how penalty side of availability based maintenance contracts is adding costs. These costs are visible when availability percentage is lower that the customer is requiring. For example, in the calculations the required availability is set to be 80 % or more, if the availability decreases under that the penalty is adding costs every percentage it decreases. In the calculation model the penalty per one percentage can be changed as needed.

Availability is calculated using the total moves per machine type information which is then translated into lost moves based on the availability percentage. One move in the calculation model is the equipment movement from point A to get the baggage from point B and moving that into point C. These moves are possible earnings and it is possible to turn this information into loss of profit.

The calculation model also calculates how many extra units are required to do the baggage transfer to get the required 100 % of baggage moved. Cost of additional units can be calculated, the calculation only takes a notice of small equipment and bigger ones are left out. This is because it is not possible to replace bigger equipment with another [86].

There is a list of countries in the calculation model because Company A's customers have plants all over the world. Every country has its own work costs which are considered in the calculation. Costs factors are gotten from Company A's internal material and hour costs is a minimum rate covering all internal costs [94]. Country is selected from the main window of the case study. Hour costs are originally in local currency and are being converted into Euros. The calculations are done in Euros to get more comparable result with all currency being the same. There is a possibility to add country factors into hourly costs for example if India performs maintenance tasks slower that Finland country factor will add that into calculations.

Maintenance actions are listed based on Figure 4. All maintenance actions have a time that it takes to perform each task. Those are then calculated to a total of what each action costs. Based on those it is then possible to find out the total downtime and the costs of it. These maintenance tasks are done to each equipment type separately to get the real estimate of maintenance per equipment type. It takes more time to perform maintenance for large equipment than it is for a smaller one [79, 91, 94]. There are also type differences [79].

4.5.2 Analysis of the case study

Simulating ROCE changes when altering values affecting it to visually show what are the factors most affecting it. When changing OEE with a 10 % increase the ROCE percentage increases up to 21 %, this also increases profitability percentage around 12 %. Trying to have the same earnings with different methods it takes up to 6 % increase of price or reducing maintenance costs by more than 95 %. This clearly presents why it is important to notice the OEE factors and to invest in those.

Corrective maintenance is set to be 20 % of all maintenance hours. This is as mentioned in the literature review [62], benchmarking [19, 22, 25] and interviews [27, 30] corrective maintenance should be close to 20 % of all maintenance actions and preventive maintenance should be the other 80 %. As Al-Turki also mentioned in [62], it is important to have at least 80 % of the maintenance planned [62]. This assumption sets the base for the calculation model. It is not possible without correct data to calculate what is the real share in corrective and preventive maintenance in Company A, which is why the assumption is made.

In corrective maintenance the maintenance tasks are hard to predict. Corrective maintenance task can be about tightening a screw or changing a turbocharger, these tasks take a different amount of time to do. This makes evaluating the corrective actions harder. It should be recorded a well as possible, from where the corrective actions come from and how long those take to repair. Different time periods were presented earlier in chapters 2.1 and 2.2.

By making a 20 % change to corrective maintenance changes availability. In Figure 26 capture A illustrates a 20 % increase in corrective maintenance (the overall calculation model is visible in Appendix D). Lower figure B, in Figure 26, illustrates a 20 % decrease in corrective maintenance (the overall calculation model is visible in Appendix E).

A:

Single equipment Ao	Single equipment At	Fleet availability Ao	Fleet availability At	Fleet Ao Penalty	Fleet At Penalty	Lost (€) against 100% Ao fleet	Lost (€) against 100% At fleet
75,67 %	70,52 %	57,26 %	49,73 %	-2 820,33 €	-3 753,48 €	1 260 000,00 €	1 540 000,00 €
95,30 %	93,98 %	68,05 %	60,84 %	-5 929,18 €	-9 504,48 €	3 360 000,00 €	3 840 000,00 €

Operational availability	38,96 %	Ao OEE	38,96 %	Ao ROCE %	-3,08 %	Penalty € / Ao	-25 444,80 €	Ao costs	63 565,20 €
Technical availability	30,25 %	At OEE	38,96 %	At ROCE %	-9,83 %	Penalty € / At	-30 842,14 €	At costs	67 167,86 €

B:

