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TAMPERE UNIVERSITY OF TECHNOLOGY

PYRY RINKINEN
DEVELOPEMENT AND IMPLEMENTATION OF CRITICALITY
ANALYSIS TOOL FOR SPARE PARTS OF FLUIDIZED BED
BOILER

Master's Thesis

Examiner: Postdoctoral Researcher
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ABSTRACT

PYRY RINKINEN: Development and Implementation of Criticality Analysis Tool for Spare Parts of Fluidized Bed Boiler

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The main objectives of this Master's Thesis was to develop a criticality analysis tool to classify spare parts of the fluidized bed boiler according their criticality and implement the CA-tool into the Service department of the case company. The spare part packages assure the availability of an installation during the guarantee time. This Thesis was made in order to gather required information to divide the spare part package into lean availability guarantee package (sold on the side of the boiler sales project) and into more profitable extended package (sold as aftersales).

The research answered to the questions: How to create an accurate and an efficient criticality analysis tool, which factors the tool should include and which type of parameters should be used in the analysis and how the tool should be implemented? The thesis was restricted to the spare parts of circulating fluidized boilers and bubbling fluidized bed boilers. In addition, this Thesis was restricted to consider the spare parts packages sold with new installations by Valmet Technologies units in Finland i.e. Capital Projects business unit and Service Spare Parts division in Finland.

The study in this thesis was constructive case study i.e. the research problem was solved by using a construction based on practical case problem and previous theory. The research was done by working at Valmet Technologies Oy, interviewing and discussing with the personnel of Valmet Technologies Oy and with supplier company's representatives, examining documents and reports related to the spare part packages and analyzing researches, articles, books and other theoretical literature concerning criticality analyses, fluidized bed boilers and implementation of a new tool in industrial environment. The most of the empirical data was collected by interviewing the personnel in the case company. The theoretical framework was formed based on previous researches, articles and books related to spare parts criticality and Valmet's training material related to circulating fluidized bed boiler called CYMIC.

The main results of the thesis are the new criticality analysis tool, complete analysis of pilot case spare part package, done using the new CA-tool, and careful verification and validation of the CA-tool for preparing the tool to be taken into action.

TIIVISTELMÄ

PYRY RINKINEN: Leijupetikattilan varaosien kriittisyysanalyysityökalun kehitys ja implementointi

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Tämän Diplomityön päätavoitteena oli kehittää leijupetikattilan varaosille kriittisyysanalyysityökalu, jonka avulla kattilan varaosat luokitellaan niiden kriittisyyden perusteella. Toisena tavoitteena oli ottaa työkalu käyttöön kohdeyrityksen Service osastolla. Varaosapakettin tarkoitus on kattaa kaikki uuden kattila-asennuksen käytettävyystakua aikana tarvittavat varaosat. Tässä työssä kehitetyn työkalun avulla kerätään tietoja joiden perusteella varaosapaketti voidaan jakaa niukkaan takuuajan pakettiin, joka myydään kattilan myyntiprojektin yhteydessä, ja kannattavampaan lisävaraosapakettiin, joka myydään jälkimyyntinä.

Tutkimus vastaa kysymyksiin: kuinka luoda riittävän tarkka ja tehokas kriittisyysanalyysityökalu, mitä tekijöitä ja parametreja työkalun olisi hyvä sisältää ja kuinka työkalu tulisi implementoida? Tämä työ rajattiin käsittämään Valmet Technologies Oy:n uusien leijupetikattiloiden myyntiprojektien varaosapaketteja.

Tämä työ on konstrukttiivinen case-tutkimus, jossa tutkimusongelma ratkaistaan rakentamalla työkalu pohjautuen ongelmatapaukseen ja taustateoriaan. Tutkimustyö on tehty Valmet Technologies Oy:llä, haastattelemalla alihankkijoita ja keskustelemalla Valmetin työntekijöiden kanssa, tutkimalla asiakirjoja ja raportteja liittyen varaosapaketteihin ja analysoimalla aikaisempia tutkimuksia, artikkeleita ja muuta kirjallisuutta liittyen kriittisyysanalyysiin ja leijupetikattiloihin. Suurin osa kokemuksesta tiedosta kerättiin haastattelemalla kohdeyrityksen henkilökuntaa. Taustatiedot kerättiin aiemmista tieteellisistä julkaisuista ja kohdeyrityksen koulutusmateriaalista.

Työn tuloksena syntyi uusi kriittisyysanalyysityökalu ja pilottikohteen varaosapakettin loppuunsaatettu kriittisyysanalyysi. Työkalun täyttämät vaatimukset ja tulokset verifioitiin sekä validoitiin. Kehitystyön myötä nousi esiin lisäkehitysvaatimuksia työkalulle ja lisätutkimuskohteita sen käyttöympäristölle.

PREFACE

This Master's Thesis has been done in the Service unit of Valmet Technologies Oy in Tampere during the autumn 2016 and spring 2017. The subject of the research is development and implementation of criticality analysis tool for spare parts of fluidized bed boilers.

I would like to thank the supervisor in Valmet Technologies Oy, Spare Part Manager, Aleksi Tammentie, for the opportunity to do my Thesis to this subject and for trusting my skills to work independently. I would like to thank whole spare part team for help at the office, excellent information I got and the knowledge they shared concerning the projects and the personnel of the company. In addition, I would like to thank all the people interviewed for the research and people involved for the pilot project meetings.

I would also like to thank the supervisors at Tampere University of Technology, Postdoctoral researcher Henrik Tolvanen and Professor Jouni Kivistö-Rahnasto, for the help and information I got concerning the academic issues and research methods, which helped me to finalize my research and accomplish it with proper Thesis paper. Finally, I would like to thank my family and friends for the care and guidance.

Pyry Rinkinen

In Tampere, 12.4.2017

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NOMENCLATURE

Abbreviations

A	Analysis
CA	Criticality Analysis
CFB	Circulating fluidized bed
D	Demonstration
ECI	Equipment Criticality Index
ERP	Enterprise Resource Planning
I	Inspection
ICC	International Criminal Court
ID	Induced Draft
IED	Industrial Emission Directive
IN	Interview
ISO	International Organization for Standardization
ME	Meeting
MTBF	Mean Time Between Failure
PCI	Process Criticality Index
PSK	Finnish process industry's standard center
RCM	Reliability Centered Maintenance
RPN	Risk Priority Number
RPN _s	Risk Priority Number of safety effect
RPN _e	Risk Priority Number of environment effect
RPN _p	Risk Priority Number of production loss effect
T	Test
US	United States
VaCRM	Validation Cross Reference Matrix
VCRM	Verification Cross Reference Matrix
WHO	World Health Organization

Symbols

C _{score}	Criticality score
P	Price [€]
D	Delivery factor
C	Capacity [%]
Pe	Probability of environment effect
P _{Loss}	Production Loss [€]
Pn	Probability
Pp	Probability of production loss effect
Ps	Probability of safety effect
R _d	Risk parameter of delivery
Re	Risk parameter of environment effect
Rf	Risk parameter of fuel effect
Rl	Risk parameter of location effect
Rn	Risk parameter
Rp	Risk parameter of production loss
Rs	Risk of safety effect

t	Time [d]
wd	Weight factor of delivery parameter
we	Weight factor of environment parameter
wf	Weight factor of fuel parameter
wl	Weight factor of location parameter
wp	Weight factor of production loss factor
ws	Weight factor of safety factor

Definitions

Capital project	Long-term investment project requiring relatively large sums of capital assets.
Criticality	Character which describes the size of the risk
Design validation	Confirmation the design will result in a system that meets its intended purpose in its operational environment
Design verification	The process of ensuring the design meets the rules and characteristics defined for the organization's best practices associated with design
Fluidized bed	Furnace technology where fuel and bed material is floated with air during the combustion process
Requirement validation	Confirmation the requirements clearly communicates the company needs and expectations in a language understood by the developers.
Requirement verification	The process of ensuring the requirement meets the rules and characteristics defined for writing a good requirement

1 INTRODUCTION

Industrial maintenance has gone through radical changes during the past decades. Changes are a result of increasing needs for maintenance. In addition, the industrial machines and equipment has developed more and more complex. Also new maintenance technologies have been invented and different responsibilities for companies have arose. Nowadays maintenance has a significantly greater role and expectations in companies' strategies and both national and international legislations than in the end of last century. Awareness to the relevance of maintenance in the point of view of occupational safety, environment and quality of production as well as the ever increasing pressures for usability of machines have attracted to notice its importance in broader vision.

Companies worldwide are targeting to find suitable strategic frames to combine systematically the new technologies to current requirements of maintenance. Reliability-Centered Maintenance (RCM) is this kind of frame. The RCM is a method to create a company-specific preventive maintenance program which leads to an improved safety, usability and economy. [13, 6 p.] Under the this frame the full RCM analysis is to be done.

The RCM analysis carefully considers the following questions: [35]

1. What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
2. In what ways can it fail to fulfill its functions (functional failures)?
3. What causes each functional failure (failure modes)?
4. What happens when each failure occurs (failure effects)?
5. In what way does each failure matter (failure consequences)?
6. What should be done to predict or prevent each failure (proactive tasks and task intervals)?
7. What should be done if a suitable proactive task cannot be found (default actions)?

As a part of the RCM analysis the spare parts classification is recommended, which purpose is to classify spare parts according their criticality. Various methods to go through the criticality analysis is shared in public distribution. Some of these methods are introduced and their suitability for this development project are evaluated in Bachelor's thesis written for introduction to this study. [21] For example, case study research published in year 2012:” *Criticality Classification of Spare Parts – case study*”, which presented multi-criteria classification method of spare parts called Analytic Hierarchy Process – AHP, which is a sophisticated mathematical tool for decision making that can deal with unstructured and structured inputs. [1] These general and published methods were found to be too complex or based on history data of failures, which is available mostly only in

aircraft or space industry. Case company of this study have not collected systematically data from the failures or the spare parts – not yet at least. Suitable criticality frames and tools are developed for other companies but those tools of course are confidential or company secret. So the research cap for this study is to find suitable and more simple way to perform the criticality analysis without leaning to history data.

The case company, Valmet Technologies Oy, has adopted the RCM-philosophy and have decided to serve customers according to RCM frame, so a need of a criticality classification was noted in spare part team of the Pulp- and Energy department. Internal development project was initiated based on the need for a criticality analysis of the spare parts of the power boilers. The development project was conducted internally in the case company. Background of the development project was lack of a proper classification based on criticality of spare part at that moment. The criticality analysis tool was considered to be needed to split spare parts into the “availability guarantee spare part package” and into the “extended spare part package” in the future. Rationale of the project was a need to find clear arguments to divide the spare parts into these packages. Business potential laid in new offerings with improved rationales of sold goods and opportunity to achieve better profit sales as well as more satisfied customers on account of better quality service.

Main objectives of the internal development project were:

- Criticality Analysis Tool for case company’s spare part business to be used globally
- Criticality Analysis Tool to help to create more exact availability guarantee package and better-profit extended package
- Criticality Analysis Tool to help the capital project organization to define the spare part package for customer by using this tool together with service organization
- Better spare part service to offer for customer when there is more knowledge behind the contents of spare part package

Main activities of the development project were to collect data of the spare parts from the suppliers, to find out useful data from ERP-software (Enterprise Resource Planning) of a case company, to do a research to find out generally more information about critically analyses, which was contracted out for a bachelor’s thesis of engineering technology student [21], and finally make a choice of method to be used in the final criticality classification tool. In addition, the proper user instruction for the tool was to be created and a spare part list of ongoing boiler installation project was to be finalized by the new criticality analysis tool.

In the case company a few researches has been done concerning spare parts packages which has resulted a need for a tool to gather up the customized spare parts package based on parts criticality. This Master’s Thesis is conducted in order to develop such tool. The

objectives of the internal development project were handed over into objectives of this Master's Thesis with some activities replaced. The research problem of this Thesis is also practically as such in the development project.

The research problems of this MSc Thesis are:

- How to create an accurate and efficient criticality analysis tool?
- Which factors the tool should include and which type of parameters should be used in the analysis?
- How the tool should be implemented?

The objectives of this Master's Thesis are:

- To develop and finalize the Criticality Analysis Tool
- To implement the tool correctly to be used for future projects
- To do a proper verification for the CA-tool
- To do a proper validation for the CA-tool
- To create instructions for the users of the tool
- To finalize the spare part criticality analysis of the pilot case using the CA-tool

The framework of the CA-Tool was built by the group of employees of the case company in the previous internal development project meetings. Preliminary design requirements for further development of the CA-tool were acknowledged in the launch meeting of this study.

Preliminary design requirements for the development of the Criticality Analysis Tool are:

- To take the effect of geographic location of the site into account in the criticality analysis of spare part
- To take the effect of variety of used fuel into account in the criticality analysis of spare part
- To explore suitable weight factors for the parameters of the analysis
- To explore other factors that have an effect to the criticality of the spare parts

Questions that came up during the previous development project concerning effective usage of the generic information of the spare parts from the ERP and suppliers, and on the other hand communication with the capital's sales project are left outside of this thesis. Functions, some calculations and actual values of the criticality analysis tool are not presented in this study due to their confidential nature.

The study begins with a literature review. The theory related to the criticality analysis of spare parts in general and common parameters of the criticality analysis will be intro-

duced. Also operations of circulating fluidized bed boiler will be presented focusing especially on its subsystems and main components. In addition, the characteristic failure modes of several well-known parts will be detailed. Later, the theory will be used in order to develop advanced criticality analysis tool. After the theory is examined, the previous results of development project are introduced, which also defines the initial state of the CA-tool from where the development of this study begins. Each parameter of the tool is explained separately. Next, all the design requirements (also those requirements that arose during the actual development) are defined as a vision of the practical tool became clear. The results of the research are analyzed, going through first each design requirement separately in the result chapter, and finally the results in broader vision in discussion chapter. Conclusion chapter will include the explanation of the results and their meaning for the case company. Recommendations concerning critical analysis of the spare part packages and the different usage purposes and the limitations of the tool regarding its use as well as the further research recommendations are presented in the discussion chapter.

2 BACKGROUND AND THEORETICAL FRAMEWORK

Criticality analysis of spare parts is based on multiple parameters and its purpose is to generate a criticality number and on the basis of the number the criticality classification can be made. Circulating fluidized bed boiler is a complex construction containing thousands of special made parts. The two-year spare parts packages which are dealt with in this study consider approximately 300 parts. The research of this study began in previous internal development project and the criticality analysis tool frame was given as initial state of this study. The frame consisted of three basic parameters of criticality analysis: production loss, environmental effect and safety effect. This chapter links together the knowledge of these separate subjects needed to develop a CA-tool.

2.1 Criticality Analysis of spare parts

In this chapter the criticality as a concept and theory of criticality analysis is introduced to increase understanding of the basis for the study. The criticality analysis is done to gather and structure enough information to decide which spare parts should be kept at store at the site and which are not. For more background information and previous studies about criticality analysis methods see Bachelor's Thesis written as an introduction for this study [21].

Criticality of spare parts

Criticality in frames of industrial maintenance management is a character which describes the size of the risk. In other words, an object is critical when the risk related to the object is not on the acceptable level. Criticality analysis is a task that belongs under the risk management. Its purpose is to recognize and predict possible risks. As a result of a criticality analysis a certain criticality number is formulated by calculating probabilities and consequences of the risk together. [13, 2 p.] The method provides basic data required for preparing a maintenance plan. It can also be used in the purchasing stage to support determining the characteristics, quality level and acceptance criteria for critical equipment.

In industrial business, one important part of the machinery maintenance is a quick repair of unexpected failure. To succeed the repair in minimum time the needed spare parts should be at hand at the site. All the possible spare parts cannot be at the site due their expensive investment and storing costs. So, to decide which spare parts should be on site,

one has to make a criticality analysis which takes account field of industry related factors and customer-specific values and needs.

Criticality analysis for spare parts can be made in many variable ways depending on the considered object and predominant circumstances. Done carefully, it can help developing offered products and processes, leading to enhanced reliability and quality of the maintenance service, resulting more satisfied customers, which means bigger income by lower costs for the supplier. [13, 2 p.] Traditionally criticality analysis has been divided in two optional methods, qualitative and quantitative methods. Considering this study and the criticality of the spare parts of a power plant boiler, the proper method to define criticality for individual part is to use semi-quantitative method as was discovered in bachelor's thesis, Criticality of Parts of a Steam Boiler, written as introduction for this study. [21, 29 p.]

In general, the criticality analysis for any industrial machine's spare parts is done using three separate parameters. The consequences and probabilities of a failure of the part is estimated in figures from the point of view of a production loss, safety effect and environmental effect. After that the figures is calculated together with weight factors chosen by the group of experts and representative of a client company according to their values and desires. [27]

Criticality analysis factors

Basic criticality analysis factors are production loss, environmental effect and safety effects. The production factor is important because companies are achieving better profit and safety and environment factors are important for wellbeing of people and surroundings and because the laws require compliance with certain restrictions. These values have improved significantly over the years, at least in Finland

Production loss

In industrial maintenance management the monetary effects of failure of important component of some machine is commonly to be measured in production loss. Production loss term is originally used in US army operations to describe lost production in enemy attacks. The Free Dictionary states the original definition of production loss as follows: "*An estimate of damage inflicted on an industry in terms of quantities of finished products denied the enemy from the moment of attack through the period of reconstruction to the point when full production is resumed.*"[29] In industrial business the production loss means the monetary value of lost products from the moment of failure in a system to the situation where the failure is completely fixed and the production is on its normal level.

For example, in case the power plant has to shut down because of sudden failure in main systems of the boiler the production loss would be calculated in this way: One day, to wait the boiler cools down, two days, for the actual repair, assuming the spare parts are available at the site, and jet one day, to start up the boiler and entire power plant. [11] Estimating the price of one-day shutdown to be 100 000 € the final monetary value of lost production is 400 000 euros. This is calculated with Equation (1)

$$P_{Loss} = Pt = 100\,000 \frac{\text{€}}{d} (1 + 2 + 1)d = 400\,000 \text{ €} \quad (1)$$

where P_{Loss} is production loss [€],
 P is price of one-day shutdown [€/d] and
 t is time in days [d].

When analyzing the criticality of spare part, the production loss is in many cases the most effective factor increasing the criticality. The spare parts criticality is the greater than the production loss caused by this certain failure is. Failure can also bring on continuously reduced production which does not lead to shut down of the boiler but running the power plant with for example 90 % output until the planned maintenance break. The production loss in this case would be calculated by Equation (2) in following way: 50 days of 90 % output of the 100 000 € regular monetary value of daily production means in total 500 000 € production loss.

$$P_{Loss} = (1 - P)Ct = (1 - 0.9) 100\,000 \frac{\text{€}}{d} 50 d = 500\,000 \text{ €} \quad (2)$$

Where P_{Loss} is production loss [€],
 C is output capacity [%],
 P is price of one-day shutdown [€] and
 t is time in days [d].

Environmental effects

In the field of environmental protection, all industries have both economic and environmental responsibilities. The aim of companies should be to find a proper balance between social and environmental considerations and economic benefits. According to International Criminal Court - ICC industry must plan and perform its operations in environment friendly way. The guidelines of ICC's environmental protections for world industries are following factors that they must take in full consideration [23, 528 p.]:

- *“The need to maintain species diversity and balance in ecological systems, where air land and water ecosystems are considered*
- *The importance of protecting human health*

- *The cumulative effects on the environment of harmful wastes and other disadvantages produced by their industrial operations*
- *The potential effects of their products on the environment*
- *The need to develop alternatives to non-renewable resources*
- *The need to minimize risks to the environment from industrial activities”*

In Finnish legislation, Environment Protection Act (527/2014), the environment protection principles states that companies have to organize their operations in a way, that contamination of environment is to be prevented in advance. If the contamination cannot be fully prevented, it must be constricted as strict as possible. [6] According Finnish legislation in industrial operation that causes risk of environmental effects the laws to be comply with are: Finnish Waste Act (646/2011) [7] and especially in chapter 2 stated general duties and principles, and obligations concerning safe usage of chemicals and to prevent pollution of the environment and its danger in accordance of chemical law Chemicals Act (599/2013) [3]. Also in Finland the European Union’s chemical regulations, REACH - Registration, Evaluation, Authorization and Restriction of Chemicals (1907/2006), is to be obeyed. [19]

Nowadays environmental protection is not only being seen as a pile of limitation of business or as ever-increasing costs in energy sector. New approach for environmental protection is a green marketing. Green marketing means that companies promote the environment in some substantial way, and advertise it to their customers. So the operation of the company would seem ethical and environment friendly. Conscious consumers prefer the product compared to products produced in environmental harming way and are willing to pay the higher price. [24] This is seen already at least in Finnish energy dealers marketing. This kind of development can be seen on statistics of energy sector’s emissions shown in Figure 1.

