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Spare parts optimization solution and its integration requirements for Outotec

Thesis 2013

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Abstract

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This thesis is a research on the integration requirements on a storage optimizing software called StockOptim, provided by a reliability-engineering company Ramentor. This thesis was made with a Finnish mining and metallurgy company called Outotec (Finland) Oy, from September 2012 to February 2013.

This thesis researches the usability of the software and the usefulness of the results for Outotec purposes. The information architecture of Outotec is examined, and the basic guidelines for information systems are analyzed, which would support the use of StockOptim. The communication between ELMAS, an event logic modelling software by Ramentor, is also examined in this thesis.

A model for an optimized spare part plan was created in this thesis. The optimized spare part plan will focus on the spare parts for four PF60 filters. An optimized spare part plan will provide the user with excellent cost-availability-rate on warehousing, while also maintaining the spare part availability level high. Being able to provide customers with optimized spare part plans is a business advantage for Outotec.

Keywords: Spare part optimization, availability, system integration

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Tämä opinnäytetyö selvittää varaosaoptimointisovellus StockOptimin integraatiovaatimuksia kaivos- ja metalliteollisuuden alan teknologiayritykselle, Outotec (Finland) Oy:lle. StockOptim on tamperelaisen luotettavuuskeskeiseen kunnossapitoon keskittyneen yhtiön, nimeltä Ramentor, tuote. Opinnäytetyö tehtiin yhteistyössä Outotecin kanssa syyskuun 2012 ja helmikuun 2013 välisenä aikana.

Tämä opinnäytetyö käsittelee ohjelman käytettävyyttä sekä hyödyllisyyttä Outotecin näkökulmasta. Outotecin järjestelmäarkkitehtuuria käsitellään tässä opinnäytetyössä ja suuntaviivat myös määritellään, jotka tukisivat StockOptimin käyttöä. Ramentorin valmistama ELMASin, tapahtumalogiikan analysointi ja mallinnusohjelman, kommunikaatiota StockOptimin kanssa tarkastellaan myös tässä opinnäytetyössä.

Opinnäytetyössä luotiin malli optimoidulle varaosasuunnitelmalle. Optimoitu varaosasuunnitelma luotiin neljälle PF60-suodattimelle.Optimoitu varaosasuunnitelma tarjoaa käyttäjälleen erittäin hyvän hinta-palvelutaso-suhteen varastointiin, samalla säilyttäen varaosasaatavuuden korkealla. Optimoidun varaosasuunnitelman tarjoaminen asiakkaille on Outotecille suuri kilpailuvaltti.

Asiasanat: varaosa-optimointi, käytettävyys, järjestelmäintegraatio

Abbreviations

APM	Asset performance measurement
EAM	Enterprise asset management
ERP	Enterprise resource planning
SCM	Supply chain management
RCM	Reliability centered maintenance
FMEA	Failure mode and effect analysis
MTTR	Mean time to repair
MTTF	Mean time to failure
MTBF	Mean time between failures
PF	Pressure filter
CM	Condition monitoring
PM	Preventive maintenance
SC	Service center
SPC	Service product center
R	Reliability
A	Availability
M	Maintainability
TLT	Total lacking time
LT	Lacking time
IT	Information technology
Acc.	Accumulated

1 Introduction

1.1 Objectives of the thesis

The objectives of this thesis are to create an optimized spare part plan for four Outotec Larox 60-series pressure filters of the Outotec Filtration Plant. The criticality analysis done preceding the optimization was done with an event logic modeling software ELMAS. The integration requirements for storage optimization solution are also gathered in this thesis. The spare part plan will emphasize the most critical fault modes of the PF60 filters, especially those which cause equipment shutdown and thus production loss. Preventive maintenance spare parts requirements also need to be incorporated to the same optimized spare part plan.

Outotec is known to compete with quality, and by applying the best practices into use, to serve its customers. Having a good understanding of the behavior of assets, gives Outotec a solid foundation to build its business upon.

When determining the need for spare parts, the results gathered from the RAM-analysis done for the Filtration Plant are examined. RAM-analysis identifies elements of an asset or a process, whose failure affects the reliability, availability or maintainability of the asset. By focusing spare part availability and maintenance for the most critical elements, the availability of assets should rise.

The information imported and exported from storage optimizing software StockOptim and its format needs to be inspected, so in the end the best way for this software to communicate with the existing IT systems of Outotec can be determined. The results of the optimization process are inspected to determine the scope on how the results can be used.