Single equipment Ao	Single equipment At	Fleet availability Ao	Fleet availability At	Fleet Ao Penalty	Fleet At Penalty	Lost (€) against 100% Ao fleet	Lost (€) against 100% At fleet
81,86 %	77,64 %	67,01 %	60,27 %	-1 610,38 €	-2 445,92 €	980 000,00 €	1 120 000,00 €
97,60 %	96,91 %	82,36 %	77,78 %	0,00 €	-1 102,84 €	1 920 000,00 €	2 400 000,00 €

Operational availability	55,19 %	Ao OEE	55,19 %	Ao ROCE %	9,51 %	Penalty € / Ao	-15 379,52 €	Ao costs	43 690,48 €
Technical availability	46,88 %	At OEE	55,19 %	At ROCE %	3,06 %	Penalty € / At	-20 534,59 €	At costs	40 335,41 €

Figure 26. A: *The calculation model with 20 % increase in corrective maintenance.*

B: *The calculation model with 20 % decrease in corrective maintenance.*

Adding 20 % to corrective maintenance reduces single equipment operative and technical availability with around 5%. More noticeable change is the fact that the overall fleet operational availability is decreasing by more than 10 % and that also technical availability is decreasing by more than 10 %. These changes are visible in Appendix D.

By decreasing corrective maintenance with 20% will add single equipment operational availability with around 2 %. Looking at the whole fleets' operational and technical availability by approximately 4 %. These modifications are illustrated in Appendix E.

Changing the corrective maintenance present how availability change and what kind of changes that will bring to costs. As mentioned by the benchmarking organizations [19, 22, 25] it is important that corrective maintenance actions are transferred into preventive maintenance because corrective maintenance actions are usually more expensive and take longer time to work on that preventive maintenance actions. Preventive maintenance actions are planned and does not cause as big challenges to the customer operation that unexpected stoppages.

The case study clearly presents the factors influencing availability and their influence on it. The case study shows that when increasing corrective maintenance preparation, diagnostic, getting parts, correcting fault, and testing times all increases at same proportion. Same happens when preventive maintenance is increased or decreased. It is important to remember that unexpected failures can also cause customer operation declines and problems.

4.5.3 Importance of data gathering: Where, what, why and analysis

Data gathering is one of the important things in calculating availability. If data is not accurate it is not possible to do exact calculation and make precise decisions and operations base on those calculations. Gathering data should be standardized and done the same way throughout the whole organization. In Company A every division has its own way of gathering information and there is no standardized methods and data that is collected.

To manage availability, it is important to gather time periods in which the failure occurs and in which time it takes to repair it and what are the parts that take that time. Currently Company A does not gather for example the time that it takes the maintenance person to identify the failure or the time it takes to repair or do the preventive maintenance. Company A has identified whether the maintenance is for example corrective, preventive or emergency but for instance the time that corrective maintenance takes might include travelling and maintenance time. It is not classified what that time includes. It is obvious that travelling and the size of the plant is affecting availability which is why it is important to enter those into system. When these can be ruled out from the availability it is easier to get into more detailed factors in availability.

Currently the maturity of data is not at that state that advanced calculation could be made. Data that needs to be gathered is the equipment serial number for identification of equipment, time periods per spend maintenance actions depict earlier in chapters 2.1 and 2.2. These consist of 7 phases: realization, access, diagnosis, spares, replace, check and align, phases are influenced by logistic, administrative time and access [14, 39, 47]. Also maintenance actions need to be divided and explained. These are necessary for calculations and for finding root causes for availability. Division for different maintenance tasks is crucial for distributing these into correct availability factors.

5. CONCLUSIONS AND DISCUSSION

Aim in this thesis was to create a framework for availability based maintenance contracts and to define factors and costs influencing availability in Company A. The study started with a literature review with a goal to define availability, its factors identified already and to get a view of the ways availability can be measured. Besides the literature review, benchmarking and interviewing were used with a case study as a research method. Benchmarking and interviewing were done to gather the needed material for the final outputs, the framework and the availability factor and cost calculation. The framework is a process model that is focused with RCA model toll and KPIs. The calculation of availability factors and their costs on the other hand is used as a tool for the framework to calculate availability more clearly and to visually illustrate the effects different factors have on availability and costs on organization.