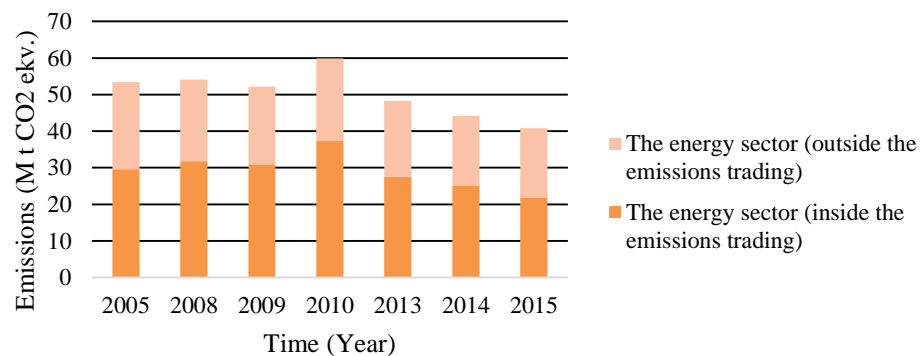


Figure 1. *The development of Finnish energy sector emissions during past decade.* [28]

The emissions of Finnish energy sector have been under significant improvement after the peak year 2010. The energy sector, inside the emissions trading, reduced emissions

by 17% and outside the emission trading 42% in five years between years 2010-2015. When analyzing the criticality of spare parts, the environmental effects of the failure are in some cases the single factor that makes the part critical. If the failure causes emissions or other harmful releases to nature it must be repaired in immediate concern to avoid the contamination of environment. The spare parts criticality is the greater than the environmental hazard caused by this certain failure is.

Occupational safety and health

The research and regulation of occupational safety and health are a relatively recent phenomenon. As labor movements arose in response to worker concerns in the wake of the industrial revolution at 18th century, worker's health entered consideration as a labor-related issue. Since that the importance of work related wellbeing has been increasingly developed throughout the whole world but mostly in developed countries. [25] Work related safety have also been under discussion among companies and widely in the media past years.

The general approach to health and safety problems involves two activities that are objective measurement and subjective judgement. Safety is not an absolute figure, so there is a need to consider some criterion and definition to measure and compare different situations and dangers. Society or “media” nowadays would wish the dangers associated in everyday life to be minimized, but that is not reasonable in real life. Each safety decision involves balancing of risks against other factors like costs, convenience or need of comfort for example. [4, 27 p.] Development of safety issues should be done in harmony of these factors as it stands also with the environment issues, which are defined via legislations and on the other hand via marketing of ethical values of a company. Occupational accident rate in Finland have been decreased about 30 percent between the years 2000 and 2013 as shown in Figure 2.

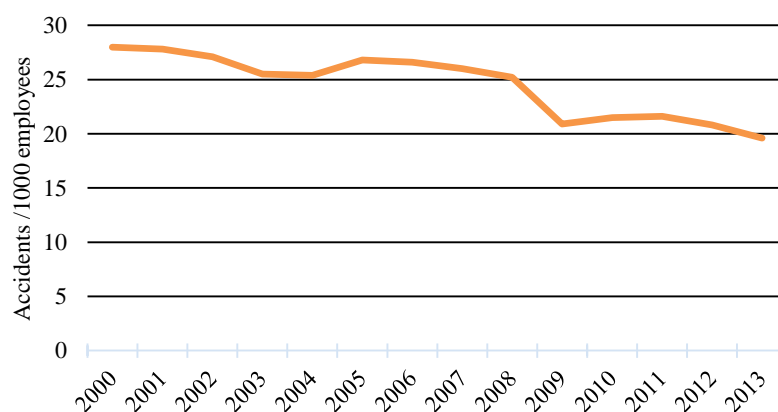


Figure 2. *The development of accident rate of Finland in occupational accidents in years 2000-2013 [26]*

According to Finnish terminology center's term bank [29] occupational safety is a part of company's safety management and it is defined as a state of a working environment from viewpoint of worker's safety and health.

Finnish judiciary has legislated employers' duties to maintain employees working environment at the satisfied level. The law called Occupational Safety and Health Act (738/2002) [8] orders employers to plan, choose, dimension and operate all the requisite measures to improve occupational safety. The employer is demanded to take into account of employees work, working environment and each worker's personal needs at all company levels. [8]

According to World Health Organization (WHO) the main focus in occupational health is on five different objectives: [35]

- 1) *“Devising and implementing policy instruments on workers' health*
- 2) *Protecting and promoting health at the workplace*
- 3) *Improving the performance of and access to occupational health services*
- 4) *Providing and communicating evidence for action and practice*
- 5) *Incorporating workers' health into other policies”*

When analyzing the criticality of spare part, the safety effects are in some cases the single factor that makes the part critical. That is because of when the failure causes risk to harm an employee or other danger to health of people nearby it must be repaired in immediate concern to avoid the accidents to happen. The spare parts criticality is the greater than the safety effect caused by this certain failure is.

2.2 Circulating Fluidized Bed boiler main components

To understand the criticality of a certain spare part of a boiler it is essential to have knowledge of its position and meaning in the boilers operation. In this study the boiler is divided in eight main systems. Each of these systems contains several main components and these components are consisted of hundreds of parts. The figures in this chapter are images of Case Company's (Valmet Technologies Oy) CFB-product named CYMIC. Variation of construction between different CFB models do occur. Failure of parts will result different consequences depending on the function of the equipment they belong. Some failure might shut down the whole production immediately, where the other has none affect to production but will contaminate environment severely.

Operational principles

The primary function of the circulating fluidized bed boiler is to generate high pressure steam for industrial use by combusting variable fuels such as biomass, waste and coal. Fluidized bed means that fuel and bed material is floated with air during the combustion process. This provides more effective chemical reactions and heat transfer. Most commonly used bed material is sand. A cyclone is used to separate non-combusted particles and sand from the flue gases generated in the combustion process. These particles are returned to the furnace for recirculation. After preceding features comes the name circulating fluidized bed boiler – CFB boiler. [36]

Subsystems and main components

Power plant boiler is a complex system which can be divided in multiple ways, for example after functions, processes or components. In this study the system hierarchy is done using division of subsystems and each subsystem's main components as it is shown in Figure 3. This is common division in spare part business hence of its focus on parts of each component rather than processes or functions of a boiler. In this chapter the subsystems are introduced and the functions of main components are described in order to understand the effects of certain parts failure. Complete system-component-map is presented in the Appendix A. The figures are from training material of the case company and presents Valmet's CFB-boiler product called CYMIC. The main components are also found from every other CFB-boiler.

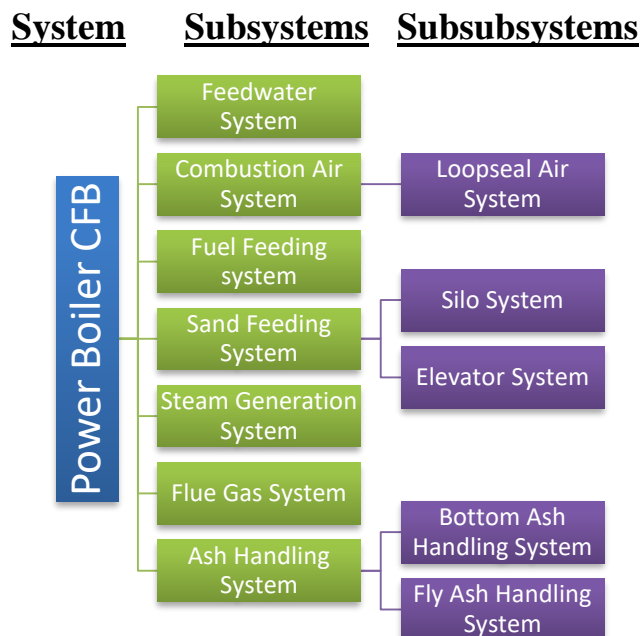


Figure 3. *The System Hierarchy of CFB boiler*

In this study the CFB boiler is divided in seven subsystems which are feedwater, combustion air, fuel feeding, sand feeding, steam generation, flue gas and ash handling systems. Other auxiliary subsystems do exist but these are the most important systems relative to spare parts. Combustion air system includes also the loopseal air system because they are practically the parts of one system. Sand feeding system is divided into silo system and elevator system due they are alternative systems. Ash handling system includes two separate systems bottom and fly ash handling systems.

Feed and boiler water system

The purpose of the feed and boiler water system is to keep the water and steam circulation in balance. The system replaces the high pressure steam leaving the boiler with the corresponding amount of feed water. Feed water tank operates as a container and as a mixer of the circulated and replacement water. Inside the tank is situated a deaerator which purpose is to remove dissolved gases from boiler feed water to protect the steam system from the effects of corrosive gases. [27] Feed water pumps generates adequate pressure for the steam generating system by pumping feed water from the feed water tank into the boiler. The feed water then passes through the economizers. The purpose of the economizer section is to recover the thermal energy of the flue gas, by using it to heat boiler water typically to 100 – 200 °C. Economizer is a heat exchanger which works by the counter flow principle. Water does not evaporate in the economizer due to the ambient pressure. Economizer significantly improves the efficiency of the boiler by reducing the heat loss. [18] After economizers the feed water passes through the steam drum. Figure 4 illustrates the locations of the components in the boiler. [36]

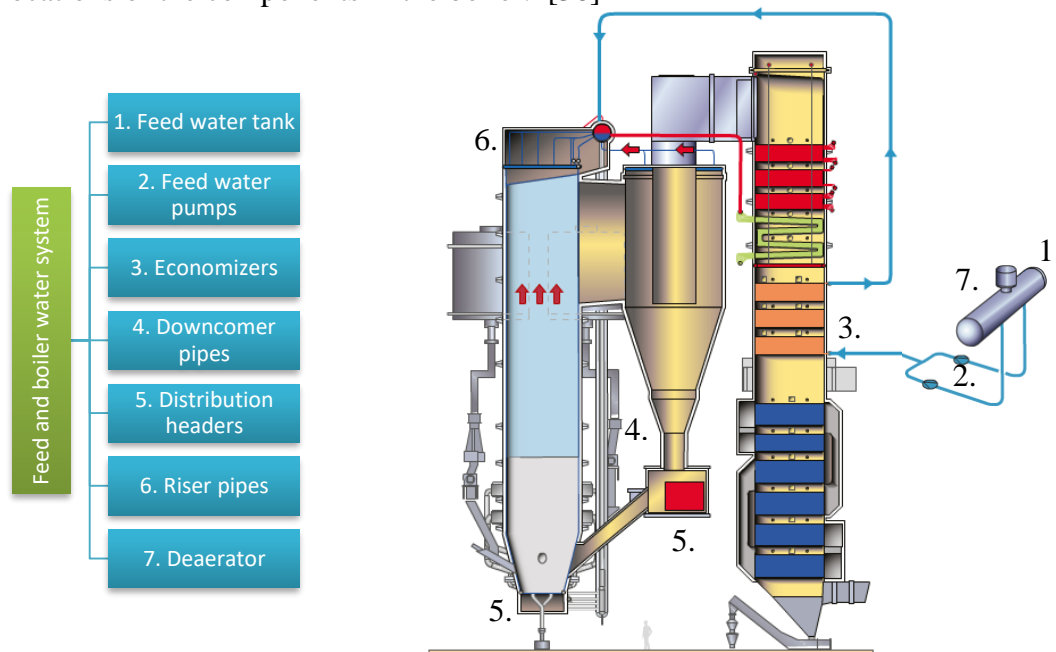


Figure 4. *Feed and boiler water system's main components*

The water leaving the drum is referred to as boiler water, and it passes through down-comer pipes, to the lower distribution headers of the furnace, loopseal, and in some boiler designs, the generating bank. From the lower distribution headers, the boiler water flows upward through the wall and generating bank tubes and back to the drum through riser pipes. [36]

The downcomer pipes and distribution headers are not shown in the Figure 4. The Down-comer pipes are located on each four sides of the cyclone. The distribution headers are located on the bottom of the furnace and the cyclone.

Combustion air and loop seal air system

The purpose of the combustion air system is to provide the amount of air required to achieve efficient and controlled combustion of fuel at all boiler loads and to fluidize the bed material in the furnace and create the solids circulation in the hot loop. [36]

The main components of the combustion air system are: silencers for the suction air ducts, burner air fan and primary air fan, feed water or steam-coil air preheaters for the primary and secondary air, flue-gas air preheaters, primary and secondary air nozzles and air ducts, with flow dampers and measuring devices. Figure 5 illustrates the locations of the combustion air system's components in the boiler.

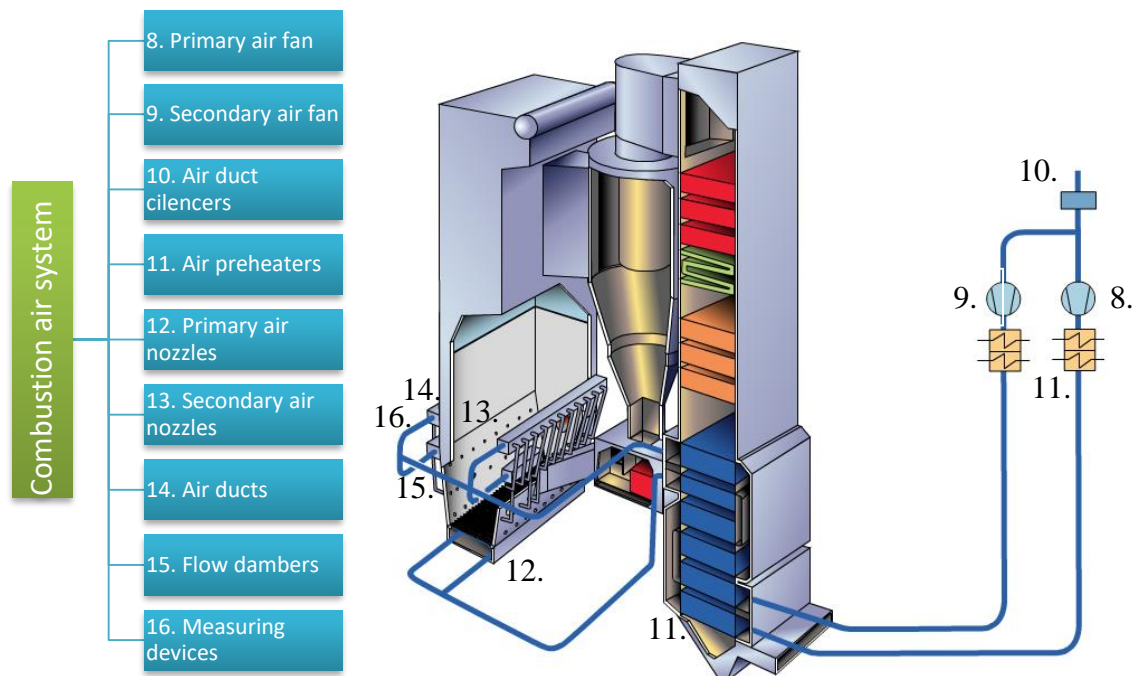


Figure 5. *Combustion air system's main components*

The air required for the combustion is supplied to the furnace in two phases. The primary air, which serves to keep the bed in a fluidized state and to maintain stable combustion throughout the entire bed. Secondary air, which serves to finalize the combustion of solid fuel. The secondary air is divided into two elevations; upper and lower. The secondary air also supplies most or all of the air needed to combust liquid and gaseous fuels through burners. [36]

In order to obtain correct air distribution and air pressure for optimum combustion, air ducts are equipped with dampers and different air control devices. Combustion air taken before the air heater can also serve cooling functions around furnace openings, and can be used to assist fuel or other product entering the furnace. [36]

The loop seal air system is also considered part of the combustion air system. The purpose of the loop seal air system is to maintain fluidization in the loop seal. The main components of the loop seal air system are silencers, high pressure blowers, either multi-stage centrifugal or positive displacement type, and air ducts, with flow dampers and measuring devices. Figure 6 illustrates the locations of the components in the boiler.

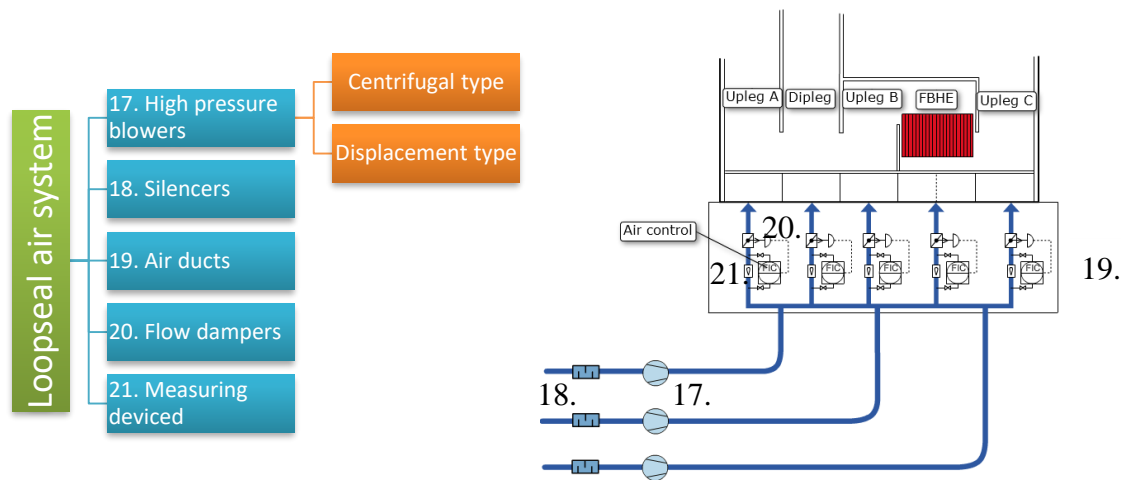


Figure 6. *Loop seal air system's main components*

The loop seal blowers supply the required air to the floor of the loop seal. The air enters the loop seal bed through air nozzles in the same way primary air enters the furnace. The loop seal air is distributed via the ductwork to each fluidization chamber of the loop seal. The loop seal air ducts are equipped with air controls in order to obtain correct air distribution to each chamber. [36]

Fuel feeding system

The purpose of the fuel feeding system is to store the solid fuel mixture in the fuel silo and supply the required flow of solid fuel from the silo to the boiler. Boiler size and type of fuel determines the design of the fuel feeding system and variety between the designs can be great. So in this study an example of a fuel feeding system for a medium size biomass boiler is introduced. [36]

The main components of the fuel feeding system are: a fuel silo with a silo reclaimer, conveyors, metering screws, fuel feeding chutes with rotary valve feeders, wall screws and fuel feeding air piping. Figure 7 illustrates the locations of the components in the boiler.

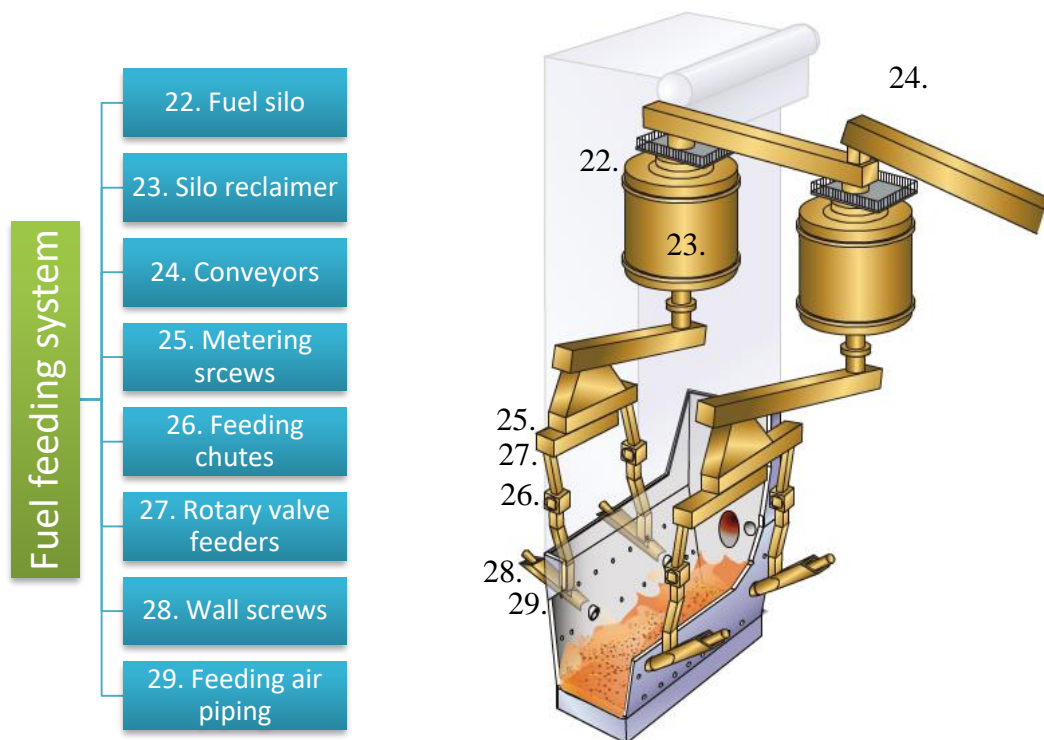


Figure 7. *Fuel feeding system's main components*

The fuel is transported from the fuel field to the fuel silo. To ensure stable and efficient combustion, the solid fuel mixture must be well mixed prior to entering the fuel silo. The fuel silo is equipped with a silo reclaimer, which purpose is to keep the fuel in good condition by constantly stirring it. Motion prevents chip pile deterioration. From the silo the fuel is fed onto conveyors, running parallel to the furnace side walls. [36]

The conveyors drop the fuel into a balancing hopper, which enables even distribution of the fuel to the metering screws and boiler. The metering screws convey the fuel to the fuel chutes located on the front and rear walls. The fuel chutes are equipped with rotary

valve feeders to prevent backfire from the furnace. Wall mounted screw conveyors are used to convey the fuel directly into the furnace. The flow of fuel into the furnace is controlled by adjusting the speed of the silo reclaimer, conveyors and metering screws. Fuel feeding air is used to cool the fuel chute. [36]

Sand feeding system

In the CFB boiler, as the name suggest, the bed material circulates around a so called hot loop. The bed material varies but it is most commonly sand or limestone. At the time the boiler is running the amount of bed sand is reducing mainly by leaving among the bottom ash. The purpose of the sand feeding system is to store and periodically supply make-up sand to the boiler. [36]

The make-up sand feeding system consists of make-up sand silos with discharge pipes using rotary feeders or screw conveyors or, a sand hopper with a feeding screw, and an elevator system with feed piping. Figure 8 illustrates the locations of the components in the boiler.