The user experience of the storage optimization software StockOptim will be reviewed in this thesis. Determining the requirements on using the software is evaluated, since it is important to define what it takes to use StockOptim. Once these objectives are covered, the future scenarios for StockOptim are evaluated.

1.2 Outotec

Outotec is a Finnish company that specializes in the metal and mineral processing industry, and the head office is in Espoo. Outotec focuses on providing and producing machines and required technology to mine and separate minerals from earth, and use them in a nature preserving fashion. The motto and general guideline of Outotec is “Sustainable use of earth’s natural resources”. (Outotec homepage 2013, About us)

Outokumpu Oyj, a large metal industry company from Finland, was formed in 1910. A large copper ore deposit found in Eastern Finland was one of the main reasons for starting Outokumpu. Outokumpu originally developed sophisticated processing and production methods, leading the company towards rapid growth. One major event in the history of Outokumpu was in 2001, when merging with Avesta Sheffield, making Outokumpu the third largest stainless steel producing company in the world.

In 2007 a separate company was formed out of their technology division, called Outokumpu Technology Oyj. The majority of the stocks, 80 % that is, was sold to foreign investors. In 2006 Outokumpu Technology listed themselves in the Helsinki Stock Exchange, changing their name to Outotec Oyj. (Outotec homepage 2013, History)

In figures, the sales of Outotec in 2012 amounted to EUR 2 087,4 million, operating profit at EUR 193,8 million, and number of employees was close to 4000. Outotec has branches in almost 30 countries, so it can be considered as an international business enterprise.

The personnel headcount has almost doubled within the last two years, so the growth of the company has truly intensified. The growth has been largest especially in the Service market area, for which this thesis was done. (Outotec homepage, Financial Statements 2012)

1.3 Ramentor

Ramentor is a software company that was founded in 2006 and their main office is in Tampere, Finland. Ramentor provides maintenance planning software, training and consultation on RAM-methodology. The goal of Ramentor is to be the best designer of reliability and availability planning tools on the market, and to combine the latest theories into practice.

Ramentor’s customers are both small entrepreneurs and large business enterprises from various branches of technology and industry. Some examples of the companies Ramentor has worked with are YIT, Outotec, Efora and Nokia. The communication between two reliability planning softwares are researched and in this thesis; Event logic modeling tool ELMAS, and storage optimizing software StockOptim. (Ramentor website, Company, 2013)

Outotec has been using the Ramentor event logic modeling tool for some years now for criticality analysis and for improving reliability, maintainability and availability of assets. ELMAS event logic modeling can be used with the storage optimization software StockOptim, in the case that the consumption data of the spare parts does not exist.

1.31 ELMAS - Event Logic Modeling and Analysis Software

ELMAS is an event logic modeling and analysis tool, which can be used to model a large variety of different processes. ELMAS is used to evaluate different assets and stages of a process, to identify possible weak spots and to estimate the reliability of the process as a whole. ELMAS can be used to create a Fault tree, Cause tree, Cause-Consequence tree, Block Diagram or a 2-level process diagram.

ELMAS will be able to estimate the most likely fault modes, and thus it gives the user some insight, on where to focus on maintenance operations. Quite often it is found out, that a small part of the process causes most of the shutdowns. With simple modifications and by altering the process, e.g. equipment duplication, it is easy to improve the availability. By providing ELMAS with the financial values, the financial gains and losses can be seen. (Ramentor website 2013, Products, ELMAS)

Information needed for ELMAS Fault tree analysis:

- Asset information broken down to a single fault
- MTTR information
- MTTF information
- Financial figures (e.g. production loss per hour)
- Cost of plant shutdown (production loss per hour)
- Cost of maintenance (maintenance personnel costs)

Figure 1 presents an example of an ELMAS Block Diagram. This is the actual block diagram which was created to model the behavior of the Outotec Filtration Plant, which is inspected in this thesis. The arrows point to the direction of the process flow and each green box consists of a system entity, which holds up all possible failure modes for each device (Figure 2).

The block diagram starts with slurry entering the *Slurry screen,* after which it goes to the *Slurry feed,* which pumps the slurry to the filters. The four green boxes, or nodes, titled 5, 6, 7 and 8 represent the four filters on the Filtration Plant. After the filtration, the end result – *cake* – is dropped on to the conveyor, which delivers it to be transported. This block diagram is presented in figure 1. More extensive information of the filtration process is given in chapter 4.