In the first instance, non-availability is generated from failures and downtime, preventing failures is done by maintaining the equipment. In availability based maintenance contracts it is essential that the costs of the contract can be calculated properly. This requires knowledge and ability to clarify how the equipment in question fails. Based on that pool of knowledge can be calculated or simulated the incurred costs. In the contract, there are several other factors to consider but if the costs cannot be calculated precisely, there is not base for profitable contract.

This chapter illustrates the results and conclusions received based on the findings of literature review, benchmarking and interviews in Company A. These results are then discussed and analysed further. This chapter is presenting the key outcomes obtained and what possibilities those have in the future in Company A and in other organizations.

First this chapter introduces the summary of the results and the key factors formed based on the research. Secondly the recommendations for the Company A are discussed and presented. Some limitations came up while working the thesis, those are visible in the third phase with the statement of the method used in the thesis and its suitability. Last phase illustrates the suggested future research that was discovered during the research.

5.1 Summary of the results

The thesis was a research on developing a framework of availability based maintenance contracts and on resolving the factors affecting availability. The literature review aimed on creating an image of availability, its factors and costs, it also aimed on producing a view of contracts life cycle and how those are managed. The implementation of the thesis included four benchmarking and several interviews in Company A.

The benchmarking aimed to create an overall picture of how availability could be managed, how availability based maintenance contracts are seen in different fields, what are the factors influencing availability and how availability based maintenance contracts can be handled. The goal of the interviews was to find out the current state of availability and availability based maintenance contracts in Company A. The interviews objective was also to describe how the target company sees availability and the future of availability based maintenance contracts. The benchmarking and interviewing results are presented in chapter 4.1.

From these results literature review, benchmarking and interviews, the preliminary framework was created, and suggestions were made on what are the factors in availability and how to measure availability. Interviews were also used to validate the preliminary framework to get it better fitted in the Company A's market. Based on those validation interviews the final framework was conducted (chapter 4.3) and the RCA model was created (chapter 4.4.1). The conducted framework answers the first research question:

Question 1: How is the framework created to serve company's and customers vision of availability where equipment are different from each other?

The final framework presented in Figure 22 illustrates how to manage availability based maintenance contracts. The framework needs to be clear and user-friendly. In Company A's field, it needs to be flexible and not too detailed to work with different customers. The framework needs to have a customer's and a company's cost structure presented, the critical equipment for customer's operation needs to be clear for all parties that are involved in the contract are aware of these. The customer's service level agreement is one of the most essential aspect in creating a framework.

The documents created aimed to make availability more elaborate and tangible that the process is not too complex. In Company A's field the customers have variety of solutions and ways of working. The customer might have many different equipment types in the plant and those can be manufactured by a third party. To make it easier to manage different equipment availability the framework was introduced and to tackle challenges the RCA model (Figure 23 and Figure 24) was created.

The RCA model is dealing with the execution, evaluation and enhancement phase of the framework. It helps on finding the root causes of the failure and this way tackling the factors causing non-availability. Using literature review, benchmarking, interviews and the framework, the suggested KPIs were presented in chapter 4.4.2. Based on a vision of those being the indicators that calculates the success of the contract and the Company A's performance.

To handle and better calculate the availability, its factors and costs the case study was created. It is depict in the chapter 4.5. Answers to research question 2 to 5 were studied with the case study:

Question 2: What are factors that affect availability of an equipment?

Factors influencing availability of an equipment are maintainability, maintenance support and reliability. It is essential to have preventive and predictive maintenance clearly planned. Also, it is important to have all influencing downtime factors played out. These downtime factors are logistic downtime, preventative maintenance, preventive maintenance, administrative and corrective maintenance time.

Question 3: What type of data is needed to manage availability?

One purpose for this thesis was to make a statement on what data to collect for managing availability based maintenance. The data to be collected and needed is the time spend on different maintenance tasks and what are those maintenance tasks. It is important to know the maintenance resources and know how many maintenance people are available for handling downtime and keep equipment available. To be able to manage availability the equipment failure model needs to be visible for the maintenance people to be able to plan maintenance tasks.

Question 4: How availability is measured with adequate information and with a sufficient accuracy in availability based maintenance contracts?