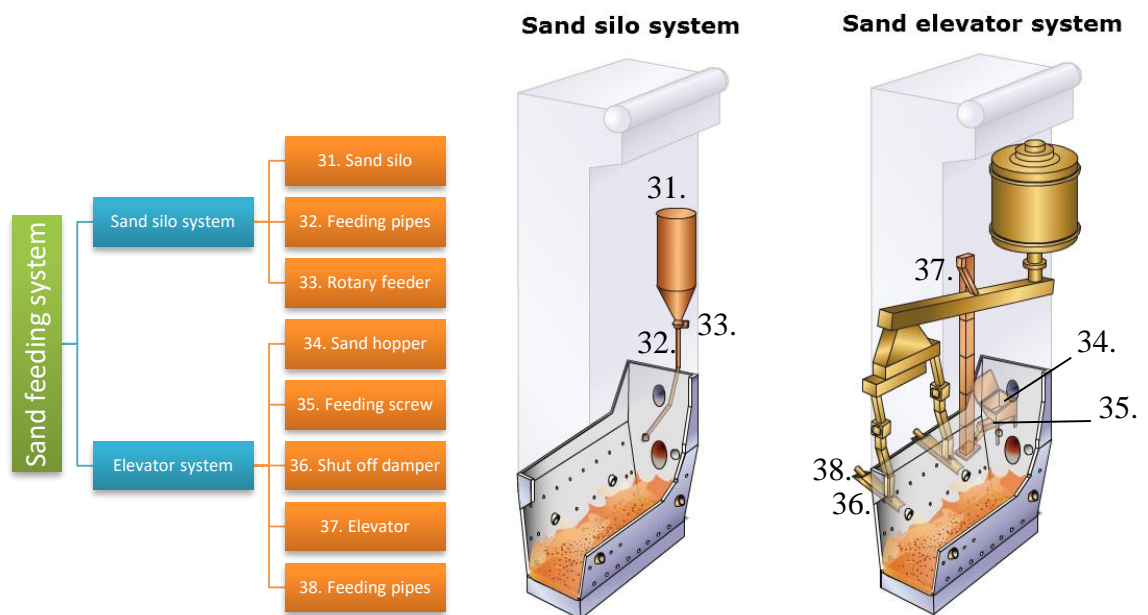


Figure 8. *Sand feeding system's main components*

There are two basic types of sand feeding systems: the sand silo system and the elevator system. In the sand silo system, the make-up sand silo is filled pneumatically from a truck. From the silo, the sand is gravity fed into the boiler through a rotary feeder or screw conveyor and then through sand feeding pipes. In the sand elevator system, the sand is first fed to a hopper, from which it is conveyed by a sand feeding screw to an elevator, and then gravity fed into the boiler through a shut-off damper. [36]

Steam generating system

Generating high temperature and high pressure steam is the main function of the entire CFB boiler. The boiler uses natural circulation to keep the furnace walls cooled. Natural circulation takes place because the water and steam mixture in the boiler walls has a lower density than the water in the downcomers. [36]

The main components of steam generating system are: wall tubes, in furnace and in cyclone walls, team drum, superheaters, which can be located in the backpass, in the loopseal, and in some designs, the furnace as wingwalls, and attemperators. Figure 9 illustrates the locations of the components in the boiler.

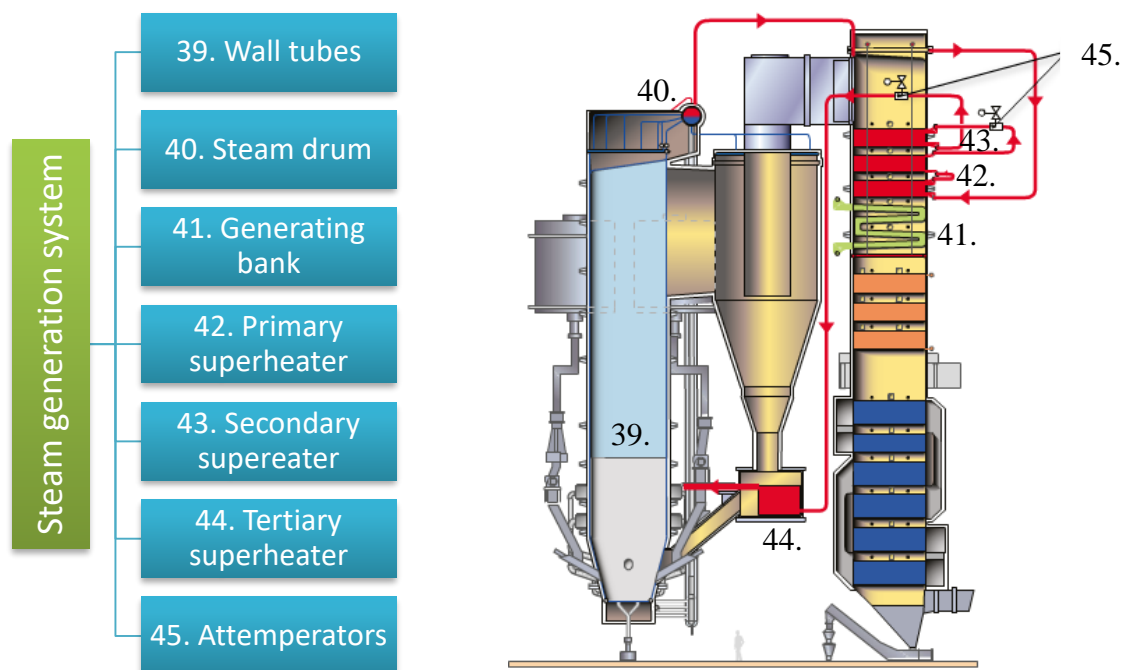


Figure 9. *Steam generation system's main components*

Feedwater and boiler water is mixed in the steam drum. When the mix leaves the drum, it is referred to as boiler water as explained earlier in this chapter. Boiler water flows through downcomers to the lower furnace distribution headers and, when applicable, to the generating bank distribution headers. [36]

When water-cooled cyclones and loopseals are used, there will be additional downcomers that bring boiler water to the lower headers of the loopseals, and boiler water then flows upwards into the lower headers of the cyclones. The water temperature in the headers is below the boiling point at operating pressure. This is partly due to it being mixed with feedwater, but mainly because of the difference in elevation between the drum and the lower furnace distribution headers, which causes an increase in static pressure. Increase of static pressure is the reason why no steam is generated in the lower part of the boiler walls, until the water is heated up to the boiling point. [36]

The generation of steam starts some meters up along the furnace or loopseal walls. Steam generation will then take place continuously in the wall tubes up to the steam drum. The mixture of steam bubbles and water reaches the steam drum through riser pipes. In the generating bank, and cyclone and loopseal assembly the steam generation is similar as it is in the furnace walls. The boiler furnace makes a challenging environment for tubing because of the high temperature flue gas and the bed material particles (over 875 degrees of Celsius), which are colliding to surface of the pipes. [36]

The steam is separated from the water in the steam drum. This is done in cyclones and droplet separators inside the steam drum. The water separated by the cyclones is mixed with the water in the drum. Before the steam leaves the drum, water droplets are removed in separators positioned at the top of the drum. From there, the steam continues to the primary superheater. [36]

The saturated steam from the steam drum is superheated in the primary, secondary and finishing superheaters. In a CFB boiler, superheaters can be located in the backpass, in the furnace as wingwalls, or in the loopseal heat exchanger. The steam temperature is controlled by attemperators located between the superheaters by spraying feedwater into the steam. If a fluidized bed heat exchanger is used, steam temperature can also be controlled by varying fluidization air flow proportions. [36]

Flue gas system

The purpose of the flue gas system is to utilize the heat content of the flue gas to heat feed and boiler water, combustion air, and to superheat steam, to remove dust from the flue gas and to transport the flue gas to the stack. The flue gas system also includes the emission control systems, for removal of pollutants like dioxins and furans, heavy metals, sulfur and nitrogen oxides and other environment harmful particles from the flue gas. [36] According to the World Health Organization Dioxins and Furans are a group of chemically-related toxic compounds that are persistent environmental pollutants and mainly by-products of industrial combustion processes. [37] Heavy metals are defined by US National Library of Medicine as mostly toxic elements that have a high atomic weight and a density at least five times greater than that of water. They are occurred both naturally and as by-product of industrial processes. [15]

The main components of the flue gas system are: flue gas ducts, emissions control equipment particulate collector; either electrostatic precipitators or bag house filters, ID fans, in some designs, a flue gas recirculation fan and ducts, and a stack. Figure 10 illustrates the locations of the components in the boiler.

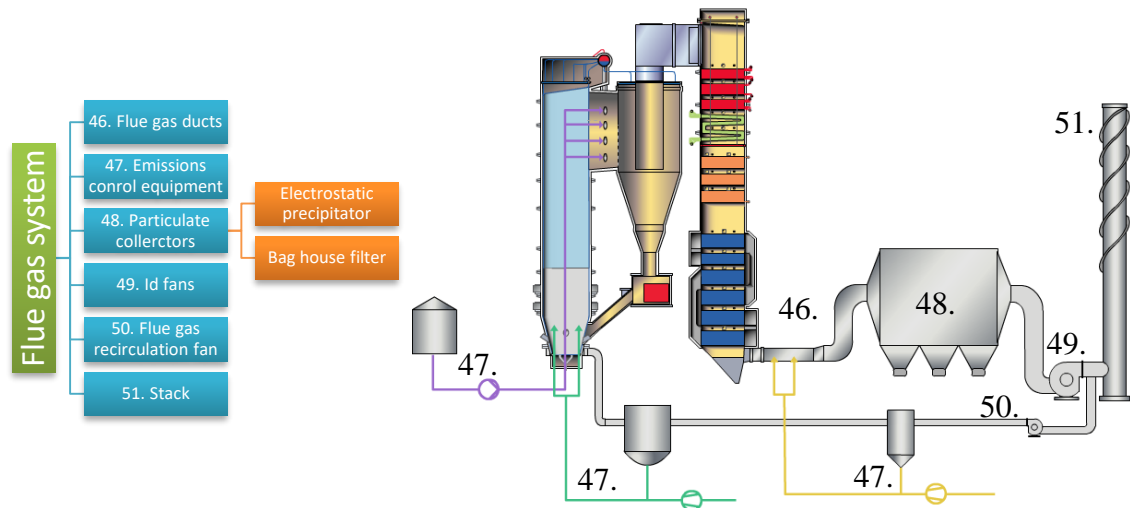


Figure 10. *Flue gas system's main components*

Hot gas generated from the combustion of fuel in the furnace is extracted by negative pressure produced by Induced Draft (ID) fans. The flue gas flows over the heat absorbing surfaces and releases most of its heat content. The flue gas then passes through a particulate collector, either electrostatic precipitators or bag house filters, where the ash is separated from the flue gas. The ID fans are positioned after the particulate collector to feed the gas to the stack. [36]

To control temperature in the furnace, part of the flue gas can be recirculated back to the furnace via a recirculation fan, located after the ID fan. Emissions of nitrogen oxide can be limited by injecting ammonia or urea through nozzles located in the cyclone inlet duct. Furnace injection may also be used for low load operation. Ammonia or urea is usually injected by means of pumps from a holding tank. The piping system with its attachments evenly distributes the reagent across the cyclone inlet duct. If catalysts are required for a greater reduction of nitrogen oxides, they can be located in a third pass with ammonia injection in the cyclone. It is also possible to place the catalyst after a high temperature particulate collector. [29]

Sulfur dioxide emissions can be reduced by injection of limestone in the furnace. This is typical when burning high sulfur fuels. Even lower sulfur dioxide emissions can be attained by injecting sorbents, such as of hydrate lime and sodium bicarbonate, into the flue gas upstream of the bag house filters. These sorbents will also remove other acid gases, such as hydrogen chlorides, and other sulfur oxides. [36]

Heavy metals and dioxins and furans can also be captured by injecting activated carbon. Sorbents and limestone are usually stored in a silo, metered using a screw conveyor, and passed through a rotary valve to be pneumatically conveyed to the injection point using high pressure blowers. The sorbent is conveyed and evenly distributed to the ductwork or furnace the by the piping system and injection nozzles. [36]

The electrostatic precipitators remove particles from the flue gas through the use of electrostatic forces. More than 99 percent of the particulate is removed by the electrostatic precipitators. The flue gas is channeled into a collection chamber that contains two electrode systems. One system is connected to high voltage direct current and its electrodes are called discharge electrodes. The other system is at ground potential and its electrodes are called collector plates. A strong electrical field is created between the electrodes, with the highest field intensity closest to the discharge electrodes. The electrical charge is so strong that it forms what is known as a corona along the electrodes. The gas is ionized, causing a flow of negatively charged gas particles to migrate towards the collector plates. The dust sticks to the collector plates and is removed by a rapping system. [36]

The bag house filters remove particles from the flue gas. This is done by utilizing fabricated filter bags, in which the dust is collected and periodically removed by pulses. More than 99.5 percent of the particulate is removed by the bag house filters. Bag house filters consist of rows of circular filter bags suspended from a tube sheet which separates the dirty and clean flue gas chambers. Each bag has an internal wire cage which supports the filter bag and prevents collapse. When the flue gas passes through the bag house filter, dust is collected on the outer surface of the filter bags. From the top chamber the clean flue gas is transported to the stack. The dust is removed from the filter bags by pulses of compressed air. Loosen dust falls into ash hoppers below the bag house filter. From there, the dust is transported by ash conveyers to a fly ash silo. [36]

Ash handling system

The purpose of the ash handling system is to control bed height, remove coarse material from the bed and transport them to the bottom ash containers, to remove fly ash from the backpass and baghouse ash hoppers and transport it to the fly ash silo, and to remove the ash from the silo by an ash discharge system. [36]

The main components of the ash handling system are: bottom ash drains and pneumatic slide gates, cooling screws, chain conveyor, sand sieve system with pneumatic transmitter to recirculate the reusable part of the bed material back to the furnace when required, and a bottom ash container, rotary valve feeders and screw conveyors for second and third pass ash removal, rotary valve feeders for baghouse fly ash removal and a fly ash silo with a discharge system. Figure 11 illustrates the locations of the components in the boiler.

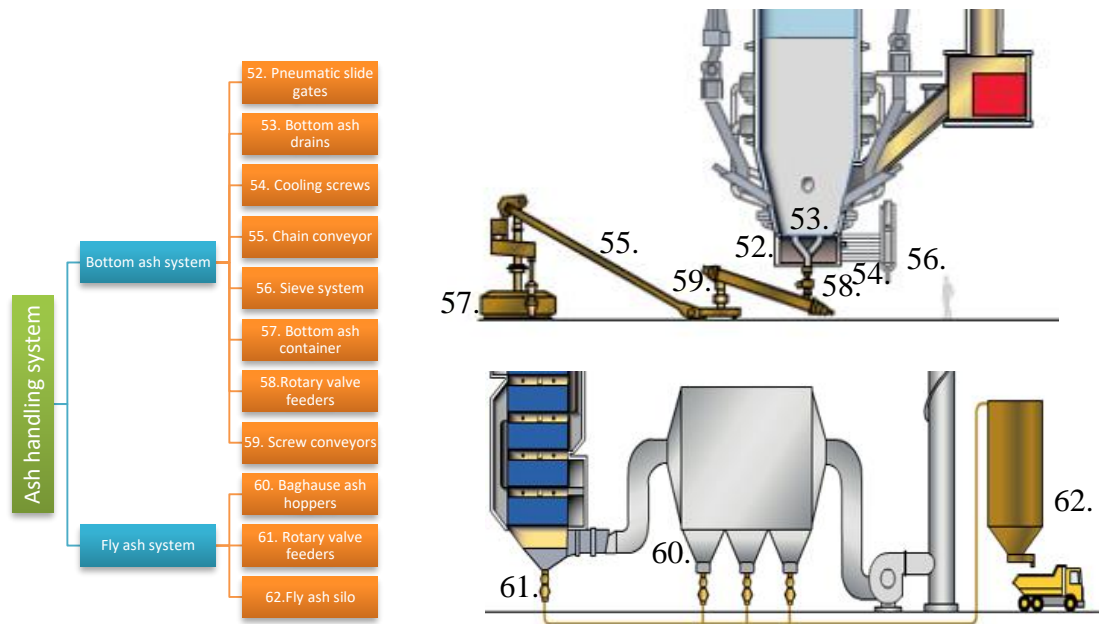


Figure 11. *Ash handling system's main components*

Bottom ash, including stones and other impurities delivered with the fuel are removed via bottom ash drains. Removing rate depends on fuel quality. Typically, rate is manually adjusted to meet the required bed state. The ash from the backpass and ash separated in the baghouse is collected in the bottom hoppers and transported to the fly ash silo. [36]

Typical failure modes of differently failing components

In the Table 1 is described the parts failure mode, reason for failure and failure caused consequence on operation of the boiler. The components of Table 1 are chosen to give diverse sampling of different parts and failures. All the components have different functions and effects to the boilers operation. This consequence classification is used to define criticality of components in relation to operation of boiler.