As an example of reading the Figure 1, one may inspect the failure of the Slurry feed tank. It is the only node to continue the process flow, and if it fails, the entire process stops. However if one of the filters fails, the capacity of the process is lowered. The amount of how much the capacity is lowered can be determined in the node settings. Different terms can be assigned for each relation, but as a demonstration this is one way to present the process flow of the PF plant. As a conclusion, Slurry feed tank and Cake discharge unit are highly critical devices.

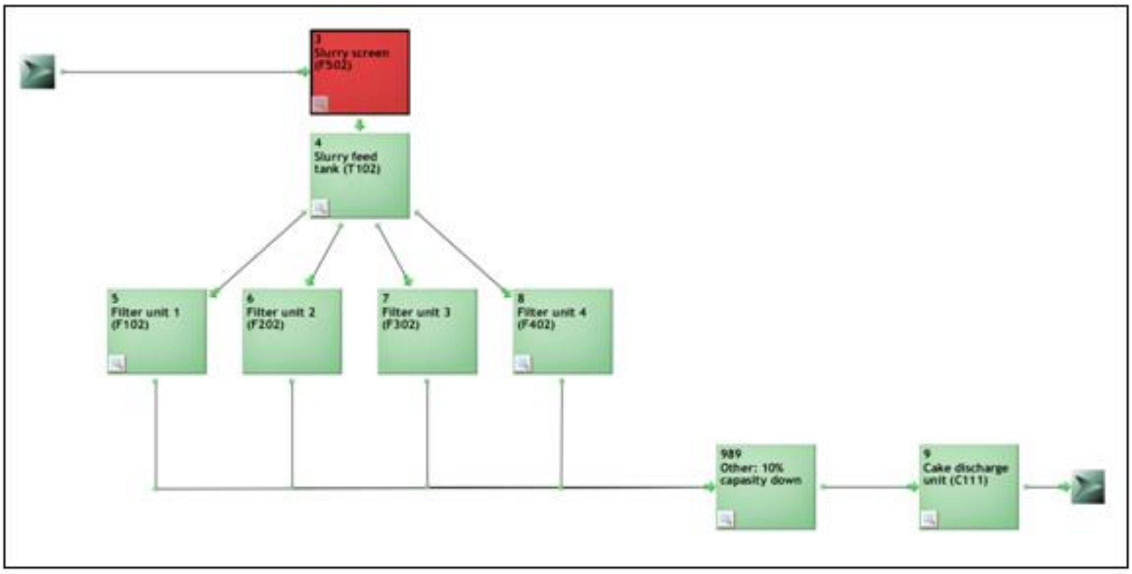


Figure 1. ELMAS Block Diagram

The nodes of the block diagram open up to the *Fault Tree*, which demonstrates the single failure modes of the process. Figure 2 represents an example of a Fault Tree. The Fault tree breaks down the asset hierarchy into single failure modes. A failure mode is a single way an asset can fail.

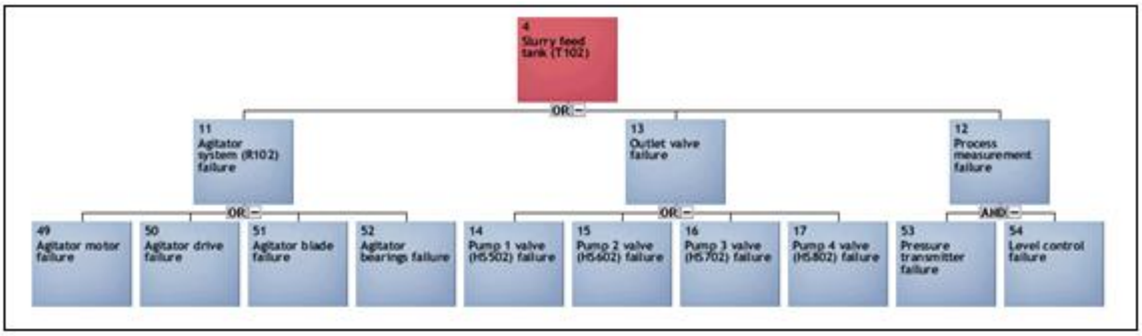


Figure 2. Fault tree

ELMAS results, which include e.g. the availability times, production losses and maintenance personnel estimations can be exported to an Excel spreadsheet, or to an HTML-file. These failure modes are also used to model the behavior of spare part consumption, as will be explained in chapter 5.4.1.