To measure availability with adequate information it is not needed to leave the unnecessary information for example screws and nuts out of calculations. It is needed to identify equipment critical parts to functionalities. In availability based maintenance contracts the critical equipment for the customer operation should be identified to guarantee customer operation. To measure information accurate, it is important to register all times spend and to get more out of availability calculation those times should be registered with a correct maintenance tasks labels. It is not possible to measure availability if all maintenance done in the plant is registered with a single line and not by equipment number and maintenance task performed.

Question 5: What are costs of availability and where do those come from?

Unexpected failures are causing extra costs to availability. Unexpected failures are interrupting the customer's operation and causing extra costs to the customer and to the maintenance. It takes more time to do corrective maintenance than preventive maintenance. Corrective maintenance is also causing interruptions in preventing maintenance and taking resources from preventive maintenance. Correcting maintenance demands more resources and it typically also requires all the maintenance personnel attention because the failure might stop the customer operation.

One of the goals was to create a method for calculating availability by using KPIs. The most important KPIs in availability based maintenance contracts for Company A is operational availability and for the customer it is technical availability. These KPIs are calculated using downtime factors and equipment standby and operating times. Costs for those can be calculated based on the costs of the maintenance tasks and adding spare parts into those.

Adding human errors into downtime it is possible to calculate technical availability for the customer. In technical availability it is essential to notice that it is not possible to predict human errors. Those can be reduced with training and informing to the operator what kind of costs human errors cause for availability and for the customer.

The case study was a calculation model that has all availability affecting factors and those costs presented. Based on the calculation it was easily noticed how availability is in an essential role of organizations value creation. The OEE has a major influencer when it comes to ROCE percentage and the organization profitability. One of the most interesting matters the calculation model visualized was the fact how much the corrective maintenance influences downtime and from there to availability. Downtime costs are a big part in availability costs.

It was found out that the vision of using availability based maintenance contracts in the future in Company A is quite clear, but the content of those contracts and what availability means the company, are not standardized and transparent. Some challenged found will resolve themselves as more availability based maintenance contracts are sold and managed. With this also the process will be clearer for the organization. Other issues are related to the availability, its factors and needs. These should be paid closer attention to improve the availability. These are closely related to the communication, explaining and opening the variety of needs inside the different departments and customers. These also link to the data issues and gathering it as standardized as possible.

5.2 Recommendations

As seen in this thesis, putting effort on contract management and availability will have greater impact on profit and to the company's profitability. Optimizing the maintenance overall costs will help on finding a balance between preventive and corrective maintenance. The balance will help the company to get better value from its maintenance contracts. Recommendation for optimizing corrective and preventive maintenance is to have a project around the topic every 2 to 5 years. In the project all maintenance tasks are reviewed and analyzed. The project should include different stakeholders for example from design, product development, contract management and maintenance. Results from the project should then be presented to everyone in the company. The direct yield savings from the maintenance is hard to achieve and not easily managed. With financial calculations it is possible to calculate the improved quality and increased profit. Equipment availability is kept good and costs in minimum with maintenance. To manage these requirements demands clear maintenance strategy and optimized maintenance program.

To calculate factors influencing those it is essential to have accurate data in the systems. It is not possible to calculate costs, make decisions or improve availability if the correct factors are not in the system. Company A is a large organization with many different customer plants over the world and with variety of ways of recording maintenance actions. It is recommended that the company created a platform for all maintenance people to be filled when maintenance action is taking place. This platform has compulsory fields for example for time the maintenance started, what time it took to determine the failure and what was the exact maintenance work. The data collected would then be transferred into Company A's or the customers system. The managers need to make a more firm statement on what is expected and why. It is also important to follow up with that to make sure people will do the needed recordings.

When data has been gathered for example from one plant and it has been validated, it is possible to add more accurate data into the calculation model. When Company A starts using the calculation model more internal the next step for it is to bring it to the customer. When the calculation model is showed to the customer it is important to create more visual platform for the customer where only needed aspects are within a sight. The Microsoft Excel might not be the most reliably and professional looking tool in the eyes of the customer.