Table 1. *Typical failure modes and consequences of parts of four example equipment*

Component	Part	Failure mode	Reason for failure	Consequence
Wall tubes	Straight tubes	Leakage	corrosion and erosion	Failure in systems will stop the boiler within hours
	Tube bends	Leakage	corrosion and erosion	
ID-fans	Bearings	Breakage	Wearing due impurities and destabilized rotating	Failure in this systems will result boiler running with a reduced load.
	Impeller	Vibration	Adhesion of impurities	
	Shaft seal	Leakage	Wearing due abrasion	
Drag chain conveyors	Drive wheel	Slipping	Wearing due abrasion	Failure in systems will stop the boiler within hours
	Conveyor chain	Snap	Wearing due abrasion	
Start-up burners	Impeller	Disengaged	Poorly attached	Failure in this systems will result boiler running with a reduced load.
	Oil nozzle	Malfunction	Wearing due abrasion	

Wall tubes

In the power boiler there are kilometers of different kind of tubes. Their purpose is to transport and heat water and meanwhile generated steam from feedwater tank into the turbine. The typical failure mode of tube is leakage, where high temperature and high pressure steam spurts out in extremely high speed acting like water cutter destroying components nearby. Leakage in tubes will stop the boiler within minutes to hours depending on the severity of the leak. Typical reason for tube to leak is wearing due corrosion and erosion. [11]

Fans

The purpose of a fan is to produce a pressure differential which leads to movement of the certain matter. In the CFB boiler there are four types of fans, which are primary air fan, secondary or burner air fan, induced draft fan and recirculation fan. The fans differ from each other in shape and size, but the main parts are the same. For good example, the failure modes of few distinct parts are described in this study: bearings, impellers and shaft seals. Bearings of a fan are very sensitive for even the smallest damage, and minor impurity in the lubrication can cause vibrancy to whole fan. If the bearing brakes the fan will stop operating. Even with good lubrication the bearings will eventually wear and fail. Impellers purpose is to move the fluid by rotation. Impellers weak point is also the adhered impurities, which destabilize the fan and finally breaks the bearings. The dirtier the fluid is the faster the impurities start to effect. Shaft seals purpose is to seal the cap surrounding the shaft, and keep the lubrication inside the fan without allowing impurities to

enter inside, while the shaft is rotating. The shaft seal is under great abrasion and will wear out time passing. Shaft seal and bearings spare parts are classified both as strategic and wear part. Impeller is considered only as a strategic part. [11]

Conveyors

In the CFB boiler there are two basic types of conveyors, flight conveyors and screw conveyors. The purpose of conveyors, for example, is to transport fuel from the fuel silo into the furnace or to transport ash from bottom ash hoppers into the ash silo. The wearing circumstances of the parts of these conveyors varies a lot. The factors that effect to the wearing depends on used fuel and the utilization rate of a conveyors. In the flight conveyors of CYMIC boiler there are two components which causes severe damage if fails: drive wheel and chain. The breakage of these components will stop the conveyor and failure in the equipment will stop the boiler within hours. The purpose of the drive wheel is to move the chain. It works like a bicycle sprocket. The failure mode of drive wheel is slipping due broken or worn teeth. The purpose of the chain is to transfer the rotation energy of the drive wheel to the movement of the flights which conveys the fuel. The failure mode of a chain is snapping due wearing and abrasion. [11] [36]

Burners

In the CYMIC boiler there are two types of burners: start-up burners and load burners. The purpose of start-up burner as the name implies is to start-up the boiler. It works with gas or oil fuel and it sets up the right temperature in the furnace for feeding the actual fuel of the boiler. Load burner is used if the solid fuel supply is not functioning correctly and the same amount of steam is to be created. Load burner is used to varying degrees. If there is a bad fuel, it can be used continuously in order to achieve a better vapor production. It can also be used as a booster when more steam is wanted. There are two of each burner because of their critical nature. Just one start-up burner can provide boiler to start, but more slowly, which leads to production losses. The parts of the burners are the same only the size of the parts varies. The parts of the start-up burners are significantly bigger than the parts of the load burner. For example, there are two parts which failure results boiler running with reduced load due slower ignition: a worn oil nozzle spreads the fuel poorly and the burning is not efficient, so the failure mode is malfunctioning, and the impeller which is too often poorly attached in the first place and it drops into the bottom of the furnace, which failure mode is disengaged. [11] [29]

2.3 Results of previous internal development project

In this Chapter the Criticality Analysis tool is introduced. Development of the CA-tool at issue study started from the point where the development project ended. The CA-tool presented in this chapter is incomplete. The initial status of the study and the results of the previous internal development project is clarified. The criticality parameters are presented. This Chapter also presents separately criticality scores and criticality levels and basics of the criticality classification of at issued CA-tool. The criticality analysis in the case company is a part of the reliability centered maintenance analysis (RCM-analysis). The purpose of the CA-tool is to help to go through systematically all the spare parts of each components of the boiler and efficiently transfigure expert's knowledge into criticality score and furthermore to classify the parts in three criticality classes.

Criticality parameters

In general CA-tool in industry usage consists at least three basic parameters: production loss, environment effect and safety effect. Depending on the area of the industry and different country related cultural factors other parameters do occur. Viewpoints of parameters varies from each other widely so each parameter's value scale must be set up individually. Also the possible criticality points of each parameter differ. Points must be estimated in a way it reflects as exactly as it can the severity of risk.

The user of the tool selects a suitable option from the dropdown list the CA-tool offers. CA-tool will turn the selection from the dropdown list in numeric value. Numeric values are necessary because they can be calculated together to generate the risk priority number. Via risk priority numbers the risk level of certain criteria can be classified. The risk levels are comparable with each other. As a basic assumption all the necessary preventive actions of each equipment are considered to be taken. Selection of consequence parameters, is made according to worst case scenario hazardous event in question. In case of failure of reduplicated equipment, the residual unit is considered as a full substitution during the time of repair, or in some cases where residual item is not scaled to cover the whole operation, the covering share is used in percentage.

In Table 2 stands the options of probabilities used to estimate the probabilities of each basic parameters introduced in this chapter. These options are usually considered as a commonly known maintenance management term: "mean time between failures" – MTBF. In CA-tool of this study these probability options have multiple purpose of use, so it differs slightly from original MTBF term.

Table 2. *Options of probability for production loss, environmental effect and safety consequences*

Probability description	Probability options (P_n)	Numeric value
Very likely	once per year	P_{n4}
Likely	once per 1-2 years	P_{n4}
Possible	once 2-5 years	P_{n3}
Unlikely	once per 5 - 10 years	P_{n2}
Very unlikely	once per 20 years	P_{n1}

When choosing an option from the list of probabilities shown in Table 2 it is necessary to think carefully which probability is in question. Probability for production loss means how often certain failure causes production loss of some kind. There are many situations where effects on production comes up irregularly, which leads to estimate that probability for production loss is smaller than probability for the failure. Same logic works also with other criticality factors. Probabilities of environment and safety effect may also vary from failure probability. Probabilities under once-per-20-years are not considered for the characteristic of energy industries spare parts, meaning that every part of the boiler are replaced due planned maintenance under that time.

Production

Effects of failure in system is commonly quantified as production loss. The amount of production lost according its definition should be estimated in loss of finished products and their monetary value. In energy business it's better to estimate the quantity of days or weeks of total production stop of a plant, since each plant, their products and values varies very much. It is easier to estimate price of one-day production stop and multiply it by the quantity of days required to fix the failure and get the production back on its normal level.

In the CA-tool of this study production loss is calculated using risk priority number (RPN) shown in Equation (3)

$$RPN_p = R_p P_p \quad (3)$$

where R_p is a severity of consequence on production loss,
 P_p is a probability for such production loss.

The severity of the consequence and the probability of production loss is chosen from the dropdown lists illustrated in Table 2 and Table 3.

Table 3. *Production loss consequence scale and effect options*

Consequence severity	Consequence description	Numerical value
Extreme consequence	Production stop more than a week	R_{p5}
High consequence	Production stop less than a week	R_{p4}
Moderate consequence	Production stop less than three days	R_{p3}
Low consequence	Reduced production	R_{p2}
Minimum consequence	No effect to production	R_{p1}

Extreme production loss consequence means a risk of a failure that causes shutdown of the boiler and stopped production from one week to several weeks. For example, an unfixable failure in the impeller of the ID fan. High production loss consequence means a consequence risk of a failure that causes shutdown of the boiler and stopped production for several days but less than a week. Moderate production loss consequence means a consequence of a failure that causes shutdown of the boiler and stopped production for less than three days. For example, leak in main steam valve. Low production loss consequence means a consequence of a failure that causes reduced production for the time of the repair. For example, leak in drain or vent valves. Minimum production loss consequence means a consequence of a failure that does not cause any effect on production. For example, explosion safety panel of s fuel silo.

Environment

As in production loss parameter the environmental risk is also calculated with two figures: the greatness of the environmental consequence caused the failure in system the part belongs to and the probability of the environmental effect. Here is to be noted that the failure in some environmental related component does not necessary causes the environmental effect. So the probability for environmental effect is in many case smaller than the MTBF of the certain part.

In the CA-tool of this study environmental effect is calculated as risk priority number (RPN) using Equation (4)

$$RPN_E = R_e P_e \quad (4)$$

where R_e is severity of environmental consequence,
 P_e is probability for environmental consequence.

The severity of environmental consequence is chosen from the dropdown lists illustrated in Table 4 and probability of environmental effect from Table 2.

Table 4. *Environmental consequence scale and effect options*

Consequence severity	Consequence description	Numerical value
Extreme consequence	Serious off-site environmental impact	Re5
High consequence	Significant off-site environmental impact	Re4
Moderate consequence	Some local environmental impact	Re3
Low consequence	Minor environmental impact	Re2
Minimum consequence	No environmental impact	Re1

Extreme environmental consequence means serious off-site environmental impact which requires significant redemption. For example, toxic release into water system. High environmental consequence means significant off-site environmental impact which requires some redemption. For example, pollution from flue gas released into air. Moderate environmental consequence means some local environmental impact or release significantly above reportable limit. Low environmental consequence means minor environmental impact or release above reportable limit. Minimum environmental consequence means small release contained onsite and no local or off-site environmental impact.

Occupational safety

As in other parameters safety effect is also calculated with two figures: the severity of the safety consequence caused the failure in system the part belongs to, and the probability of the safety effect. Here is to be noted that the failure in some safety related component does not necessary causes the safety effect. So the probability for the safety effect is in many case smaller than the mean time between failures (MTBF) of the certain part.

In the CA-tool of this study the safety effect is calculated as risk priority number for safety effect (RPN_s) using Equation (5).

$$RPN_s = R_s P_s, \quad (5)$$

Where R_s is severity of safety consequence,
 P_s is probability for safety consequence.

The severity of risk is chosen from the dropdown list of the CA-tool illustrated in Table 5 and probability of safety effect from Table 2

Table 5. *Safety consequence scale and effect options*

Consequence severity	Consequence description	Numeric value
Extreme consequence	Fatality	R _{s5}
High consequence	Serious injury or permanent disablement	R _{s4}
Moderate consequence	Significant injury or illness with sick leave	R _{s3}
Low consequence	Medical treatment	R _{s2}
Minimum consequence	Minor injury	R _{s1}

Extreme safety consequence means a consequence for accident which causes death of an employee immediately or later for the sake of lethal injury. For example, explosion in fuel tank. High safety consequence means a consequence for accident causing serious injury which ends in permanent harm or disablement. For example, leak in steam pipe. Moderate safety consequence means a consequence for accident causing significant injury or illness with sick leave for more than four days. Low safety consequence means a consequence for accident which causes small injury that needs to be treated but does not affect much to the working ability of an employee. For example, first class skin burn. Minimum safety consequence means a consequence which causes insignificant minor injury. For example, small wound.

Criticality classification

The risk level of individual criticality factor is expressed by the Risk Priority Number-level. Final classification is made according the calculated criticality score and classification levels. Following two chapters explain these levels and scales.

Risk Priority Number-level

Risk priority number is a numeric value which shows the criticality of spare part from the point of view of one certain factor for example environment. Because RPN scores are comparable with each other they can also be classified according their value. In this CA-tool the classification of criticality factors is done using common color coded risk matrix shown in Table 6. Such classification enables user to see by quick glance which factors are critical and which are not.

Table 6. Risk matrix for RPN classification of criticality factors [11]

R_{n5}	Tolerable	Tolerable	Unacceptable	Unacceptable	Unacceptable
R_{n4}	Acceptable	Tolerable	Tolerable	Unacceptable	Unacceptable
R_{n3}	Acceptable	Tolerable	Tolerable	Tolerable	Unacceptable
R_{n2}	Acceptable	Acceptable	Tolerable	Tolerable	Tolerable
R_{n1}	Acceptable	Acceptable	Acceptable	Acceptable	Tolerable
	P_{n1}	P_{n2}	P_{n3}	P_{n4}	P_{n5}

The row scale of the risk matrix (R_{n1}...R_{n5}) refers to values of Tables 3, 4 and 5, which reflects the severity of consequence of certain criticality factor. The column scale of the risk matrix (P_{n1}...P_{n5}) refers to values of Table 2, which reflects the probability of the

unwanted effect. The real numerical values of the scales are not presented due their confidential nature.

Criticality score and levels

Criticality score is calculated with Equation (6) that sums up together all the RPN-values of the criticality parameters [11]

$$C = \sum RPN_n = RPN_P + RPN_E + RPN_S \quad (6)$$

where **RPN_P** is a Risk Priority Number for production loss,
RPN_E is a Risk Priority Number for environment effect and
RPN_S is a Risk Priority Number for safety effect.

Criticality scores of spare parts are comparable with each other. Criticality analysis is usually done for long list of supplier's recommended spare parts. Classification can be made according to the score of the parts. In the CA-tool of this study the classification consists of three levels shown in Table 7. The classification is based on criticality score limits C_1 and C_2 . Limit C_1 is between levels I and II and limit C_2 is between levels II and III. The actual values of the limits are not shown because of their confidential nature.

Table 7. Criticality classification levels [11]

Level	Risk	Description	Actions
I	Acceptable risk	Risk acceptable with current preventive actions	Recommended for spare part and included in extended package
II	Tolerable risk	Actions to be considered to lessen the risk	Necessary for spare part and included in the guarantee package
III	Unacceptable risk	Risk unacceptable and must be minimized	Necessary for spare part and included in the guarantee package

Level I, acceptable risk, means that the risk is on the acceptable level with current preventive actions. On the point of view of parts criticality, it means that part is not critical but still recommended for spare part and it is included in the extended spare part package. Level II, Tolerable risk, means that the risk is on tolerable level but actions to lessen the risk is to be considered. Part is critical and it is necessary to store as a spare part at the site. Part belongs to two-year availability guarantee package. Level III, Unacceptable risk, means that the risk is on unacceptable level and the risk must be minimized. Part is very critical and it is necessary to store as a spare part at the site. Part belongs to the two-year availability guarantee package.

3 CASE AND RESEARCH TASKS

In Chapter 3.1 the case company, Valmet Technologies Oy, is introduced and the framework of the study is explained. This study is straight continuation of previous researches done in the case company related to improvements to spare part package business. In Chapter 3.2 the target of the research is clarified and the research methods are explained. Target of the research is to finalize the objectives of previous internal development project with some changes in the tasks. The methods of research are literature exploration and expert interviews. In chapter 3.3 is found the research tasks related to development of the CA-tool (requirement numbers 1-5) and in the chapter 3.4 the research tasks related to implementation of the CA-tool (requirement numbers 5-8).

3.1 Case company and framework of the study

Valmet is a developer and supplier of technologies, automation and services for the pulp, paper and energy industries with 12,000 employees globally. The wide technology offering includes pulp mills, tissue, board and paper production lines, as well as power plants for bio-energy production. Valmet's automation solutions range from single measurements to mill wide turnkey automation projects. Valmet's services cover everything from maintenance outsourcing to mill and plant improvements and spare parts. Valmet total net sales was over 2.9 billion in year 2015. This Masters of thesis is done for spare part team of Valmet's service department of pulp and power business line. Spare part team manages the sales of daily spare parts of boilers globally and the creation of spare part packages relating to the capital sales project.

The case company, Valmet Technologies Oy, has adopted a Reliability-Centered Maintenance (RCM) approach to ensure efficiency and cost optimization in the power boiler business. In power boiler business the sales and deliveries of new products are based on projects. New call for bid and subsequent offer launches a sales project. When the boiler is sold the sales project gets closed and an execution project gets launched. With a new system a spare part package is sold included the availability guarantee of first two-year period. Spare part package is considered as after-sales service even if it is sold originally as a part of the main sales project. In the Appendix G is shown a flow chart of spare part package sales process. Nowadays conscious customers have begun to ask from installation companies to offer spare part packages customized to serve their customer-specific needs. As a part of the reliability-centered maintenance analysis there is a criticality analysis which results a list of the most critical spare parts of the analyzed machine.

In Valmet's spare part team some researches has been done tangential to this subject during past ten years. In the Master of Science thesis of Elina Sillanmäki (*Improving the process of spare part packages in delivery projects*) in year 2010 the necessity to find the most critical spare parts was noted. [26] Nanna Jaakkola's Master of Science thesis (*Spare part management of bubbling fluidized bed boiler*) in year 2016, criticality classification was studied and the need for systematic criticality analysis were discovered although the encountered problem was the lack of resources to go through full criticality analysis of whole spare part package. Based on Jaakkola's thesis an internal development project was launched to create a criticality analysis tool for efficient classification of spare parts. [12] By a straight continuation this study finishes the objectives of ongoing development project by constructing the actual excel-based tool for the criticality classification. This research is outlined to consider only fluidized bed boilers. In Figure 12 is shown the Valmet's CFB product called CYMIC.

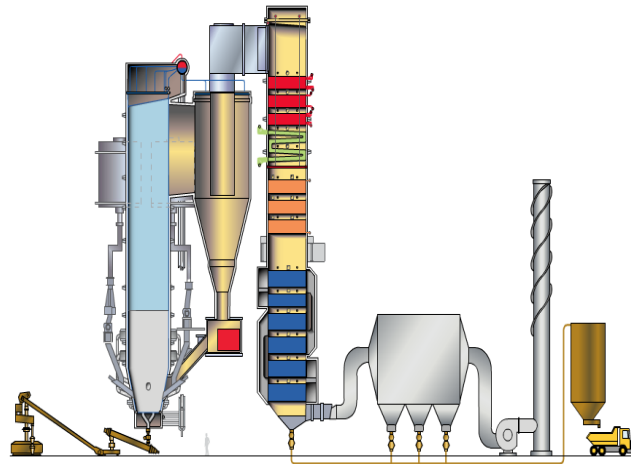


Figure 12. *Valmet's CFB-boiler CYMIC*

3.2 Target and methods research

Target of the research is to find answers to questions: how to create an accurate and efficient criticality analysis tool, which factors the tool should include and which type of parameters should be used in the analysis and how the tool should be implemented. The other target of this study is to: develop and finalize the Criticality Analysis tool, implement the tool correctly to be used for future projects, create instructions for the users of the tool and finalize the spare part package of the pilot case using the CA-tool

The research is done by working at Valmet Technologies Oy, interviewing and discussing with the personnel of Valmet Technologies Oy, examining previous studies, documents and reports related to the spare part packages and analyzing researches, articles, books and other theoretical literature concerning criticality analyses, CFB boilers and spare parts

in general. In order to reach the objectives, the theory is analyzed from the research problem point of view. Preliminary information was explored in Pyry Rinkinen's Bachelor's thesis of (*Criticality of Parts of a Steam Boiler*) [21] in year 2016, done as introduction for this study. The most of the empirical data was collected by interviewing experts in the case company and representatives of supplier firms. Data was stored via recorder or writing memorandums during the interviews. The personnel were interviewed in order to gather the knowledge of several experts on their own field to summarize their specific information together from different angles. By interviewing the personnel, the right parameters and weight factors were found and the criticality analysis tool could be created. In order to refer to the interviewees and the meetings, they are coded with a combination of letters and numbers, such as IN3, ME4 etc. The codes of interviews are listed in the Appendix B and the codes of meeting are listed in the Appendix C. Pilot case spare part list was analyzed in expert meetings in company of three to six personnel. The CA-tool was developed according to constructive criticism from the experts.

The user friendliness of the tool was improved according to a results of a user interface research with help of spare part team workers of the case company. Verification of the tool and development process was made after the tool was complete using common method called Verification Cross Reference Matrix - VCRM. Validation of the development process and result of the tool was made continuously during the study. The results of the validation were gathered in Validation Cross Reference Matrix – VaCRM. Research is a constructive research and concentrates on real life problems, which are necessary to solve in practice. The research strategy is an applied research, which means solving problems, creating wide effects and developing and testing new methods [9, 129 p.] The research was conducted in two stages. First stage was the constructive part of this study which consisted the actual development of the CA-tool and the expert interviews for constructive feedback. Second stage consisted verification, validation and implementation of the tool. During the second stage, the results of the first round interviews and developed tool was tested in a pilot case where spare parts package of ongoing sales project was analyzed with the group of experts using the CA-tool.

3.3 Development of the Criticality Analysis tool

The initial state of the development of this study is the CA-tool created in the previous internal development project presented in the Chapter 2.3. The project ended as incomplete so it could be continued and finalized based on this study. In this chapter is explained the research methods used to gather up the information needed for the development of the CA-tool. First, the parts of the tasks are defined and the approach to the design requirements is described. After that, partially answers to the research problems “*How to create an accurate and efficient criticality analysis tool?*” and “*Which factors the tool should*

include and which type of parameters should be used in the analysis?” is to be given. Constructive part of the study is explained step by step separately for each design requirement. Tasks are numbered to match the requirements.

1. Addition of Location factor

The preliminary design requirement was: *“To take somehow the effect of geographic location of the site into account in the criticality analysis of part “*. At first, the accurate design requirement was defined by collecting information from expert interviews. After that, the most important effective factors were selected and the location factor options and scale was formed based on the interviews. The tentative numerical values were added for the options according to the interviews. The added location factor of the CA-tool was tested by a demonstration in a development meeting in company of experts. According the experts feedback, the location options were revised to be more explanatory and numerical values were adjusted to be more accurate. Finally, validity of the results of the CA-tool were evaluated after the addition of location factor.

The case company operates internationally and the customers in many cases are located on the other side of the globe from Finland. The customers from different countries have their own cultural habits of business and national legislations effecting on the trading of the goods. Because of this the criticality of spare part is the higher the more challenges are in the delivery.