1.3.2 StockOptim - Minimized Stock Levels and Improved Availability

StockOptim is a spare parts optimizing software, that strives to give the customer the optimum warehouse conditions. Calculating the optimized re-order point and amounts are useful tools for storage planners, since they can be directly implemented to warehouse plan. StockOptim can be used to simulate the behavior of different warehouse scenarios, if the supply chain has not been planned yet. Results on the prices vs. spare part availability can be calculated from the results.

StockOptim estimates the optimum storage levels by using a complex mathematical algorithm, which follows the values given. One important thing to remember is the emphasis on the validity of the initial data. If the values provided are far from realistic, the optimized results will not be useful. (Ramentor website; Solutions, Mass optimization)

A challenge for many companies is to have proper, recorded history of asset behavior, which could be used for research, such as StockOptim optimization. The consumption history of the spare parts is needed however, since it is the foundation for the optimization. If the spare part history is not documented, or it does not exist, it can be created with ELMAS, since the software is capable of simulating the behavior of the assets.

One part of the results of the optimization is the potential risks involved with warehousing. StockOptim tells the user the duration, behavior and character of the lacking times that will appear during the simulated time period. Lacking time (LT) means a period of time when the spare part is being waited for.

StockOptim is made with Java code, and the first version was published in 2005. A project sharing service has been created to StockOptim, which allows different users to compare their projects together. (Ramentor website; Products, StockOptim, 2013)

2 Applied theory

2.1 Maintenance terminology

Maintenance means keeping assets in the condition in which they can be completely utilized. Every device, plant or structure needs some sort of upkeep; which can be from simple cleaning all the way to a full-on time-based maintenance plan. Running assets to failure can cause secondary damages, which can wreck several other components from the asset. Production losses can also be expected, if the asset has to be overhauled. Well executed maintenance is also an environmental and health and safety issue as well. Production should never be made on the expense of risking people's health, or the environments. (Moubray, 2007, p.130)

When dealing with customers and signing industrial contracts, some information of the reliability, availability and maintainability of assets are crucial to have. The customer must know how much production he can expect. Total availability is the figure which the customer is interested in, and it consists of mechanical and spare part availability, and of course reliability. Calculating these values has a lot to do with in terms of MTBF (mean time between failures) and MTTR (mean time to repair), as Figure 3 presents.

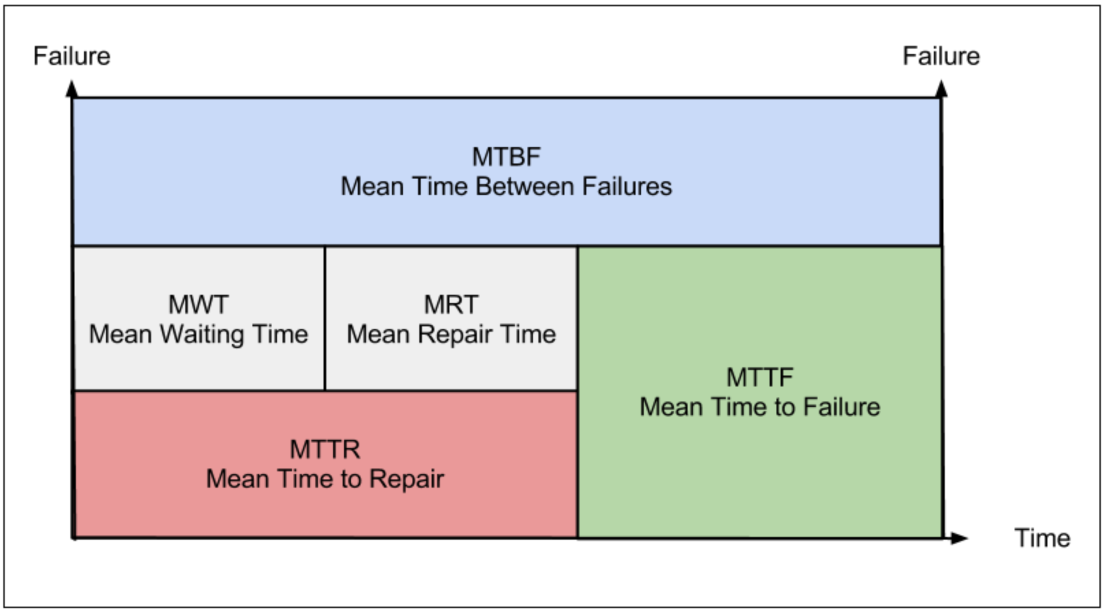


Figure 3. MTBF definition

MTTF (Mean Time to Failure) is the term used to describe the average time, in which the asset is fixed, until it breaks down again. MTTF is the average time of TTF's (Time to Failures) combined. MTBF presents the time elapsed from the point a failure mode appears, until it is fixed, and when it appears again. (Relex reliability articles 2009)