It is recommended that when selling availability to the customer the framework is used and made visible for all parties. The RCA model, Figure 24, should be validated with the maintenance personnel and the contract team to make sure it fits Company A's processes. It is also recommended that the three failure impacts, Figure 23, are harmonized to suit the needs. The RCA model should be implemented in to the customer plants one by one to start gathering information to Company A's system and to start getting better knowledge on failures.

Company A has some inconsistences when it comes to definition and calculations of availability. The company does not have a one similar way of looking at availability. This thesis gives a standardized form of availability and a suggestion of how availability should be seen in Company A. It is important to find a way of communicating different meanings of the words to different departments and later also to the customer. Currently Company A has 4 different types of availability and these all are calculated very differently. It is important for the management to get this straightened out and to create systematical ways of communicating different matters. Recommendation to get more harmonized definitions and calculations within the Company A is to have small availability seminars or stand where all different stakeholders are welcome to visit and talk about the viewpoints in availability. It would help on opening up a dialog between departments and to get everyone to hear variety of perspectives that need to be considered when talking about global availability based maintenance contracts.

Company A has a desire to use RCM in the future [9, 26, 28] and as it is well used in the Finish Defence Forces [23] the desire is even greater than it was at the start of this thesis [95]. If the company commits on RCM it should start the work with small steps. First of all, as mentioned earlier in 2.7.1 RCM need extensive amount of data. This data needs to be accurate and clearly presented. It is also important to have the equipment subdivision done based on functionality of the equipment. This means that the company should start designing equipment based on that and based on availability. It also means that to make the RCM process easier the maintenance manuals and instructions should be based on the equipment functionality. This is a big change for Company A and it requires management support, instructions and commitment. To start with RCM, it should be done for one equipment type at the time and starting with one customer plant data. This way it the results will give more arguments and reasoning to get the other plants and design teams onboard.

5.3 Suitability of the method / limitations

During the research, it was found out that availability and maintenance are extremely studied. There are a lot of different studies conducted and the information is very widely spread, the thesis is agglomerating all needed and essential availability information into one. One of the greatest challenges was to compress all information available into a compact and clear package.

As the research went onwards, it was decided to put more emphasis on identifying the factors that have the most influence in availability and how those can be detected. This was done for the two reasons. First, Company A does not have excessive amount of clear data collected to make standardized and exact research on the costs of availability and where those come from. Second, it was noticed that to be able to calculate costs and to deal with availability it is important in big organization, Company A, to start building availability based maintenance contracts from the start and not expecting miracles that it is possible to start doing it without the ground work.

The research method used was the case study which was grounded with benchmarking, interviewing and literature reviewing. The four benchmarking were done in variety of organizations which gave a great over look of how availability is seen in different types of organizations, what are the main factors in availability based maintenance contracts and in more general in maintenance. The result got were easily compared and implemented with Company A's vision.

Conducting the case study, it was comparatively easy to do the calculations and measure availability. The challenge came when real data was needed to but down into the calculation model. The Company A doesn't have a standardized method on gathering data and what data is really needed to be gathered. This caused a problem and led to the fact that using the information collected from the interviews the assumption was made that corrective maintenance is about 20 % of all maintenance and the human errors are around 5 to 10 % of corrective maintenance. This will give approximate figures of availability. Simulating the changes after this was fast, but if Company A wants to do more precise calculations it is essential to have better registered data at hand. In the calculation many deductions and assumptions were made to get the results.

To view the results into previous studies it is visible that the results are on the same lines and organizations are doing things fairly similar. To get more and added information it would have been useful to utilize more the design and maintenance teams in Company A to get better knowledge and information about the preventive and corrective maintenance time factors that are not visible in Company A's system. On the other hand, the case study was the best method suited for answering the research questions.

5.4 Suggested future research

The framework is possible to generalize if it is studied in other organizations. Currently the framework created is done based on four benchmarking, literature review and internal interviews in Company A. Because it has not been tested and validated throughout other organization it cannot be said to be a generalize model. As a future study it is possible to conduct a research about the framework to make it suitable also in other organizations. The framework is validated in Company A and it fits the company's needs and requirement, whether it works elsewhere needs future studies. This also raises a question of what kind of maintainability management is needed to master availability based maintenance contracts. Should there for example be control desks which are used in remote monitoring?