In the case of a failure in the most ordinary component of the boiler, it could lead to major problems if the boiler is located in troubled place and the failure cannot be fixed in reasonable time. For example, there is a customer located in small town the middle of jungle of Asia and the only way to deliver the goods to the site is by a river boat. Therefore, the delivery time from Europe without exception is counted in weeks. Also, for example, some eastern European countries commit so strict and unpredictable border controls that the delivery can delay weeks just for bureaucracy. [IN1]

On this account the location parameter in the CA-tool should stand for two factors relating to the delivery of the goods to the customer site. It should evaluate the time of the actual shipping and the time for the border control bureaucracy. Almost all spare parts of the boiler manufactured by the case company are produced in Europe so the location factor can be simplified to estimate the shipping in every case from Europe. [IN1]

2. Addition of Fuel factor

The preliminary design requirement was: *“To take the effect of variety of used fuel into account in the criticality analysis of part”*. First the accurate design requirement was de-

fined by gathering information from new scientific publications and listing the most important effective factor in expert interview. The fuel factor options and scale was formed based on the interviews. The tentative numerical values were added for the options according to the interviews. The added fuel factor of the CA-tool was tested by a demonstration in a development meeting in company of experts. According the experts feedback, the fuel options were revised to be more explanatory and numerical values were adjusted to be more accurate. Finally, the validity of the results of the CA-tool were evaluated after the addition of fuel factor.

The variety of fuel types which can be used in fluidized bed boilers is large. The quality and composition, and hence the behavior of the fuels differ greatly. This makes certain demands on the design and operation of the boilers. Also the fuel type affects to the wearing of components due corrosion and erosion. So along with changes in the combusted fuel the criticality of ash contacted parts changes. In order to take account on the effect of fuel in the weariness of the components into the criticality calculations, the factors that increases erosion is to be explored. [11] The amounts of harmful components differ widely between different fuels. Harmful components include chlorine, alkali metals and trace metals. They are especially reactive components in the surrounding conditions of a running boiler. Such harmful components can cause different kinds of problems in the boiler, for example: bed sintering, fouling of heating surfaces and corrosion. [11]

Chlorine and alkali metals are especially reactive components that can lead to sintering, fouling and corrosion. Potassium and Sodium can react with silica in the bed material, forming low melting-point silicates that can cause bed sintering. [36]

Bed sintering is caused by alkali metals present in the fuel. The alkali metals react on the surfaces of the bed particles forming low melting-point alkali silicates and other alkali species. These make the surface of the particle adhesive, causing particles to stick together. Consequently, fluidization is disturbed, causing local hot spots in the bed and accelerating the sintering. [36] Figure 13 shows the relation of main factors that causes sintering in fluidized bed of the CFB boiler.



Figure 13. *Relation of factors causing sintering in the CFB boiler*

The composition and melting or sintering behavior of the fuel ash play a major role in the fouling of heating surfaces. Deposits formed on the heating surfaces by fly ash consist of ash particles of the fuel and fumes condensed from the flue gas. Partially molten ash

particles present in the flue gas impact and deposit on the heat transfer surfaces causing reduced heat transfer which, may reduce the availability of the boiler. The composition of fly ash at a heat exchanger depends on the composition of the fuel, combustion conditions, and flue gas temperature. [36]

Some substances in the fuel have important effects on the melting or softening behavior of the fuel ash. They are alkali metals, which reduce the melting temperature and chlorine, as a high chlorine content decreases the melting point of the ash. If the flue gas temperature at a heat exchanger is above the softening temperature for any molecular components in the ash, fouling can become especially problematic. [36] Figure 14 shows the relation of main factors that causes fouling in fluidized bed of the CFB boiler.



Figure 14. *Relation of factors causing fouling in the boiler*

Corrosion is the loss of tube metal by chemical reactions that remove the protective oxide layers from the surface of the metal. Corrosion can occur in boiler tubes where there is sub stoichiometric combustion, such as in the lower part of the furnace, or in superheater tubes, after the flue gases leave the combustor. Corrosion of superheater tubes becomes a problem with high-chlorine fuels, especially at high steam temperatures. Ash melting and fouling of heat transfer surfaces increase the corrosion rate radically. [36]

Factors that affect superheater corrosion are: the flue gas temperature, the steam temperature and, consequently, the metal temperatures, the composition of the ash, particularly in terms of Chlorine, Sodium, Potassium, and Sulphur and the ash melting temperature. [36] Figure 15 shows the relation of main factors that causes corrosion in fluidized bed of the CFB boiler.

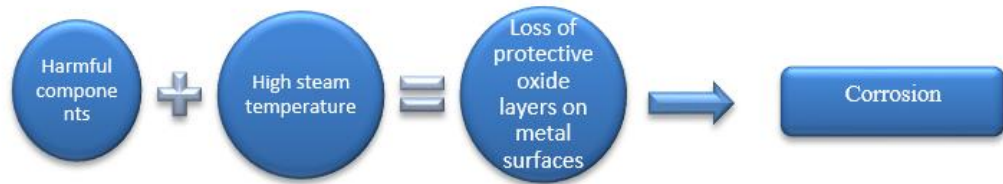


Figure 15. *Relation of factors causing corrosion in the boiler*

In addition to sintering fouling and corrosion the fuel wears heavily before it is burned in the furnace. When a rough, hard surfaced parts of fuel, for example waste, glides across the transporting surface which is relatively softer it causes erosion. This kind of wearing is called abrasion and in the boiler it is appears mainly in the fuel feeding system. Abrasive wear is typically categorized by the contact environment and the type of contact. The contact type defines the abrasive wear mode. In general, there are two types of abrasive wear; Two-body abrasive wear – which means that hard particles, for example sand, eliminate material from the opposing surface, this can be best described by thinking of a material being displaced or removed by a cutting operation, and three-body wear - which means that the particles are unconstrained and are able to slide down and roll on a surface. The relation of factors causing abrasion in the fuel feeding system is presented in the Figure 16.



Figure 16. *Relation of factors causing abrasion in the fuel feeding system*

3. Addition of Delivery factor

The need for delivery factor came out during the pilot analysis. The preliminary design requirement was: “*To take the effect of delivery time from supplier into account in the criticality analysis of part*”. First the accurate design requirement was defined by interviewing spare part sales engineers. On the grounds of interviews, the fuel factor option and scale was formed. The tentative numerical values were added for the options according to the interviews. The added delivery factor of the CA-tool was tested by a demonstration in a development meeting in company of experts. According the experts feedback, the fuel options were revised to be more explanatory and numerical values were adjusted to be more accurate. Finally, the validity of the results of the CA-tool were evaluated after the addition of delivery factor.

Delivery time is not standardized term and it is used to describe the actual delivery in variety of limitations. In the spare parts business of case company, the delivery time means period of time from the received purchase order at the supplier till the received goods on customer's site. The delivery time of spare parts is very important to know and it has an exponential effect on parts criticality due possible long production stop if failure on such part occurs. In order to avoid the risk spare parts with long delivery time should be kept at the site. Some suppliers maintain huge storages and the needed spare parts are available all the time during opening hours. This is a fact that must be considered in calculating the criticality of parts. Especially when the warehouse is close to the site for example in the same country or along fast transport possibility. [IN1] [ME1] [11]

4. Addition of Weight factors

The preliminary design requirement came out during previous internal development project: *“To explore suitable weight factors for the parameters of the analysis”*. At first, the accurate design requirements were defined by exploring commonly known industrial standards. The values of the weight factors were initially selected straightly from the standards. After that, the values were adjusted according to the experts' feedback from the demonstration meeting and in the pilot analysis meetings. Finally, the validity of the results of the CA-tool were evaluated after the addition of weight factors.

The purpose of weight factors is to adjust the calculations of the CA-tool to reflect more accurately the criticality of parts in reality. Concretely speaking weight factors are changeable multipliers inside the calculation formula. In general weight factors are used to balance parameters in relation to each other. They also give an opportunity to take account on changing directives, legislations and customer-specific values for example. Weight factors are usually given by industry-specific regulations, instructions or standards. For example, the Finnish standard PSK 68000 describes the suggested criticality analysis weight factors to Finnish production industry. In the standard there are also stated that weight factors are to be modified to suit for usage of unique companies and strategies. [27]

5. Improvement of user interface

The preliminary design requirement came out during the pilot analysis: *“To improve the user-friendliness and efficient usage of the CA-tool”*. At first, the accurate design requirements were defined by exploring standards of presented information. After that, three end user interviews were arranged. Each user was given a simple analysis task. During the task the confused parts of the tool were put on record. Users suggested improvements

according to the attributes of the standard. Between the interviews the tool was edited according to suggestions and confused part were clarified. Finally, the validity of the results of the improvements of the CA-tool were evaluated in the pilot case analysis meeting.

Improvement of the user interface was not an original design requirement. It is a part of a task which arose during the CA-tool's development when was noted the importance of efficient usage of the tool. The user interface improvement is done by user interview method using seven attributes recommendations described in Part 12 of the ISO 9241 standard. [10] Coals of the improvement is to enhance user friendliness, unambiguity, simplicity, effectiveness and clear appearance and layout. Coal for the CA-tool's effectiveness is to analyze fifty parts in one-hour meeting. Meetings are arranged in two-hour period. So in one period should be analyze one hundred parts. Normal spare part package consists of about 300 parts. So it takes three expert meetings go through the whole package. In the meeting there are on average four persons present. This means it takes altogether twenty-four hours to finalize the analysis of one spare part package. This sets up a coal for the CA-tool to be so easy to use that on average there are only little over a minute time to analyze one part.

In the ISO 9241 [10] standard the "attributes of presented information" represent the static aspects of the interface and can be generally regarded as the "look" of the interface. The attributes are detailed in the recommendations given in the standard. Each of the recommendations supports one or more of the seven attributes. The seven presentation attributes are listed in Table 8.

Table 8. *Attributes of presented information*

Attributes	Description
Clarity	The information content is conveyed quickly and accurately
Discriminability	The displayed information can be distinguished accurately
Conciseness	Users are not overloaded with extraneous information
Consistency	A unique design, conformity with user's expectation
Detectability	The user's attention is directed towards information required
Comprehensibility	The meaning is clearly understandable, unambiguous, interpretable, and recognizable
Legibility	Information is easy to read

3.4 Implementation of the Criticality Analysis tool

In this chapter are explained the research methods used to gather up the information needed for the implementation of the CA-tool. First, the parts of the tasks are defined and the approach to the design requirements is described. After that, partly answers to the research problem “*How the tool should be implemented?*” is separately given based on a research of each design requirements. Tasks are numbered to match the requirements.

6. Pilot case

The preliminary pilot case requirement was handed from the previous internal development project to this study in form: “*To finalize the spare part package of the pilot case using the CA-tool*”. The meaning of pilot case analysis was to test the tool and find the targets for development. The pilot analysis was decided to be done in meeting using experts in variety of fields. The expert team was created and the analysis were done in meetings in order of attended expertise. During the progress of the analysis the participants of the meeting changed according to needed expertise. Validity of the results of the CA-tool and the development process were evaluated during the pilot case analysis meeting.

As a target boiler of the pilot project in this study is the new CFB CYMIC boiler of the power plant called Kilpilahti Power Plant Limited which is located in Porvoo, Finland. It is owned 40% by Neste, 40% by Veolia and 20% by Borealis. New power plant will produce and supply steam, electricity and feed water to Neste's refinery and Borealis' petrochemical plant. Boilers capacity is 150 megawatts (MW). Boiler will be equipped with flue gas cleaning systems including baghouse filters as well as wet scrubbers. Valmet DNA distributed control system will cover the whole power plant. The startup of the plant is scheduled for 2018. [34]

The boiler combines high efficiency combustion with various solid and gaseous side stream fuels from the refinery. New power plant will comply with the latest environmental regulations, including the European Commission's Industrial Emission Directive (IED). [34] “*This power plant will supply energy to an industrial process and it is technically very demanding. Our solution combines wide range of Valmet expertise from boiler and flue gas cleaning technology to process automation to enable good fuel flexibility, high availability and low emissions at the Kilpilahti power plant. The boilers will be able to utilize various solid and gaseous side streams from the refinery and petrochemical plant for energy production*” says Kai Mäenpää, Vice President, Energy Sales and Services Operations, EMEA, Valmet. [34]

Piloting project is done by testing the tool in action to find new development areas and validate the results of the tool. Piloting of the CA-tool includes full analysis of the entire spare part package of the boiler in question. The spare part package consists parts defined

in contract of the sales project, which are gathered from supplier recommendations. Analysis is done in expert meetings (ME3-ME9, Appendix C), where group of expert from different field of expertise together estimates and selects the values for all the different factors of the tool. The tool calculates the final criticality of the parts. The results of the tool are immediately reviewed by the same group. On the grounds of constructive criticism from the meetings the tool is developed to represent more accurately the criticality of the parts. The validity of the results is this way under constant consideration. Development of parameters also depends on the expert meetings experiences as well as usability of the tool.

7. Verification

The preliminary design requirement came out in the start-up meetings of this study and it was put in form: *“Do a proper verification for the CA-tool”*. At first, was explored the prevailed methods in the energy sector and in the industrial field in general. After exploring the suitable verification frame, was picked and modified to meet the needs of this study. The proper methods of verification were also chosen. The selected frame was Verification Cross Reverence Matrix-VCRM. After the CA-tool was finalized, a verification meeting was hold. In the meeting the all the design requirements were verified one by one in two ways. First was done requirement verification, where was estimated how well the requirements meet the rules and characteristics defined, and after that the design verification, where was estimated how well the design meets the rules and characteristics defined for the organization’s best practices associated with design. In the expert meetings the design requirements were verified based on comparison between internal expert knowledge on case company’s guidelines and CA-tool development process and results. Comparison was done visually by going through developed areas of the tool with the experts and reflected the result to their vision of best practices. On the basis of the meetings the VCRM was filled in and results were analyzed.

Verification is an evaluation of fulfilment of required features. It is a procedure which reviews the products correspondence to the original design requirements. [2] It can be done in several different stages for example after the design is completed or after the actual product is done. Verification can be considered to answer to question: “Are we producing the product correctly” [5]

In this study the verification of the CA-tool is done ensuring systematically that all design outputs meet design requirements to confirm that the development is done completely. Requirements were imposed at the beginning of the previous development project and in the beginning of this study. Also during the development of the tool new design requirements arose. Verification is done only in one stage after the CA-tool was completely developed confirming separately that the design requirements are reasonable (Requirement

Verification) and the actual development of the tool is done in accordance of best practices (Design Verification).

Requirement Verification: the process of ensuring the requirement meets the rules and characteristics defined for writing a good requirement. The focus is on the wording and structure of the requirement. It answers to question: “Is the requirement worded or structured correctly in accordance with the organization’s standards, processes, and check-lists?”

Design Verification: the process of ensuring the design meets the rules and characteristics defined for the organization’s best practices associated with design. The focus is on the design process. It answers to question: “Did we follow our organizations guidelines for doing the design correctly?” The design process also includes ensuring the design reflects the design requirements. It answers to question: “Does the design clearly and correctly represent the requirements?” and “Did we design the thing right?” In this study the verification is done using multiple verification methods gathering results into commonly known “Verification Cross Reference Matrix” - VCRM.

Industry accepted verification methods are: [5]

- Test (T)
- Analysis (A)
- Demonstration (D)
- Inspection (I)

Test (T) verifies that a function performs within specified parameters. Test is the verification of a product or system using a controlled and predefined series of inputs or data to ensure that the product or system will produce exact and predefined output as specified by the requirements. [20] [14]

Analysis (A) includes calculation or comparison to historical or experimental data. Analysis is the verification of a product or system using models, calculations and testing equipment. Analysis allows someone to make predictive statements about the typical performance of a product or system based on the confirmed test results of a sample to conclude something new about the product or system. It is often used to forecast the breaking point or failure of a product or system by using nondestructive tests to find the failure point. [20] [14]

Demonstration (D) verifies performance of a function that does not require qualitative measurement. Demonstration is the handling of the product or system as it is intended to be used to verify that the results are as planned or predicted. [20] [14]

Inspection (I) is an examination of a product or system using one or more of the five senses: visual, auditory, olfactory, tactile or taste. It may include simple physical manipulation and measurements. [20] [14]

8. Validation

The preliminary design requirement came out in the start-up meetings of this study and it was put in form: “*Do a proper validation for the CA-tool*”. The validation was done in same way that verification, first was explored the prevailed methods in the energy sector and in the industrial field in general. After exploring, the suitable validation frame was picked and modified to meet the needs of this study. The proper methods of validation were also chosen. The selected frame was also the VCRM, but using it for the validation it was named Validation Cross Reference Matrix - VaCRM. Validation was done during the development. The CA-tool was tested and demonstrated each time some changes was made. After the CA-tool was finalized, a verification meeting was hold. In the meeting the validity of all the design requirements were estimated one by one in two ways. First was done requirement validation, where was estimated does the requirements clearly communicates the stakeholder needs and expectations in a language understood by the developers, and after that the design validation, where was estimated how well design will result a system that meets its intended purpose in its operational environment. The validity of the results of the CA-tool were evaluated in the expert meetings based on demonstration analysis of different kind of spare parts, which criticality was well known and represented different criticality class close to the limits of the criticality levels. When the tool gave results that were expected the tool was considered to deliver validate information. This was done for each equipment separately during the pilot case analysis meetings. The validation was also done in each time that some changes was done to the CA-tool. In the pilot case meetings, the results of analyzed parts were validated based on knowledge of the equipment specialists involved to the meeting. On the basis of the meeting the VaCRM was filled in and the results were analyzed.

Validation is a procedure to confirm products suitability for purpose of use. Validation can be considered to answer to question: “Are we producing right product?” Also the correctness of the design requirements defined in the verification should be dissected. In this study the validation is done in two division defining separately validity of the design requirements (Requirement Validation) and the development of the tools validity as well as the validity of the results the CA-tool gives (Design Validation). Results of the validation are presented in “Validation Cross Reference Matrix” – VaCRM.

Requirement Validation: confirmation the requirement clearly communicates the stakeholder needs and expectations in a language understood by the developers. The focus is

on the message the requirement is communicating. It answers to question: “Does the requirement clearly and correctly communicate the stakeholder expectations and needs?” or “Are we doing the right things?” or “Are we building the right thing?”

Design Validation: confirmation the design will result in a system that meets its intended purpose in its operational environment. Will the design result in a system that will meet the stakeholder expectations (needs) that were defined during the scope definition phase that occurred at the beginning of the project? The focus is on the message the design is communicating. “How well does the design meet the intent of the requirements?” “Do we have the right design?” “Are we doing the right things?” “Will this design result in the stakeholder expectations and needs being met?”

The actions to be done in validation according to business dictionary [2] is defined with two requirements:

1.” *Assessment of an action, decision, plan, or transaction to establish that it is:*

- *Correct,*
- *Complete*
- *Being implemented (and/or recorded) as intended*
- *Delivering the intended outcome*

2. *Assessing the degree to which:*

- *Instrument accurately measures what it purports to measure*
- *Statistical technique or test accurately predicts a value”*

4 RESULTS

In this chapter the results of each parts of a task are presented. The validity of results is considered one by one. Affecting factors are also reflected with each results. Chapter 4.1 presents results of new added parameters and user interface improving research. In other words, it describes the concrete modifications done under this study. After description of results comes the final equations of the designed CA-tool. Chapter 4.2 presents the results of pilot case spare parts criticality analysis, verification of the design requirements and validation of the CA-tool’s results. In the pilot project were found many weak spots and further development targets of the CA-tool. Also the results of the pilot cases analysis are compared to imaginary situation where the power plant is moved from Finland to Indonesia to see the effect of location factor.

4.1 Development of Criticality Analysis tool

In this chapter the study behind the added features and improvements as well as all the results of part of the tasks are presented. In the Appendix D is shown the appearance of the CA-tools analysis sheet and in the Appendix H can be found the user instructions of the CA-tool.

Addition of new factors

The addition of the location, fuel and weight factors was done according the original requirements. The addition of delivery factor and user interface improvement was done according the need noticed during the development process.

1. Location factor

The meaning of site's location to the spare parts criticality is decided to determine by only one number which takes into account the difficulty in transporting the goods. Location factor consists of two variables location effect parameter R_l and weight factor w_l . The value of location parameter is selected in an analysis session estimating time of shipping and time it takes for bureaucracy from dropdown list shown on Table 9. The location factor effects as much on every part on a package because of a simplification; all the spare parts are thought to be manufactured in Europe so the shipping and border controls are the same for each part. Purpose of the weight factor w_l is as described later in this chapter.

Location factor L is calculated by Equation 7:

$$L = R_l w_l \quad (7)$$

Table 9. Location effect scale and effect options

Effect	Description (R_l)	Numeric value
Extreme effect	Long distance, hard to deliver	R_{l4}
High effect	Long distance, easy to deliver	R_{l3}
Moderate effect	Short distance, hard to deliver	R_{l2}
Low effect	Short distance, easy to deliver	R_{l1}

Extreme location effect means that the site is long distance away from Europe (shipping time approx. 3 weeks) and boarder control and other country-specific bureaucracy causes delay on to delivery (approx. 2 weeks); for example, Indonesia. High location effect means that site is far away but delivery into the country is easy and there is no significant delay with the boarder control (delivery time approx. 3 weeks); for example, Brazil. Moderate location effect means that the site is close to Europe but delivery takes long time

because of bureaucracy (delivery time from 3 days to 2 weeks); for example, Russia. Low location effect means that the site is close to Europe and shipping over the boarder goes without delays (delivery time less than 3 days); for example, Sweden.