Figure 3 breaks downtime into MWT (Mean Waiting Time) and MRT (Mean Repair Time). Mean waiting time is the time when the fault is diagnosed, maintenance personnel are in place and spare parts are available. MRT is the time it takes to repair the asset, put it back to use and perhaps with some testing done too. The combined time of all MWT's and MRT's is written down as MTTR. (Moubray, 2007, p.76)

Reliability means that assets will perform in the intended way, with proper use in good conditions for a specific amount of time. When the asset fails to perform its intended function, which means shutting down, reduction of quality, causing safety or environmental hazards, we observe failures. (Reliability engineering slide show, slide 4)

Mechanical availability means the probability, that an asset is in use or ready to be used. Planned maintenance overhauls are taken into notice when talking about availability. The formula to calculate availability (A) is:

$$\mathrm{A} = \frac{MTTF}{MTTF + MTTR} \qquad (1)$$

Total availability tells us the amount of time, when the filter is ready to be used from the planned uptime. This means that preventive maintenance procedures do not decrease availability, even though they reduce complete uptime. When calculating total availability with Ramentor tools, we can have the estimated times for unplanned shutdowns per year in StockOptim results. When this figure is added to the "total lacking time" value from StockOptim results, we will have the unplanned downtime per year – in other words when the filter is not functioning as it should. "Total lacking time" means the total amount of the time when we are waiting for the spare parts per year. When that figure is reversed, we will have the total availability. (Joel Turpela, meeting)

In this thesis, the terms *Brownfield* and *Greenfield* are also mentioned. Outotec's customers can be those who already have a site up and running, or those which need a site to be built. Brownfield scenario is the situation where Outotec's services are provided to a process, which is already operating. In a Greenfield case, the site is built entirely or partly by Outotec, and possibly also operated and maintained. In Brownfield scenarios, history data already usually exists, e.g. on the spare part consumption.

In Greenfield scenarios the data of the behavior of the assets does not even exist, so estimations are done by specialists, which present how the plant or facility will behave in the coming years. This thesis is also based on such estimations, since there is no operational Filtration plant, and thus no operational history.

2.2 Failure behavior of assets

Recognizing the way assets behave is important, since it can prepare the users to plan the maintenance and use effectively. Failure behavior scenarios for assets can vary slightly, but when inspected widely, they will have many similarities. Six scenarios have been recognized as the typical failure patterns and they are listed in Figure 4. These patterns are also briefly described in this chapter. The X-axis presents time, and the Y-axis the probability of a failure.

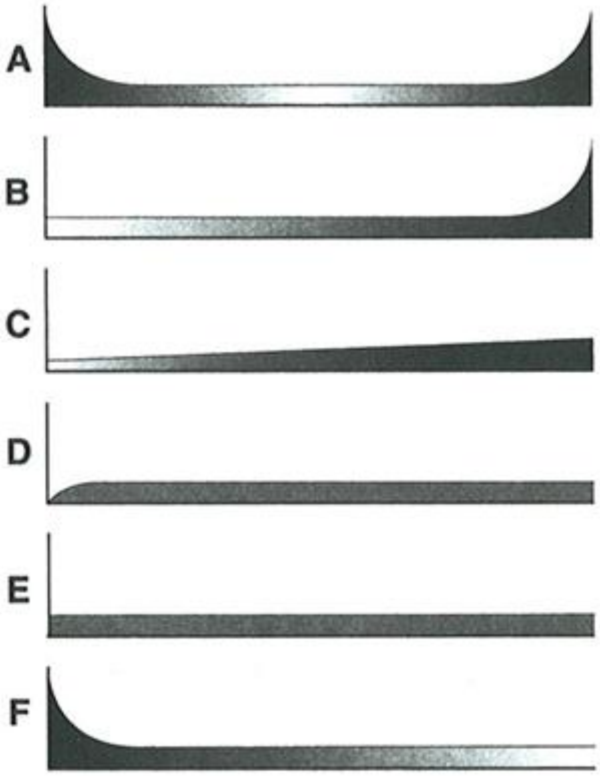


Figure 12.1: Six patterns of failure

Figure 4. Six patterns of failure

Pattern A is basically a combination of patterns A and F. A great deal of failures occur at the start and begin to reappear towards the end.