The thesis focuses on availability more on the reliability and maintenance side. It would be useful to study how maintainability and maintenance support could be improved to add value to the availability. It is essential to add designing into availability and this is one of the reasons why it is a great future research topic: how the design could better take notice of availability.

Company A has lots of customer plant all over the world and the company has some challenges on communications. Adding these together leads to a future research of how would notes and information better move between plants and between maintenance, design and research and development. Currently there is no standardized method for information flow and getting feedback from the maintenance personnel. Maybe there is a need for a role of maintainability engineering management function to handle maintainability process. This is one of the topics that Company A needs further studies.

Future studies with the calculation model are to study whether the results change when adding more data or equipment and to do the calculation model with different stakeholders and organizations. The current was done using the Company A equipment and assuming that similar third party equipment have same kind of maintenance tasks and those take approximately the same amount of time to perform. In the future when Company A has mode data from the third party equipment it is possible to study what those add to the research.

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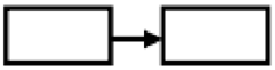
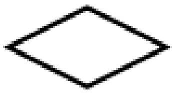
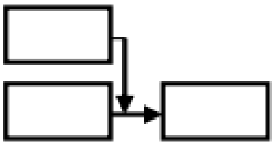
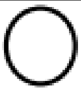
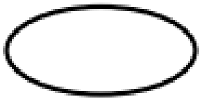
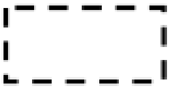
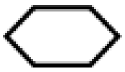
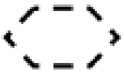
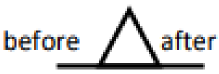
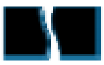
APPENDIX A: QUESTIONS TO DEFINE THE PROBLEM AND GATHER DATA [71]

Category	**Questions**
What	• What happened? • What are the symptoms? • What is the complaint? • What went wrong? • What is the undesirable event or behavior?
When	• When did it occur: what date and what time? • During what phase of the production process?
Where	• What plant? • Where did it happen? • What process? • What production stream? • What equipment?
How	• How was the situation before the incident? • What happened during the incident? • How is the situation after the incident? • What is the normal operating condition? • Is there any injury, shutdown, trip, or damage? • How frequent is the problem? • How many other processes, equipments or items affected by this incident?

APPENDIX B: FACTORY CHARTING STANDARD SYMBOLS [71]

Item	Symbol	Description
Event		An action that occurs during some activity
Primary event		The action directly leading up to or following the primary effect
Undesirable event		An undesirable event (failure, conditions deviation, malfunction, or inappropriate action) that was critical for the situation
Secondary event		An action that impacts the primary event but is not directly involved in the situation
Terminal event		The end point of the analysis
Condition		Circumstances pertinent that may have influenced and/or changed the course of events, or caused the undesirable event
Presumptive event		An action that is assumed because it appears logical in the sequence but cannot be proven
Causal factor		A factor that shaped the outcome of the situation, the root cause of the problem
Presumptive causal factor		A factor that is assumed as it appears to logically affect the outcome
Change		A change in the condition of the situation after an event have occurred
Barrier		Physical or administrative barrier to prevent an unwanted situation
Failed barrier		Physical or administrative barrier that failed to prevent an unwanted situation

APPENDIX C: THE CALCULATION MODEL OF AVAILABILITY

COMPANY A

Country:	Finland	Human errors:	30,00 %	Human errors / Total hour:	12000	Required availability:	80,00 %	Penalty € / 1 A % drop:	62

	EQUIPMENT TYPE:	Units	Annual hour / singel machine type	Moves / hour	Total hours / machine type	Total moves / machine type	GM container move net €	Price € / Unit	Extra units needed:	Single equipment Ao	Single equipment At	Fleet availability Ao	Fleet availability At	Fleet Ao Penalty	Fleet At Penalty	Lost (€) against 100% Ao fleet	Lost (€) against 100% At fleet	Maintenance time
1.	EQUIPMENT 1	2	4 000	10	8 000	80 000	35	1 000 000,00	0	79,42 %	74,81 %	63,08 %	55,96 %	-2 097,99 €	-2 981,10 €	1 120 000,00 €	1 260 000,00 €	1036
2.	EQUIPMENT 2	8	4 000	10	32 000	320 000	30	850 000,00	0	97,39 %	96,63 %	80,93 %	76,04 %	0,00 €	-1 966,57 €	1 920 000,00 €	2 400 000,00 €	107
3.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	
4.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	
5.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	
6.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	
7.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	
8.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	
9.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	
10.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	
11.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	
12.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €	