2. Fuel factor

As a conclusion the factor that affected the most on the erosion and weariness and thereby to the spare parts criticality is the corrosion, hence all the parts in the flue gas flow are metal parts. On this account the fuel parameter in the CA-tool should stand for two considered matters: is the analyzed part in touch of ash in any forms, and how erosive circumstances are due ash? The more corrosive ash is in contact of the part the more it will speed the wearing of the part and increases the risk of failure in that system. The relations of factors causing erosion and wearing are presented in the Figure 17

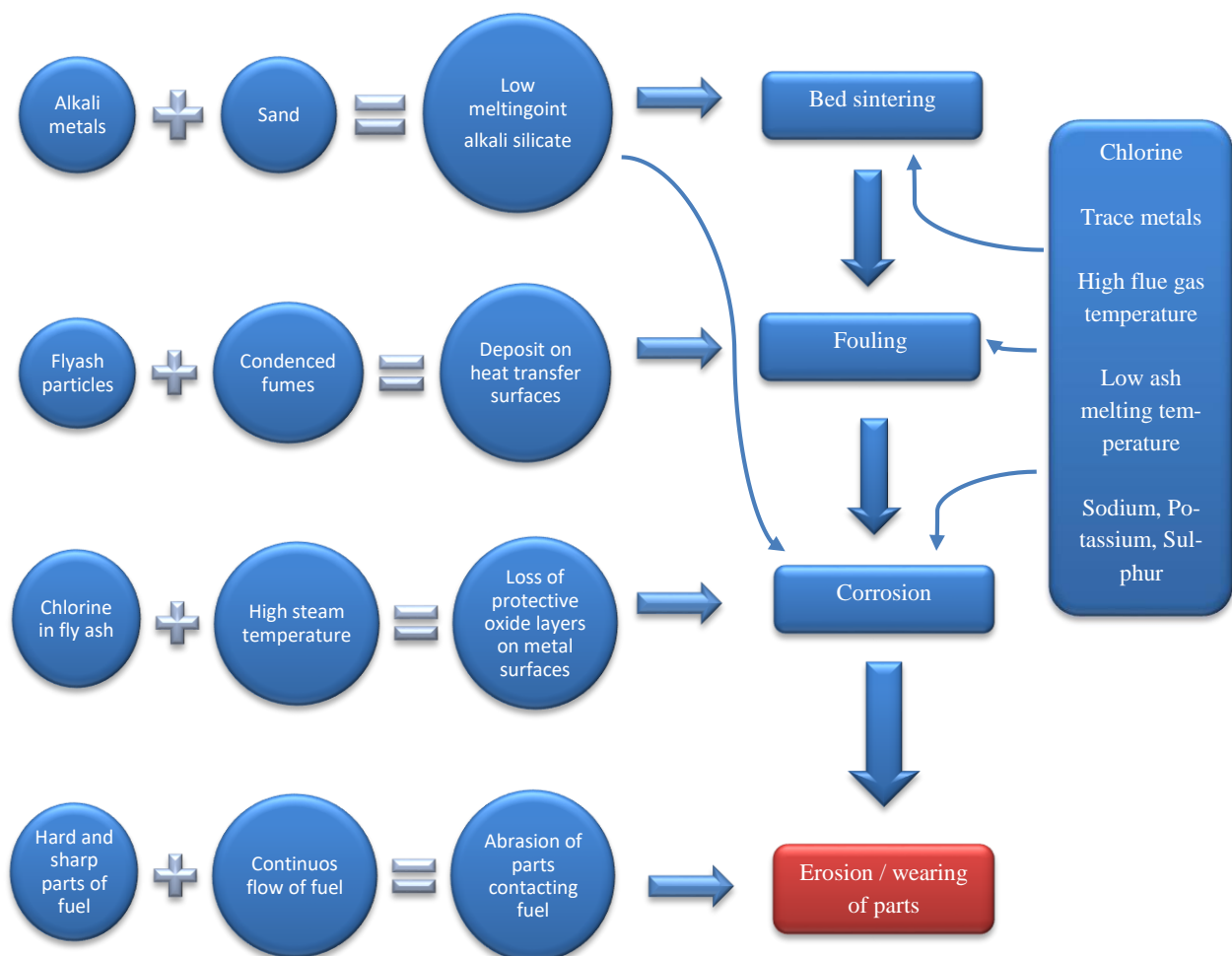


Figure 17. Factors causing boiler parts erosion and wearing

The effect of used fuel to the spare parts criticality is determined by only one number which takes into account fuel's properties. For example, waste as a fuel is much more wearing than pure coal. In addition, the facts whether the part is in contact with the fuel or ash or not and how erosive the parts circumstances are also taken in to account with same value. In the fuel feeding system the wearing of parts mainly results from abrasive flow of the fuel. So the consistency of fuel does not play major role there and mechanical wearing is the greater the sharper and harder the pieces of fuel are. In the flue gas system, the parts are constantly in touch with the bottom or fly ash and the circumstances varies along the flue gas system. Fuel factor consists of two variables fuel effect parameter R_f and weight factor w_f . The value of fuel parameter is selected from dropdown list shown on Table 10. Purpose of the weight factor w_f is as described later in this chapter.

Fuel factor F is calculated by Equation (8):

$$F = R_f w_f \quad (8)$$

Table 10. Fuel effect scale and effect options

Effect	Description (R_f)	Numeric value
Extreme effect	Part in contact with fuel or ash caused very erosive circumstances	R_{f4}
Moderate effect	Part in contact with fuel or ash caused semi erosive circumstances	R_{f3}
Low effect	Part in contact with fuel or ash caused minor erosive circumstances	R_{f2}
No effect	Part not in contact with fuel nor ash	R_{f1}

Extreme fuel effect means that part is in contact with unburned fuel or ash caused very erosive circumstances resulting part to wear very rapidly. For example, a tube of secondary superheater or bottom ash sieving mesh. Moderate fuel effect means that part is in contact with unburned fuel or ash caused semi erosive circumstances resulting part to wear significantly fast. For example, tube of furnace walls. Low fuel effect means that part is in contact with unburned fuel or ash caused minor erosive circumstances resulting part to wear a pit depending much of the used fuel. For example, bearings of bottom ash screw conveyor. No fuel effect means that part is not in any contact with the unburned fuel nor ash. For example, main steam valve.

3. Delivery factor

Delivery factor consist of two variables, delivery risk parameter R_d and weight factor w_d . Delivery risk also consists of two parts, delivery time, which means time between received purchase order from customer to supplier till the actual delivery of the goods to the site, and storing of parts, which means that part locates in stock nearby or along fast transportation. Effects of delivery time and stock possibly are estimated with one figure

chosen from option list. The delivery effect options of a CA-tool are shown on Table 11. Purpose of the weight factor w_d is as described in the chapter 7.4.

Delivery factor D is calculated by Equation (9):

$$D = R_d w_d \quad (9)$$

Table 11. *Delivery effect scale and effect options*

Risk description:	Description (R_d):	Numerical value
Extreme effect	Part never in stock, delivery time very long	R_{d5}
High effect	Part sometimes in stock, delivery time long	R_{d4}
Moderate effect	Part sometimes in stock, delivery time short	R_{d3}
Low effect	Delivery time very short	R_{d2}
Minimum effect	Part always available in stock	R_{d1}

Extreme delivery effect means that part is very complex and customized, so it is never available in stock and its delivery time is in months due long manufacture time. For example, of impeller of an ID-fan which delivery time by optimistic estimate is six months. High delivery effect means that part might be found in stock sometimes and delivery time is in weeks due long manufacture time. For example, tube of furnace walls. Moderate delivery effect means that part might be found in stock sometimes and delivery time is in days due short manufacture time. For example, shaft sealing of a screw conveyor. Low delivery effect means that total delivery time is one or two days. For example, basic drain and vent valves. Minimum delivery effect means that part is always available in stock and delivered to the site during the same day. For example, basic sealing rope of conveyors.

4. Weight factors

There are two basic position for weight factors in criticality analysis tool. Position that describes equipment's criticality compared to whole plants operation and position that describes each parameters effect in relation to others, whether the demand comes from state level or from customers themselves. In the initial state of the CA-tool the lack of weight factors were noted. In the CA-tool of this study there are two types of weight factors.

In the production loss factor there is a weight factor called Process Criticality Index – PCI. PCI's purpose is to estimate the equipment criticality for the sight of whole power plants operation taking account on how interrupted systems of the power plant is going to effect to the production and is it possible to fix via remedial actions. The criteria of PCI are presented in the Table 11.

Table 12. *Definition of equipment criticality aka Process Criticality Index.*

Index	System level	Criteria	Weight factor
PCI 1	Main process systems	Interruption will result in immediately stop of the entire Power Plant. No remedial actions can be taken.	W_{c1}
PCI 2	Primary auxiliary systems	Interruption will result in a stop of the Power Plant within hours, or a reduced load. Remedial actions are possible to take within minutes or few hours.	W_{c2}
PCI 3	Secondary auxiliary systems	Interruptions will normally not result in a stop of the Power Plant or reduced load. Remedial actions are possible to take within days.	W_{c3}
PCI 4	Supporting systems	Interruptions will not affect the operation of the Power Plant. Remedial actions are always possible to take.	W_{c4}

PCI 1 is the highest level of the equipment criticality. It means that failure in system effects to the main process systems and interruption of these systems will result in immediately stop of the entire Power Plant. No remedial actions can be taken to avoid a stop of the entire Power Plant. PCI 2 means that failure in system effects to primary auxiliary systems and interruption of these systems will result in a stop of the Power Plant within a relative short period, or forces to run boiler with a reduced load. Remedial actions are possible to take within minutes or few hours. PCI 3 means that failure in system effect to secondary auxiliary systems and interruptions of these systems will normally not result in a stop of the Power Plant or reduced load. Interruptions of these systems will normally not result in a stop of the Power Plant or reduced load. Remedial actions are possible to take within days. PCI 4 is the lowest level of criticality index. It means that failure in system effects only to supporting systems. Interruptions of these systems will not affect the operation of the Power Plant and remedial actions are always possible to take. The other type of weight factor used CA-tool in question is somewhat simpler. The weight factors are mentioned in the Table 13.

Table 13. *List of weight factors of criticality parameters*

Criticality factor	Weight factor
Production loss	W_p
Environment	W_e
Safety	W_s
Fuel	W_f
Location	W_l
Delivery	W_d

It is a weight factor which purpose is to distinguish factors by importance between all the criticality factors. This kind of weight factors are determined by legislations or by values of customers. For example, some customer is very keen on being environmental friendly and other customer operates in country with strict safety regulations. Due these differences the results from the criticality analysis for each customer are rarely the same, even though the boiler is the same.

5. Improvement of user interface

The user interface improvement research is done by interview method which is but in to practice in following way:

1. Analyze task is given for a spare part engineer who sees the tool for the first time
2. The person is asked to analyze a familiar part using the tool after short guidance
3. The person is commenting out loud all the problems and proposals that comes in mind.
4. After analyzing the part, the person is interviewed to answer for all the seven attributes of the ISO 9241 standard.

This four step interview method is done three times, each time with new engineer. Between the interviews the proposed corrections are fixed and the tool is modified according the comments.

On the basis of the interviews (IN3-IN5 Appendix B) the necessary corrections and modifications were carried out. Especially practicality and usability are enhanced significantly during the user interface improving. The improvements are gathered to Table 14.

Table 14. *Attributes of presented information*

Attributes	Improvements
Clarity	The colors of the tool are uniformed for clearer look [IN3]
Discriminability	The size of text cells is edited that each phrase fits perfectly [IN4] The results are displayed at the own result sheet[IN4] The addition of customer sheet, where are all the info meant to customers [IN5]
Conciseness	Columns where only data for calculations are hided cause of disturbances [IN3] The sentence structures are edited concisely [IN4]
Consistency	The usage of the same criticality classification markings as other case company's department [IN5] The used terms are uniformed throughout the CA-tool and instructions[IN5]
Detectability	The most important rows and columns are frozen for user to be able to see them all the time [IN4]

Compre- hensibility	The headlines of criticality factors are edited to describe more accurately the issue [IN4] In the instructions a graphical formula is presented to help to understand the calculations. [IN5]
Legibility	The spelling mistakes are corrected [IN3]

The CA-tool was given a proper facelift according the user interface improvements. The uniformed colors of the tool, perfectly fitting phrases and hided disturbing information gave a much clearer look for the tool. The frozen basic info columns and the presented graphical formula (see Appendix E) of the criticality score helps and speeds up the analysis. Concise sentence structure, uniformed terms and accurate descriptions in headlines with corrected spalling mistakes gave a professional touch for the tool. With the criticality level markings were supposed to follow the guide lines of Valmet Paper department, but the change is not done because of continual consideration of which markings are the best in the future. The results sheet was created for easier observation of the results only. The customer sheet was not to be created for a lack of resources, but it will be most likely created afterwards.

Criticality score

According the results of the research tasks the final criticality score equations could be formed. Each equation is consisted of factors presented earlier in this chapter. Final version of the tool consists of six separate criticality factors and weight factors related to them. Criticality score is a summation of criticality points of criticality factors.

1. The equation of production loss factor:

$$RPN_p = w_c w_p R_p P_p \quad (10)$$

2. The equation of safety factor:

$$RPN_s = w_s R_s P_s \quad (11)$$

3. The equation of environment factor:

$$RPN_e = w_e R_e P_e \quad (12)$$

4. The equation of fuel factor:

$$F = R_f w_f \quad (13)$$

5. The equation of location factor:

$$L = R_l w_l \quad (14)$$

6. The equation of delivery factor:

$$D = R_d w_d \quad (15)$$

Criticality score **C** is a sum of all six factors. Risk priority numbers represents criticality points that can be compared and classified according their value. Criticality factors that does not represent a risk but effect of some action can also consider as criticality points, that is because in the analysis meetings the points are decided to reflect directly of the criticality of certain effect of an action. So RPN and effect points can be calculated together to generate the final criticality score:

$$C = [RPN_P + RPN_E + RPN_S + F + L + D] \quad (16)$$

Criticality score is a number which must not be considered as an accurate figure. Its purpose is to categorize the parts into right criticality class, explained in Table 7 on page 29. Classes (Level 1, Level 2...) are comparable, but minor differences in scores are not. So for example, even though two parts with scores 146 and 149 has three-point difference, it does not mean that other one is more critical than the other. They belong to same criticality class. In case where the score of the parts are close to the limit of classification level, parts class must be decided carefully case by case on the basis of expert knowledge. The minimum criticality score is zero and the maximum score is 421. The actual criticality level limits are not to be presented in this study due their confidential nature but the regular spare parts packages criticality scores fluctuate approximately between 10 and 150. The scales of the criticality factors and on the other hand the limits of the criticality levels are adjusted in a way that each factor can in worst case impose the parts as critical. The graphical form of the criticality score equation is shown in Appendix E.

4.2 Implementation of Criticality analysis tool

In this Chapter the parts of the task of implementing the CA-tool is presented. In the frames of industrial management, the implementation of a new tool includes few different start-up reviews for example to ensure tool's functioning, accuracy, safety and the end users guidance. [17] In this study the implementation of the CA-tool is divided in three sections: piloting, verification and validation. The pilot case which serves as a test run and as an actual work performance for the CA-tool is introduced later next this chapter. Also verification and validation of the CA-tool are presented later in this chapter.

Pilot case for the CA-tool

The purpose of the pilot project was to go through full criticality analysis of the CYMIC boiler's spare part package of the Neste Kilpilahti power plant. The package was analyzed in expert meetings held in case company's facilities. Info of the meetings is presented in Appendix C. Also supplier's representatives were interviewed to gain all possible information. Suppliers had criticality classification for their products, but the results were not usable in the raw due analysis did not take account on the operation of the boiler as a whole, much less it did the take account on operation of the whole power plant. And the fact, that supplier's goal is many times to sell as much spare parts as possible, decreases reliability of their recommendations and supports the commissioning of own criticality analysis.

The other purpose of the pilot project was to test the analysis method and to find suitable practices for analysis meetings and usage of the CA-tool. During the analysis detection of improvements was done continuously because the one main objective was to develop primarily an efficient tool and way of analysis.

Pilot case's successions:

1. Knowledge from the case company's experts was sufficient and unifying knowledge from many fields of expertise turns into proper additional value
2. Feedback for the tool was constructive and instant, which helped to develop the tool
3. Develop suggestions came up intensively from different departments, which helped to understand the overall situation of spare part packages
4. Supplier interviews were valuable and extensive answer were given, thanks to well working cooperation
5. The validity of CA-tools design requirements and results was continuously evaluated
6. The meanings of the tool's results were also speculated regularly, so the objectives were clear in mind

Weak spots noted during the pilot case:

1. Inefficient working if participants have overlapping expertise
2. Inefficient working when some expert with narrow expertise takes part for unnecessary long meeting.
3. Lack of knowledge from the suppliers in internal meetings
4. Lack of knowledge from the customer or customer's maintenance firm in internal meetings
5. Too much time was used for the analysis

6. Tool was inefficient to use for the lack of copying possibility, hence there was multiple corresponding selections
7. Tool was confusing cause of progress of the analysis was hard to follow

Improvements made during the pilot case:

1. Shorter and more focused meetings with smaller groups of experts. So the meetings would more cost efficient without overlapping expertise
2. Separate supplier or customer interviews before actual analysis meeting to gather external extra information to gain more deep analysis.
3. More efficient and clearer CA-tool due to improvement of user interface research and enhanced modifications.
4. Recorded meetings, so the host of the meeting can return to unclear subject afterwards and unify knowledge between separate meetings.

The final results of the pilot case's criticality analysis are shown on Figure 16. The Diagram A present the result original analysis of the pilot project in Porvoo, Finland. As an example of the location factors effect to spare parts criticality the Diagram B illustrates imaginary situation, where the same boiler and power plant is located from Finland to South Sumatra Province, Indonesia (where stands a boiler of one customer of the case company), so the effect of location can be seen in results clearly and. The comparison is done analyzing and changing only the value of location factor in the criticality analysis table of the pilot case.

DIAGRAM A: SHARES OF CRITICALITY LEVELS IN FINLAND

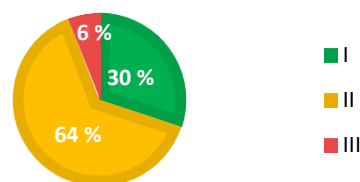


DIAGRAM B: SHARES OF CRITICALITY LEVELS IN INDONESIA

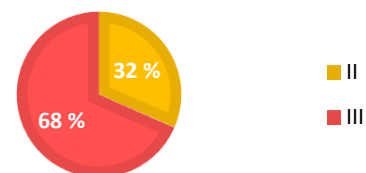


Figure 18. *Shares of pilot case's spare part packages parts by criticality class according to the criticality analysis.*

From the Diagram A of the Figure 16 can be noted that only 6 % of the spare part package, gathered according to supplier's recommendations, are on unacceptable risk level after full criticality analysis. Most of the parts, 64 %, belongs under tolerable risk level and almost one third, 30 %, goes under acceptable risk level. On the other hand, from the Diagram B of the Figure 16 can be seen that location causes huge effect on criticality

class, hence the risk level III increased from 6 % to 68 % and parts with risk level I do not exist at all.

Verification of the CA-tool

The CA-tools verification was done in company of spare parts manager of the case company once the development of the tool was finished. Verification was done in order to systematically confirm and estimate the accomplished development using Verification Cross Reference Matrix. Verification was done in two separate phases; first the requirement verification, where fulfillment of each requirement was carefully checked (Table 15), second the design verification, where was evaluated did the developed CA-tool fulfill the design demands and does the results meet the expectations (Table 16).

Table 15. *Results of requirement verification in verification cross reference matrix*

VCRM of requirement verification			
Req. ID	Design/Research Requirement	Method	Success criteria
1	Addition of fuel factor	I	req. defined inaccurately
2	Addition of delivery factor	I	req. defined inaccurately
3	Addition of weight factors	I	req. defined inaccurately
4	Addition of location factor	I	req. defined inaccurately
5	Improvement of user interfacing	I	req. definition loose
6	Pilot case	I	The spare part package of the pilot case finalized
7	Verifying the CA-tool	I	Verification done visible
8	Validating the CA-tool	I	Validating done visible

The additions of new factors, Req.ID 1-4 in Table 15, were noted to be added to the tool by testing each factor separately in action and verification was done by inspecting the requirements. The requirements were defined inaccurately so the success of the development were also difficult to define. Validity and accuracy requirements were also lacking. Improvement of user interface (Req. ID 5) was a requirement that arose during development and its verification was done by visibly to go through each improvement came up in the end user interview research explained in Chapter 5.2. The definition of requirement was loose. Pilot case's (Req. ID 6) objective was to finalize a criticality analysis of the pilot case spare part package using new CA-tool. The verification of the pilot case was done visibly by checking the whole spare part list to be analyzed. The requirement was properly and accurately defined. Requirements 7 and 8 also came up during the development and their accomplishment are also visibly verified but requirements lacked clear qualifications and demanded accuracy.