Pattern B presents a failure curve for an asset that wears out over time. There might be differences on the starting times when reaching the wear-out zone, but the important fact is that there is a significant amount of failures towards the end.

Pattern C is a behavior where the probability of failure increases steadily over time. Decent predictions can be made for the lifecycle of these sorts of components, for they are quite stress-tolerant. Differences between components always occur, so this should be seen as general guideline.

Pattern D illustrates how assets' probability of failure rises within the early stages of their lifecycle, but tend to even out after a while. After this, the failures happen on a random basis.

Pattern E reflects the possibility of a failure being constantly random, though the survival curve for a single asset also drops down within age. Even though a MTBF is hard to estimate for these parts, a rule-of-thumb has been made which states that if 63% of the parts have broken down roughly by the halfway of the time cap, then the result is the MTBF.

Pattern F is the most common of the failure patterns, which is rather interesting, since the probability of failure seems to lower when the asset ages. Common term for this is *infant mortality,* which means a lot failures occurring close to the start-up of the asset.

Reasons for pattern F can be that the asset is poorly designed, wrong materials have been used, incorrect installations have been made, and operating has been done wrong or that the craftsmanship of work has been at a low quality. There are many reasons for occurrences, and only some of them are mentioned in this thesis. Usually, they are once-off corrections, which have to do with design errors, more than maintenance errors. Thorough analyses should be made for every asset, e.g. by using RCM. (Moubray, 2007, p. 235-249)

2.3 Warehouse basics

A warehouse is a temporary storage place for goods, products of e.g. spare parts to be delivered soon. Since the economy and demand is always rather unpredictable, keeping a small excess inventory in case of unexpected consumption is a wise consideration. The inventory must not be too large though, since it will bind vast capital in short time. Every spare part stored is tied to the company’s balance sheet and will decrease in value annually. Determining the proper storage levels is a difficult task, but fortunately there are some ways to manage this problem. One of them is storage optimization. (Richards 2011, p. 14-17)

The basic idea of storage optimization is to serve with maximum spare part availability, with minimum costs. Keeping storage level high pleases the operators, but always comes with a cost. Without a clear realization of the frequency in which spare parts will be used, warehouses would most likely end up stockpiling parts that might never be even used. Having to dispose of big quantities of material is expensive and environmentally hazardous. (Ramentor website 2013, StockOptim)

There are also other drawbacks for a large and uncontrolled warehouse, some of which are increased labor costs, increased storage density, lowered pick rate and accuracy and increased inventory holding costs. (Richards 2011, p. 2)

An ideal situation would be that every part that is in the warehouse gets picked up eventually - this is where storage optimization comes into use. Discovering the optimal service level for storage ensures that plants' production proceed uninterrupted, without excessive costs from warehousing. Being able to predict the optimum storage levels is attractive to the customer, since it reduces the chance of over-selling of spare parts. Giving the optimum amount of parts also re-ensures the customer, that Outotec has extensive knowledge of its technologies.

Large and expensive components bring about challenges for a large part of the warehouse planning. Storing an expensive component in order to minimize downtime is a justified decision, but with it comes another question. If the spare part is expected to be needed after five years then, can the spare part be bought rather after two or three years? Keeping it in stock is expensive, and since it can be assumed that the spare part will not fail in the first few years, ordering it later on can be seen as a smart decision.

The spare parts of an Outotec PF60 filter are divided into 5 classes in Figure 5. It represents how the costs are divided amongst all of the spare parts on the PF60-filter. The categorization is derived from a logarithmic basis, and where class 1 is the most expensive spare parts and class 5 the cheapest.