Operational availability	51,05 %	Ao OEE	51,05 %	Ao ROCE %	6,30 %	Penalty € / Ao	-17 947,97 €	Ao costs	50 662,03 €
Technical availability	42,55 %	At OEE	51,05 %	At ROCE %	-0,30 %	Penalty € / At	-23 220,00 €	At costs	49 890,00 €

APPENDIX D: THE CALCULATION MODEL WITH 20 % INCREASE IN CORRECTIVE MAINTENANCE

COMPANY A

Country:	Finland	Human errors:	30,00 %	Human errors / Total hour:	12000	Required availability:	80,00 %	Penalty € / 1 A % drop:	62

	EQUIPMENT TYPE:	Units	Annual hour / singel machine type	Moves / hour	Total hours / machine type	Total moves / machine type	GM container move net €	Price € / Unit	Extra units needed:	Single equipment Ao	Single equipment At	Fleet availability Ao	Fleet availability At	Fleet Ao Penalty	Fleet At Penalty	Lost (€) against 100% Ao fleet	Lost (€) against 100% At fleet
1.	EQUIPMENT 1	2	4 000	10	8 000	80 000	35	1 000 000,00	0	75,67 %	70,52 %	57,26 %	49,73 %	-2 820,33 €	-3 753,48 €	1 260 000,00 €	1 540 000,00 €
2.	EQUIPMENT 2	8	4 000	10	32 000	320 000	30	850 000,00	0	95,30 %	93,98 %	68,05 %	60,84 %	-5 929,18 €	-9 504,48 €	3 360 000,00 €	3 840 000,00 €
3.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
4.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
5.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
6.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
7.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
8.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
9.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
10.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
11.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
12.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €

Operational availability	38,96 %	Ao OEE	38,96 %	Ao ROCE %	-3,08 %	Penalty € / Ao	-25 444,80 €	Ao costs	63 565,20 €
Technical availability	30,25 %	At OEE	38,96 %	At ROCE %	-9,83 %	Penalty € / At	-30 842,14 €	At costs	67 167,86 €

APPENDIX E: THE CALCULATION MODEL WITH 20 % DECREASE IN CORRECTIVE MAINTENANCE

COMPANY A

Country: Finland | Human errors: 30,00 % | Human errors / Total hour: 12000 | Required availability: 80,00 % | Penalty € / 1 A % drop: 62

	EQUIPMENT TYPE:	Units	Annual hour / singel machine type	Moves / hour	Total hours / machine type	Total moves / machine type	GM container move net €	Price € / Unit	Extra units needed:	Single equipment Ao	Single equipment At	Fleet availability Ao	Fleet availability At	Fleet Ao Penalty	Fleet At Penalty	Lost (€) against 100% Ao fleet	Lost (€) against 100% At fleet
1.	EQUIPMENT 1	2	4 000	10	8 000	80 000	35	1 000 000,00	0	81,86 %	77,64 %	67,01 %	60,27 %	-1 610,38 €	-2 445,92 €	980 000,00 €	1 120 000,00 €
2.	EQUIPMENT 2	8	4 000	10	32 000	320 000	30	850 000,00	0	97,60 %	96,91 %	82,36 %	77,78 %	0,00 €	-1 102,84 €	1 920 000,00 €	2 400 000,00 €
3.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
4.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
5.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
6.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
7.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
8.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
9.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
10.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
11.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €
12.					0	0			0			0	0	0,00 €	0,00 €	0,00 €	0,00 €

Operational availability	55,19 %	Ao OEE	55,19 %	Ao ROCE %	9,51 %	Penalty € / Ao	-15 379,52 €	Ao costs	43 690,48 €
Technical availability	46,88 %	At OEE	55,19 %	At ROCE %	3,06 %	Penalty € / At	-20 534,59 €	At costs	40 335,41 €