Table 16. *Results of design verification in verification cross reference matrix*

VCRM of design verification			
Req. ID	Design/Research Requirement	Method	Success criteria
1	Addition of fuel factor	A	Lack of exact reference data. Comparison between CA-tool and expert knowledge.
2	Addition of delivery factor	A	Lack of exact reference data. Comparison between CA-tool and expert knowledge.
3	Addition of weight factors	A	Lack of exact reference data. Comparison between CA-tool and expert knowledge.
4	Addition of location factor	A	Lack of exact reference data. Comparison between CA-tool and expert knowledge.
5	Improvement of user interfacing	T, A	Design meets the required. Comparison to external best practices
6	Pilot case	A	Design followed the guidelines of the case company
7	Verifying the CA-tool	I	Design meets the required. Comparison to external best practices
8	Validating the CA-tool	I	Design meets the required. Comparison to external best practices

In general, the whole development process followed case Company's guidelines and project plan. The CA-tool and its parts were unique in a way that there was not any reference project or such development of an excel-based tool to be compared to. The development of each criticality factor (Req. ID 1-4) were verified continuously during the study to meet the best practices according to an expert knowledge of the case company. Design meet the required features and accuracy. Requirement 5, improvement of user interface was a totally new way of development in the case company and the demands was not defined accurately. Goal was just to improve the usability of the tool. The method was verified by comparing CA-tool to ISO 9241 standard and external best practices of such developing. Design meet the required improvements and enhanced efficiency of usage. As well as additions of new factors the pilot case is also unique and impossible to refer exact data. Design verification of pilot case criticality analysis was based on comparison between analysis method and expert knowledge. The requirements 7 and 8 are verified to meet the planned VCRM method.

Validation of the CA-tool

Validation of the CA-tool and the development process was done continuously during the study and especially during the pilot case criticality analysis. After the CA-tool's development the results of the validation was gathered into Validation Cross Reference Matrix – VaCRM, presented in Table 17 and Table 18. As well as the verification section the validation is also divided into two phases; first the requirement validation, where validity

of each requirement was evaluated, results in Table 17, second the design validation, where was evaluated how well the designed features meets the design requirements and expectations, results in Table 18.

Table 17. *Results of requirement validation in validation cross reference matrix*

VaCRM of requirements validation			
Req. ID	Design/Research Requirement	Method	Success criteria
1	Addition of fuel factor	T, A, D	Requirement clarified during the process and it meets the company needs
2	Addition of delivery factor	T, A, D	The need of delivery factor was noticed during the study and it meets the company needs
3	Addition of weight factors	T, A, D	Requirement clarified during the process and it meets the company needs
4	Addition of location factor	T, A, D	Requirement clarified during the process and it meets the company needs
5	Improvement of user interfacing	T, D, I	The need of improvements was noticed during the study
6	Pilot case	T, D, I	The pilot case gave concrete information to support development of CA-tool
7	Verifying the CA-tool	I	The requirement arisen during the study and it meets the company needs
8	Validating the CA-tool	I, T	The requirement arisen during the study and it meets the company needs

Original requirements which related to the addition of features (Req. ID 1-4) was not defined accurately in the first place and the actual needs and expected demands clarified during the development process. The need of delivery factor (Req. ID 2) and improvement of user interfacing (Req. ID 5) were noted during the study. The tool and all the criticality factors were tested and demonstrated during the actual development process and qualitative analysis was done in pilot case meetings. The original requirements were proper, keeping mind the character of the study, which was to explore and create something new. Pilot case (Req. ID 6) was very important part of the development and implementation of the tool. The knowledge of the experts came out effectively and different field of expertise was well mixed. Pilot case gave lot of concrete information which helped and supported the actual development of the CA-tool. Though the pilot case's boiler could have been selected better. The boiler was selected to this study because it was a part of the original development project which scope was straightly converted to the objectives of this study. The fuel used in the boiler was never used before by the customers of the case company. So the reference to boilers functioning and parts wearing was not available.

Table 18. Results of design validation in Validation Cross Reference Matrix

VaCRM of design validation			
Req. ID	Design/Research Requirement	Method	Success criteria
1	Addition of fuel factor	T, D	Complete, implemented and delivering the intended outcome. Adding and developing fuel factor in line with expert's knowledge
2	Addition of delivery factor	T, D	Complete, implemented and delivering the intended outcome. Adding and developing delivery factor in line with expert's knowledge
3	Addition of weight factors	T,A, D,I	Complete, implemented and delivering the intended outcome. Developing weight factors according to internal and external best practices
4	Addition of location factor	T, D	Complete, implemented and delivering the intended outcome. Adding and developing location factor in line with expert's knowledge
5	Improvement of user interface	D, I	Complete. Pilot case analysis proved that improvements were suitable
6	Pilot case	D	Complete. Difficulties because of unknown fuel of chosen pilot case
7	Verifying the CA-tool	D, I	VCRM was the most common verification frame used in process industry
8	Validating the CA-tool	D, I	VCRM was the most common verification frame used in process industry

All the added new factors (Req. ID1-4) are completely developed and delivering intended outcome in satisfactory accuracy. In general, statistical techniques and calculations of the tool predicts a value of criticality on satisfactory level. Fuel factor takes into account fuels wearing properties for those parts which are in contact with fuel or ash. Development was done in line with expert's knowledge. The fuel factor does not include different parameters for different fuels. If variety of fuels are planned to be used the selection of fuel factor must be done evaluating and considering the total effect of such variety of fuels. The preliminary plan for usages of fuels is announced in the sales contract. Fuel factor could have been done calculating together all parameters of fuels to be used. In this study it was noticed to be too complex and inefficient way and it was outlined from this development. Delivery factor (Req.ID2) and location factor (Req.ID4) was created in line with expert's knowledge and they stand together for the total delivery time. Both factors evaluate separately two parameters, so finally the delivery time is a combination of values of four different parameters. This way the true criticality of parts is comes out clearer than evaluating only single factor total delivery time. Addition of eight factors (Req.ID3) was done in line with internal best practices taking account of each equipment criticality for the whole power plant using the PCI factor presented in Table 11. In the CA-tool the name

of the PCI was changed to ECI -Equipment Criticality Index, for its more suitable meaning. The weight factors of criticality parameters were adjusted according the SPK-6800 standard and modified it in pilot cases expert meetings to meet the requirements and values of the pilot case customer.

Improvement of user interface of the CA-tool (Req.ID5) meets the demanded design requirements according the comment from the participants of the pilot case analysis despite the efficiency goal. The goal of efficiency was not achieved, and the time used in the analysis were double from what was expected, but on the other hand there were delays which were not fault of the tool. The concept of the analysis meetings was first unclear, but it shaped more efficient during the pilot case. Pilot case analysis (Req.ID6) was done completely and the results were as expected. The characteristics of the fuel used in the pilot case boiler was unknown and it caused difficulties with the analysis and it forced this study to do more research on the effects of fuel than on the other factors.

Verification and validation (Req.ID7 and 8) of the CA-tool was done according the common verification frame VCRM. The requirements were fulfilled completely evaluating separately all the design requirement individually. Challenge was to understand the difference between different kind of validations and verifications and remembering to think like a tester. Also difficulties with verification and validation in this study was with compliance, planning, approach and coordination of VCRM.

5 DISCUSSION

This chapter is split in three sections. The response to each research questions is given in the Chapter 5.1. Also the problems of given CA-tool frame are revealed. The success of the development of the tool, and the meaning of this study to the case company is evaluated in the practical contribution as well as further developments of the tool, which remained undeveloped due to lack of resources are presented in Chapter 5.2. The ideas for further research, for example, big data approach, are presented in the Chapter 5.3.

5.1 Responses to research questions

The first research question was: “*How to create an accurate and efficient criticality analysis tool?*”. At first was decided which program was to be used. The Excel was a clear choice because it is widely used in the case company and the employees are familiar with it, excel can communicate with other programs and databases of the company and the tools which worked as a model were also in excel format. Next was to decide what are the factors that effect to parts criticality and to figure out how much they will effect and how the tool should be built. After the frame of the tool was existing the values, aka points, were to be added to the tool. The tool must be built in way that the changes was easy to take also afterwards. For example, if new factors are to be taken into account. When the tool gives some numbers as a result the classification limits is to be decided. Then the points of the tool are adjusted to meet the limits. This is done by testing and demonstrating the tool several times and between tests adjusting some more because there was none historical data or any reference data available at the case company. The adjustment of this tool was depending on experts’ knowledge. The effectiveness was improved via development according to results of user interface research. Also clear instructions with tips for effective usage was formed.

The second research question was: “*Which factors the tool should include and which type of parameters should be used in the analysis?*”. Most factors were given according the previous development project. They were the basic criticality factors found in every criticality analysis tool: production loss, environment and safety. These parameters consisted of risks severity and probability. In addition, in the development project was noted that other factors should take into account the location of site and the properties and effect of used fuel. These parameters consisted of only one number which described the risk. In the middle of the development arose need for new factor which could take into account the parts delivery time and it was also decided to work with one figure. There were also view factors considered to be added but was decided to leave outside of this tool. They

were actions of preventive maintenance and regular inspections, which could lessen the criticality. Also was considered the customer profile factor, which could take into account the habits and values of a customer firm.

The third research question was: “*How the tool should be implemented?*”. The implementation was decided to do via pilot case with the thought that the pilot analysis will give much feedback on the operation of the tool. During the pilot case analysis every change done for the tool was evaluated by the group of experts. Implementation also consisted of verification and validation of design requirements which were performed in the meetings of pilot case analysis. After the tool was complete and the pilot project spare parts package was analyzed the instructions for the usage of the CA-tool was created. In the future when the tool will be taken into action the proper guidance should be given.

The excel frame of the CA-tool was given for this study as incomplete to be developed further according design requirements. During the development was noted that the given risk matrix presented on table 7 on page 29 was not suitable for this kind of classification. The risk matrix pointed out for example that death once in five to ten years is a tolerable risk. Which of course cannot be accepted from the point of view of the case company, customer company and much less the personnel of the plant. For example, according to matrix adapted from standard: *Risk management - Principles and guidelines* (ISO 3000/2013) [22] this kind of risk could be categorized as likely in probability scale and as catastrophic in consequence scale, which would lead to extreme risk category. The same kind of insufficiency were found on probability levels of the CA-tool shown on Table 2, which states that probability of for example, serious offsite environmental impact is 20 years, it can be considered from the perspective of the life cycle of the plant as quite likely event. Reliability and validity of the criticality score of this CA-tool are nonetheless on adequate level and results of analysis can be used to gather the packages because they are not defined by this insufficient risk matrix. The matrix points out only the risk level of separate criticality factors. The final classification of is made according the criticality level limits presented in the table 8 on page 30. What it comes to insufficiency Table 2, the spare parts life cycle is in every case less than 20 years as a result of planned maintenance. The risk matrix and consequence has to be fixed anyway to meet the national safety standards.

5.2 Practical contribution

This study finalized CA-tool initiated in the internal development project of a case company. The tool is easy and efficient to use and it is made in excel-format so it is usable with many other applications. The tool is simple and designed in a way that it is easy to adjust case by case or modify in further developments. The study revealed flaws in risk

matrix given along the undeveloped CA-tool explained in chapter 5.1. During the development further development requirements and themes of other researches arose.

The CA-tool is supposed to be used in the capital sales project quotation phase (see Appendix G) to create a list of most critical spare parts which can be offered on the side of the project sale as a two-year availability guarantee package. The problem in this phase is that the scope of the quotation is rarely what will stand in the contract. The contents of the spare part package will change according the scope. So the communication between capital project sales and the spare parts team should be efficient and work on both directions. In the meetings of criticality analysis, the presence of representative of customer company is desirable for accurate and customer specific analysis. The analysis can be done precisely only after the actual capital sales project contact is finalized. The extended spare parts list can be created using the CA-tool and the package can be sold as aftersales. This enables Valmet to see the spare parts packages as new possibility for growing business for Service department and not only as burden in the capital sales negotiations as it has been seen before. The guarantee package should be as small as it can be, still able to cover the guarantee time unexpected maintenance, so it gives some margin to price negotiations. If the customer will not purchase the guarantee package the two-year availability guarantee will not be hold. The purchase of the extended package is well-funded to customer and the contribution margin is significantly greater in the aftersales than in the side of the capital sales.

The CA-tool meets the required features and the results of the tool are accurate enough to create mentioned packages. There are still some weak points and room for further development for the tool. Possible improvements to be considered are:

- More options for fuel factor
- Customer profile options as a new factor
- More exponential scales for the criticality factors
- Sliding scales for the criticality factors
- New risk matrix for criticality factor risk level assessment
- More thorough validation of results
- Possibility for experts to do the analysis individually. The result of the analysis would be average of their answers

Development of this tool was limited to concern only spare parts of fluidized bed boilers. To use the tool with other type of boilers, some adjustments must be made (mainly with point scales and with fuel factor). During the guarantee time Valmet is responsible of all unplanned maintenance, so perhaps with this tool other factors effecting to fluent maintenance could be also evaluate and take in consideration. One problem, yet not solved, is

that some maintenance actions, for example welding unique pipes, needs a special professional worker. Should that be somehow taken into account evaluating anticipatory maintenance? How to lower risk of this kind?

5.3 Ideas for further research

During the study, the scope of the research was to be limited and some important factors was outlined from the study. Ideas for further research came up also in the pilot case meetings and Valmet's internal workshop meetings, which were held to develop the business of the spare parts packages.

Suggestions for further research:

- An automatic transfer of generic information of the spare parts from other databases, so there would not cost so much time on copying information
- Updating the so called "master lists", which are equipment specific spare parts lists supported by Valmet's technology units, so creation of entire spare part list of the boiler could be generated quickly by adding complete equipment spare part lists together
- To join together separate tools or actions, for example, criticality analysis and pricing, so it would lessen the number on separate tool to be used and yet again lessen the copying of information from tool to another. This also makes work more effective due more focused working with just one tool
- To enhance communication between Service department and Capital sales project, to lift the relevance of business of spare parts packages from being a burden to be profitable and significant business. Also to share information more and decide the division of responsibilities.
- To implement the criticality analysis tool into Capital sales project quotation creation phase. So Service department and the criticality analysis would be involved from the beginning
- To make pricing of the spare parts packages using value based pricing (instead of pricing based on historical data of earlier projects) to enhance profitability
- To collect exact information about failures and start big data approach for defining spare parts criticality in the future

For the case company it is also suggested to develop individual tool, from the grounds of this tool, for the other boiler products and go through a pilot project to generate new basic spare parts lists for all main boilers to be used as a ground for future projects. Some new lines into the boiler sales contract which could leave the exact content of the spare part package open for changes. It is also recommended to have more communication between customer and spare part team early in the sales phase (see Appendix G).

6 CONCLUSIONS

The main objectives of this Master's Thesis was to develop a criticality analysis tool to classify spare parts of the fluidized bed boiler according their criticality and implement the CA-tool into the Service department of the case company. This Thesis was made in order to gather required information to divide the spare part package into lean availability guarantee package (sold on the side of the boiler sales project) and into more profitable extended package (sold as aftersales).

The main results of this thesis are the new criticality analysis tool, complete analysis of pilot case spare part package and careful verification and validation for preparing the CA-tool to be implemented. The results are centralizing to gather knowledge to divide the spare part list into a guarantee package and an extended package. The CA-tool is limited to operate only with a fluidized bed boiler, but it is convertible to operate with other types of boilers as well.

The results of the tool are only usable when focusing on the classification level generated by the tool. The actual numeric points of the parts are not comparable inside the classification level limits, due the analysis is based on only sophisticated guesses of the group of experts. The research was successful as the CA-tool worked as was expected and it is planned to take into action in the future boiler sales projects. The distribution of the work should be shared to the whole personnel working with spare parts and the new tool should be applied from now on. The tool is not nearly perfect, and it is clear that it will be developed further to meet the actual needs of the sales and delivery projects. Pilot case analysis gave valuable information of the contents of the equipment specific "master" spare part lists. Future negotiations of development of the spare parts package business will no longer stand on guesses, but on the systematic expert analysis. During the verification and validation of the CA-tool successions and further improvements were detected. The interviews and meetings of the pilot case brought personnel of the Valmet's technology units, some suppliers and capital sales project closer together, which helps implementing future improvements.

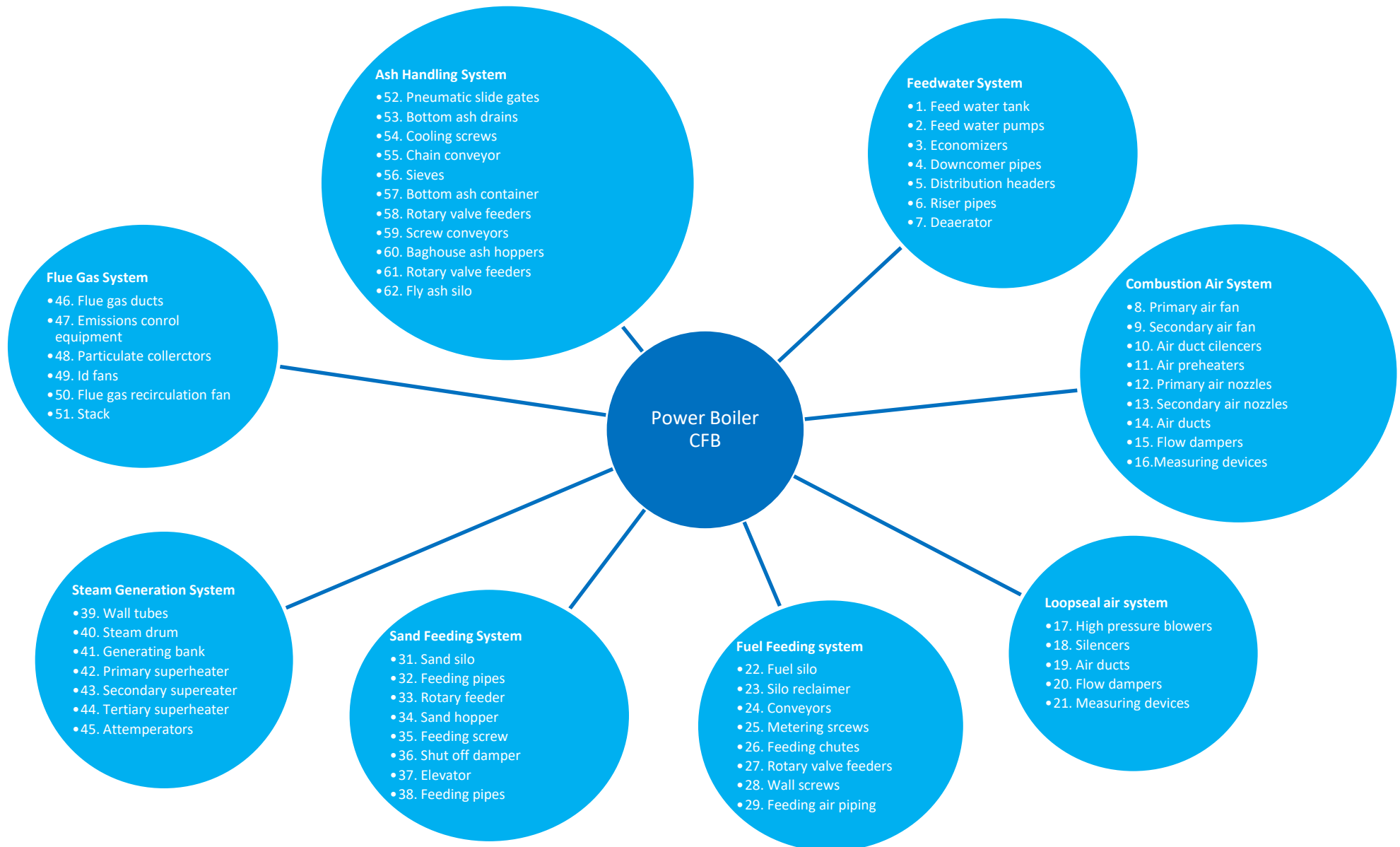
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APPENDIX A: CFB-Boiler's subsystems and main components