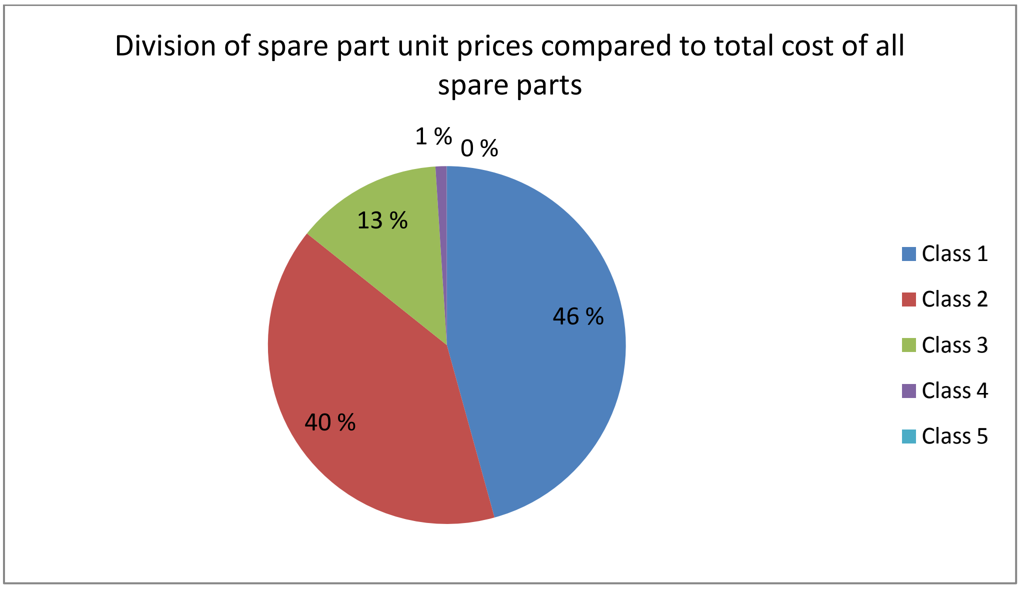


Figure 5. Division of spare part unit prices compared to the total cost of all spare parts

3 Outotec IT Systems

For companies as large as Outotec, several information systems are used to store the information relating to this thesis. Versatility of information is a large issue, since most of the information must be in an utilizable form for further researches and architectural expansions. StockOptim and ELMAS can benefit from information available for importing in a specific form; otherwise consultation from asset experts is needed in performing of the criticality analysis and storage optimization. Consulting the specialist’s binds work force of at least two employees, thus it is also quite expensive, and does not support stock optimization as a service.

Information flexibility is an important issue in modern IT systems, since it allows organizations to respond to new market conditions, and provide future integration platform for new software, such as Ramentor tools. The information systems used in this thesis are presented in this chapter, and their suitability is evaluated. (Information, Flexibility, and Competition - IESE Blog Community)

Enterprise Resource Planning (ERP) is the most important IT system concerning this thesis, since it currently holds all the spare part data. The role of the data holder is vital, since it is one of the main integration links to StockOptim. In future, Product Data Management (PDM) is designed to be the master data holder, but at the moment the information still is stored in ERP. Outotec IFS (used by Outotec Filter Oy) is the ERP used in this thesis, and it is used to collect the spare part prices information.

ERP is used to manage all the business processes in a single, integrated system. In the book *ERP Systems,* J. Manetti describes ERP as a method for effective planning and control of all resources needed to take, make, ship and account for customer order. ERP also holds the contract information on customers, along with all the necessary financial data. (Srivastava, Batra 2010, p.10 & 2)

ERP consists of different modules, and can be immensely large. The IFS system which Outotec (Filters) uses consists of the following modules:

Finance, Manufacturing, Projects, Service management, Spare parts, Warehouse and Inventory. IFS also holds the spare part prices.

Outotec (Filters) uses Aton as their PDM system, which contains the manufacturing data of the spare parts produced in Lappeenranta. Gathering the information from two systems caused some additional work, since the ones who use Aton and have knowledge on filters, did not know how to work with IFS. Two separate professionals were thus consulted when gathering this data. A global PDM should hold all of the spare part and asset data, including prices, and asset hierarchy which Outotec has. Asset hierarchy is the technical structure of devices, which is often presented in CAD-software. In future, this would be the IT system which would provide StockOptim with the spare parts to be handled, via EAM.