APPENDIX B: Interviews

Code	Titles	Date	Time	Place
IN1	Sales Engineer	Oct 30 th 2016	12:30-13:00	meeting room
IN2	Manager	Nov 4 th 2016	12:00-13:00	meeting room
IN3	Spare Part Engineer	Nov 16 th 2016	14:00-15:00	meeting room
IN4	Sales Engineer	Nov 18 th 2016	14:30-15:30	meeting room
IN5	Sales Engineer	Dec 2 nd 2016	09:30-10:30	meeting room
IN6	Project Manager (supplier)	Dec 15 th 2016	09:00-11:00	supplier's meeting room
IN7	Service and Spare Part Manager (supplier)	Jan 18 th 2017	11:00-16:00	supplier's meeting room

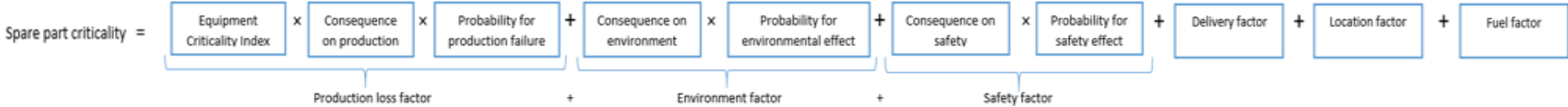
APPENDIX C: Meetings

Code	Titles	Date	Description
ME1	Manager, Spare Parts Sales Engineer, Spare Parts Subcontractor, Pulp & Energy Global Product Manager, Spare Parts	Apr. 2016– Sept.2016	Several meetings concerning the previous internal development project
ME2	Global Product Manager, Boiler Tech Chief Engineer, Mechanical Project Manager, Service Sales Engineer, Spare Parts	Nov 9 th 2016	Expert meeting to collect constructive feedback on developed CA-tool
ME3	Project Manager, Service Sales Engineer, Spare Parts Product Engineer, CFB Boilers Service Engineer, Service	Nov 30 th 2016	Expert meeting for pilot case criticality analysis
ME4	Product Engineer, Burners Product Engineer, E&I, Automation Field Service Engineer, Service Sales Engineer, Spare Parts Manager, Spare Parts	Jan 19 th 2017	Expert meeting for pilot case criticality analysis
ME5	Product Manager, Environmental Services Spare Part Engineer, Service	Feb 7 th 2017	Expert meeting for pilot case criticality analysis
ME6	Manager, Spare Parts	Feb 17 th 2017	Verification and validation meeting
ME7	Manager, Spare Parts Sales Engineer, Spare Parts Global Product Manager, Spare Parts Director, Energy Spare Parts	Mar 9 th 2017	Spare parts package business plan workshop
ME 8	Manager, Spare Parts Product Engineer Environmental Services	Mar 10 th 2017	Expert meeting for pilot case criticality analysis
ME9	Project Engineer, EI&C Product Manager, Instrumentation Product Manager, ES and service EI&C Sales Engineer	Mar 28 th 2017	Expert meeting for pilot case criticality analysis

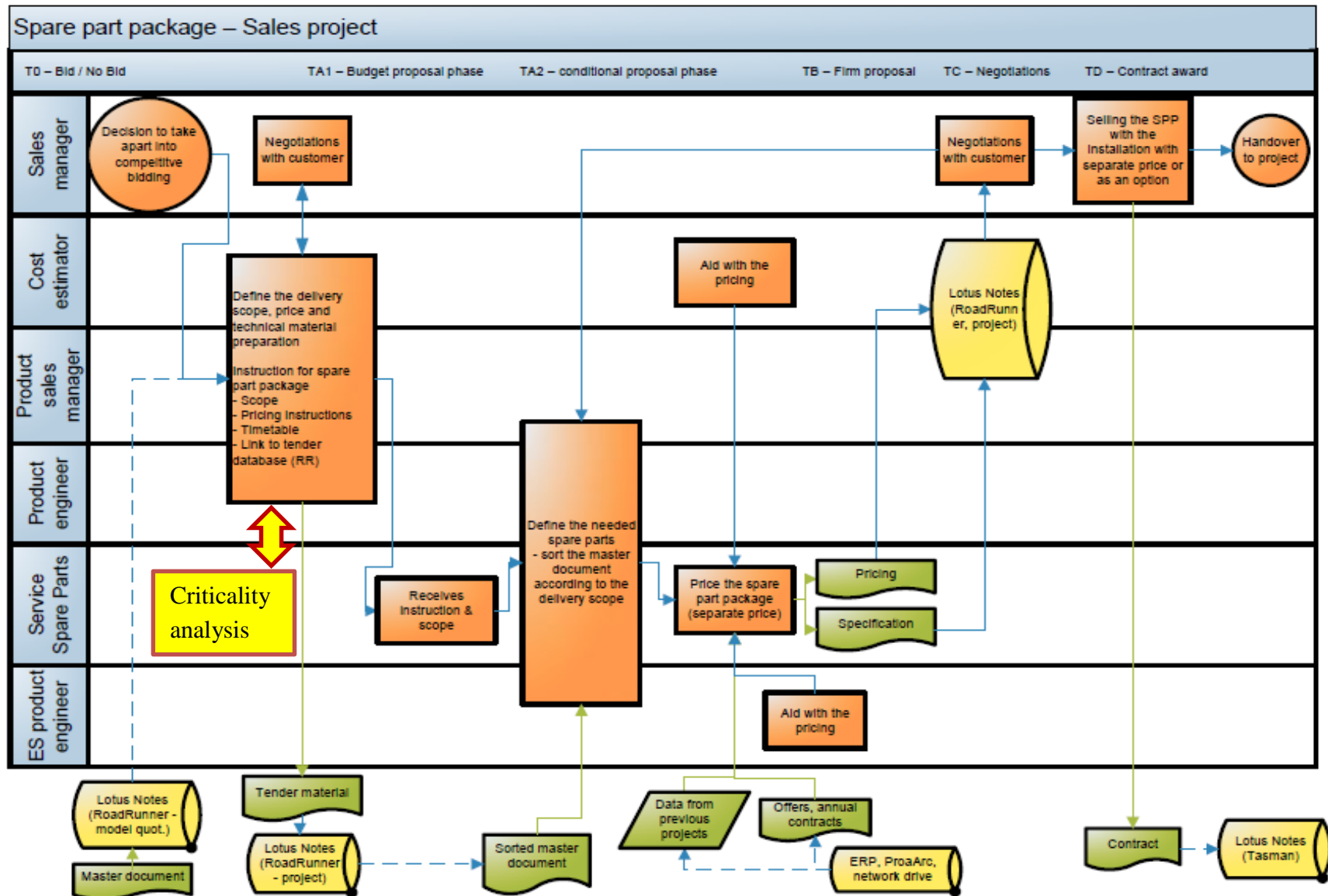
APPENDIX D: View of the analysis sheet of the criticality analysis tool

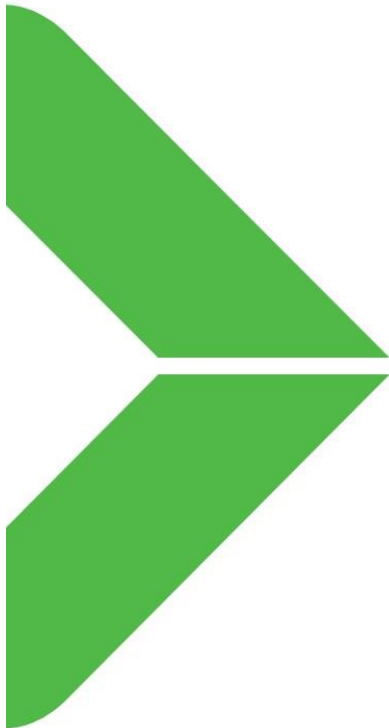
	Delivery factor	Production loss factor			Environment factor		Safety factor		Fuel factor
Criticality	Delivery time	Equipment criticality Index	Consequence on production	Probability for production failure	Consequence on environment	Probability for environmental effect	Consequence on safety	Probability for safety effect	Effect of fuel
III	50 = Part never in stock, delivery time very long	1,75 = Failure in systems will stop the Power Plant within hours	3 = Production stop < 1 week	4 = Likely (once per 1-2 years)	0 = No environmental impact	1 = Very unlikely (< once per 20 years)	0 = No effect on safety	1 = Very unlikely (< once per 20 years)	10 = Part in contact with fuel or ash caused semi erosive circumstances
III	50 = Part never in stock, delivery time very long	1,75 = Failure in systems will stop the Power Plant within hours	3 = Production stop < 1 week	2 = Unlikely (once per 5 - 10 years)	0 = No environmental impact	1 = Very unlikely (< once per 20 years)	0 = No effect on safety	1 = Very unlikely (< once per 20 years)	10 = Part in contact with fuel or ash caused semi erosive circumstances
II	20 = Part sometimes in stock, delivery time long	1,75 = Failure in systems will stop the Power Plant within hours	3 = Production stop < 1 week	2 = Unlikely (once per 5 - 10 years)	0 = No environmental impact	1 = Very unlikely (< once per 20 years)	0 = No effect on safety	1 = Very unlikely (< once per 20 years)	10 = Part in contact with fuel or ash caused semi erosive circumstances
I	1 = Part always available in stock	1,00 = Failure will not affect the operation of the Power Plant	1 = No effect to production	2 = Unlikely (once per 5 - 10 years)	0 = No environmental impact	1 = Very unlikely (< once per 20 years)	0 = No effect on safety	1 = Very unlikely (< once per 20 years)	5 = Part in contact with fuel or ash caused minor erosive circumstances
III	20 = Part sometimes in stock, delivery time long	1,75 = Failure in systems will stop the Power Plant within hours	3 = Production stop < 1 week	3 = Possible (once 2-5 years)	0 = No environmental impact	1 = Very unlikely (< once per 20 years)	2 = Medical treatment	1 = Very unlikely (< once per 20 years)	20 = Part in contact with fuel or ash caused very erosive circumstances
I	5 = Delivery time very short	1,00 = Failure will not affect the operation of the Power Plant	2 = Reduced production	2 = Unlikely (once per 5 - 10 years)	0 = No environmental impact	1 = Very unlikely (< once per 20 years)	2 = Medical treatment	3 = Possible (once 2-5 years)	0 = Part not in contact with fuel nor ash
II	20 = Part sometimes in stock, delivery time long	1,75 = Failure in systems will stop the Power Plant within hours	3 = Production stop < 1 week	2 = Unlikely (once per 5 - 10 years)	0 = No environmental impact	1 = Very unlikely (< once per 20 years)	2 = Medical treatment	3 = Possible (once 2-5 years)	10 = Part in contact with fuel or ash caused semi erosive circumstances
III	20 = Part sometimes in stock, delivery time long	1,75 = Failure in systems will stop the Power Plant within hours	3 = Production stop < 1 week	3 = Possible (once 2-5 years)	0 = No environmental impact	1 = Very unlikely (< once per 20 years)	0 = No effect on safety	1 = Very unlikely (< once per 20 years)	20 = Part in contact with fuel or ash caused very erosive circumstances

APPENDIX E: Criticality score equation graphical form



APPENDIX G: Flow chart of spare part package sales process (remodeled from source: [21])





Kriittisyysanalyysityökalun käyttöohjeet

22.3.2017

Versio 2.0

Pyry Rinkinen



Sisältö

- 1. Esitiedot**
- 2. Ohjeet analyysin tekemiseksi**
- 3. Tulokset**
- 4. Vinkit tehokkaaseen käyttämiseen**

1. Esitiedot

Työkalun käyttötarkoitus

- Tämän työkalun avulla määritetään voimakattilan varaosien kriittisyys
- Kriittisyysluokituksen avulla tuokalu muodostaa kaksi varaosapakettitarjoumaa käytettävyyystakuupaketin ja laajennetun varaosapakettin
- Työkalu luokittelee varaosalistan osat kolmeen kriittisyysluokkaan:
 - Luokka I, riskit hyväksyttävällä tasolla, osa kuuluu laajennettuun varaosapakettiin
 - Luokka II, riskit siedettävällä tasolla, osa kuuluu käytettävyyystakuupakettiin
 - Luokka III, riskit sietämättömällä tasolla, osa kuuluu käytettävyyystakuupakettiin

1. Esitiedot

Työkalun rakenne

- Työkalu on rakennettu käytettäväksi excel-ohjelmassa
- Työkalu koostuu neljästä välilehdestä:
 - Analyysivälilehdellä tehdään varsinainen kriittisyysanalyysi
 - Output-välilehdelle listautuu analyysin tulokset
 - Criteria-välilehdellä on analyysin kriittisyystekijöiden vaihtoehdot ja arvot
 - Instructions-välilehdellä on työkalun ymmärtämistä ja analyysin tekemistä helpottavia ohjeita
- Analyysivälilehti ja Criteria-välilehti on käyttäjän muokattavissa

1. Esitiedot

Analyysivälilehden rakenne

- Koostuu kolmesta osiosta:
 - Sarakkeet A-Q sisältävät varaosien tärkeimmät yleiset tiedot
 - Sarakkeet R-AO sisältävät kriittisyysanalyysin
 - Sarakkeet AP-EN sisältävät osan lisätietoja
- Analyysin kriittisyystekijöiden tarkat selitykset löytyvät Lisätiedot liitteestä (*Additional information for instructions of CA-tool*)
- Sarakkeella H näkyy osan kriittisyyspisteet
- Sarakkeella I näkyy osan kriittisyysluokka
- Kriittisyystekijän jälkeisessä solussa on tekijän riskipisteet
- Rivit 1-5 sisältävät myyntiprojektin tiedot
- Riviltä 7 alkaa varaosalista
- Kullakin rivillä on yhden osan tiedot, lukuun otamatta otsikkorivejä

1. Esitiedot

Criteria-välilehden rakenne

- Sarakkeessa A ovat työkalun osat ja kriittisyystekijät
- Sarakkeessa B ovat riski- ja kriittisyysluokat
- Sarakkeessa C ovat riski- ja kriittisyysluokkien selitykset
- Sarakkeessa D ovat kriittisyysluokkien ja -tekijöiden arvot
- Sarakkeessa E ovat lisämerkinnät

2. Ohjeet analyysin tekemiseksi

Aloituis

- 1) Täytä projektin tiedot analyysisivun vasempaan yläkulmaan
- 2) Kopioi ja liitä analysoitava varaosalista analyysisivulle (Huomaa listan rakenne)

A	B	C	D	E	F
1	Project name:	KILPILÄHTI POWER PLANT LTD			
2	Project number:				
3	Mill ID:				
4	Boiler manufacture ID:				
5	Country:	Swami	Location factor:	1	
6	Equipment	Item description	System	KK	Description
7	1.1 Tubex				
8	2	Tube of furnace wall	BOILER PRESSURE PARTS		Tubex
9	3	Tube of secondary wall	BOILER PRESSURE PARTS		Tubex
10	4	Tube of primary superheater	BOILER PRESSURE PARTS		Tubex
11	5	Tube of primary 2 superheater	BOILER PRESSURE PARTS		Tubex
12	6	Tube of secondary superheater	BOILER PRESSURE PARTS		Tubex
13	7	Tube of tertiary superheater	BOILER PRESSURE PARTS		Tubex
14	8	Economizer tube, plain	BOILER PRESSURE PARTS		Tubex

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2. Ohjeet analyysin tekemiseksi

- 3) Valitse Location factor:lle (solu D5) arvo alusvetolaatikosta. Vaihtoehdot ilmestyvät painamalla solun vieressä olevaa nuolta.
- 4) Määritä kriittisyystekijöiden painokertoimet Criteria välilehdeltä (Solut D55-D61)

Location factor	
1 = Short distance, easy to deliver (< 3 day)	1
50 = Long distance, hard to deliver (> 45)	
20 = Long distance, easy to deliver (> 30)	
10 = Short distance, hard to deliver (> 3)	
1 = Short distance, easy to deliver (< 3)	

Production	5
Safety	2
Environment	2
Fuel	1
Delivery	1
Location	1

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2. Ohjeet analyysin tekemiseksi

Delivery Factor

- 5) Valitse analysoitavan osan Delivery factor:lle (sarake R) arvo alasvetolaatikosta. Vaihtoehdot ilmestyvät painamalla solun vieressä olevaa nuolta.

Delivery factor	
Delivery time	
20 = Part sometimes in stock, delivery time long	20
50 = Part never in stock, delivery time very long	20
20 = Part sometimes in stock, delivery time long	20
10 = Part sometimes in stock, delivery time short	20
5 = Delivery time very short	20
1 = Part always available in stock	20

2. Ohjeet analyysin tekemiseksi

Production Loss Factor

Equipment criticality Index

- 6) Valitse laitteen kriittisyys alasvetolaatikosta

Consequence on production

- 7) Valitse osan rikkoutumisen seuraus tuotannolle

Probability for production failure

- 8) Valitse todennäköisyys tuotantovaikutukselle

Equipment criticality Index	Consequence on production	Probability for production failure	RPI
1,75 = Failure in systems will stop the Power Plant within hours	3 = Production stop less than 3 days	4 = Likely (once per 1-2 years)	
2,00 = Failure in system will immediately stop the entire Power Plant	5 = Production stop more than a week	5 = Very likely (1 once per year)	10
1,75 = Failure in systems will stop the Power Plant within hours	4 = Production stop less than a week	4 = Likely (once per 1-2 years)	10
1,25 = Failure in systems will affect only to secondary auxiliary systems	3 = Production stop less than 3 days	3 = Possible (once 2-5 years)	
1,00 = Failure will not affect the operation of the Power Plant	2 = Reduced production	2 = Unlikely (once per 5-10 years)	
	1 = No effect to production	1 = Very unlikely (1 once per 20 years)	

Huom. Todennäköisyys eri kuin vikaantumisväli

2. Ohjeet analyysin tekemiseksi

Environment Factor

Consequence on environment

- 9) Valitse osan rikkoutumisen seuraus ympäristölle

Consequence on environment	
0 = No environmental impact	1
5 = Serious off-site environmental impact	5
4 = Significant off-site environmental impact	4
3 = Some local environmental impact	3
2 = Minor environmental impact	2
0 = No environmental impact	0

Probability for environmental effect

- 10) Valitse todennäköisyys ympäristövaikutukselle

Probability for environmental effect	RP
1 = Very unlikely (< once per 20 years)	1
5 = Very likely (> once per year)	5
4 = Likely (once per 1-2 years)	4
3 = Possible (once 2-5 years)	3
2 = Unlikely (once per 5 - 10 years)	2
1 = Very unlikely (< once per 20 years)	1

Huom. Todennäköisyys eri kuin vikaantumisväli

2. Ohjeet analyysin tekemiseksi

Safety Factor

Consequence on safety

- 11) Valitse osan rikkoutumisen seuraus ihmisten turvallisuudelle

Consequence on safety	
0 = No effect on safety	1
5 = Fatality	5
4 = Serious injury or illness with permanent disablement	4
3 = Significant injury or illness with sick leave	3
2 = Medical treatment	2
0 = No effect on safety	0

Probability for safety effect

- 12) Valitse todennäköisyys turvallisuusvaikutukselle

Probability for safety effect	RP
1 = Very unlikely (< once per 20 years)	1
5 = Very likely (> once per year)	5
4 = Likely (once per 1-2 years)	4
3 = Possible (once 2-5 years)	3
2 = Unlikely (once per 5 - 10 years)	2
1 = Very unlikely (< once per 20 years)	1

Huom. Todennäköisyys eri kuin vikaantumisväli

2. Ohjeet analyysin tekemiseksi

Fuel Factor

13) Valitse polttoaineen vaikutus osan kulumiselle

Fuel factor	
Effect of fuel	
10 = Part in contact with fuel or ash caused semi erosive circumstances	
20 = Part in contact with fuel or ash caused very erosive circumstance:	
10 = Part in contact with fuel or ash caused semi erosive circumstance:	
5 = Part in contact with fuel or ash caused minor erosive circumstance	
0 = Part not in contact with fuel nor ash	

3. Tulokset

- Tulokset on luettavissa analyysivälilehdeltä sekä output-välilehdeltä
- Välitulokset(RPN-luvut) ovat esillä, jotta nopealla silmäyksellä on nähtävissä mistä tekijöistä osan kriittisyys koostuu

4. Tehokkaan käytön vinkit

- Analyysi tehdään useissa pienissä palaverissa, jossa on läsnä analysoitavien osien teknologiasta vastaavia asiantuntijoita
- Työkalun käyttöä tehostaa monesti analysoida tietyn laitteen kaikki osat yksi kriittisyystekijä kerrallaan
- Palaverit nauhoitetaan, jotta asiantuntijoiden vastauksiin voi palata myöhemmin ja osaltaan myös täyttää työkalua jälkikäteen
- Tarvittaessa työkalun kriittisyystekijöiden valintoja voi kopioida ja liittää toisien osien analyysiin