Figure 6 is a demonstration of how different information systems will co-operate, if StockOptim is taken into use, and a landscape of how the systems should work together in the future. (Mikko Tepponen, meeting)

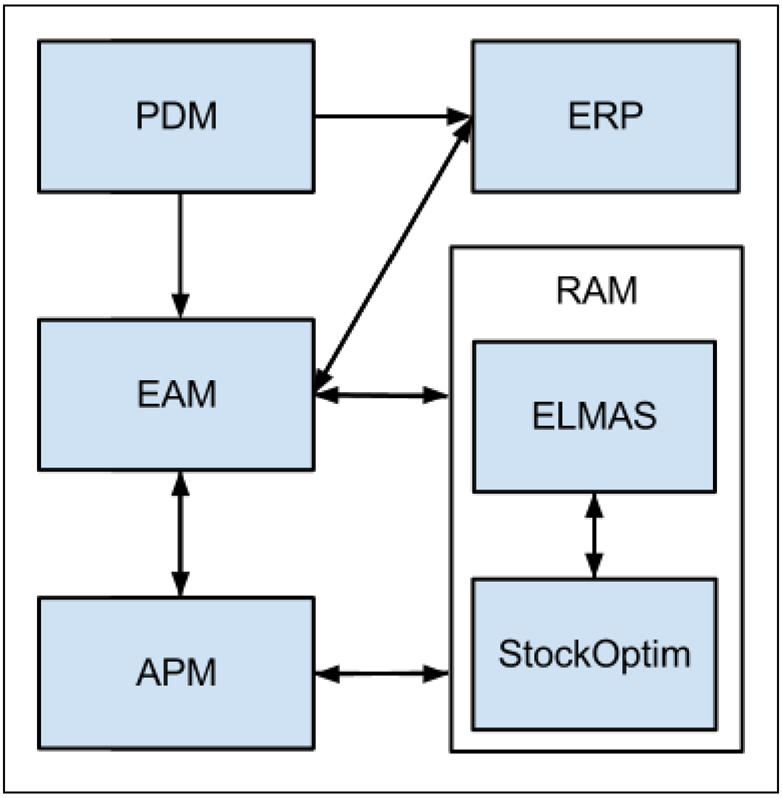


Figure 6. IT systems landscape

Enterprise Asset Management (EAM) is the IT system used for daily maintenance management. Tasks for maintenance procedures, or so called *Work Orders,* are delivered through EAM. It is also the log onto which performed tasks are written down when completed. Preventive maintenance plans can be imported into EAM systems, and they are scheduled through this system as well. EAM should hold all the failure modes for assets.

EAM sends ERP purchase requests of spare parts to be bought, in case a spare part is needed, and it is not in stock. ERP replies for EAM with a purchase order, which means that the order is placed, and the spare part is transported. (Juha Lempiäinen, meeting)

Asset management also includes handling spare parts and resourcing needed work force for tasks. The EAM system gathers valuable data to be analyzed further on – this is the work done by Asset Performance Management (APM).

APM focuses on optimizing and enhancing the maintenance tasks to be done. Failure history and behavior of assets are analyzed in APM, and solutions are figured out if some assets do not work in the intended way, or if they e.g. fail too often. Improved maintenance plans and work orders are updated into EAM, and researched again after some time in APM.

RAM-block in Figure 6 represents the use of the Ramentor tools, ELMAS and StockOptim. These tools are used to design and improve reliability, availability and maintainability (RAM) of assets, and to plan the spare part stock.

EAM, gathering its data from PDM, should hold the hierarchy for spare parts in different devices to help creating complete spare part plans for assets. The information from EAM concerning spare parts should consist of a spare part name, to which device does the spare part belong to and it’s ID code.

Failure data should provide information for criticality analyses, and be derived from EAM and APM. This data should hold the MTTR and MTTF values of failure modes, including spare parts consumed along with each failure. The asset hierarchy should be presented in these information systems, in order to ease the performance of the ELMAS RAM-analysis, since the hierarchy needs to be presented in the Block diagram and Fault tree. The failure behavior of the spare parts is needed to perform the stock optimization in case the consumption history does not exist.

The current and future information flow is presented in chapter 5.7 *Communication with other software* (page 46).

4 Outotec Pressure Filter and Filtration plant

Filtration is a process where a solid material is separated from a liquid. In case of a PF60 filter, the separation is induced by an external force gradient over a filter medium. This means that the solid material, or so called cake, stays inside the device, whilst the separated fluid runs out. Pressure filtration can also be used for washing material or removing the mother liquidrom another substance. Water is used in mineral processing stages to achieve higher mineral recovery, and to reduce emissions. Figure 7 lists the types of filtration processes, where external force is applied:

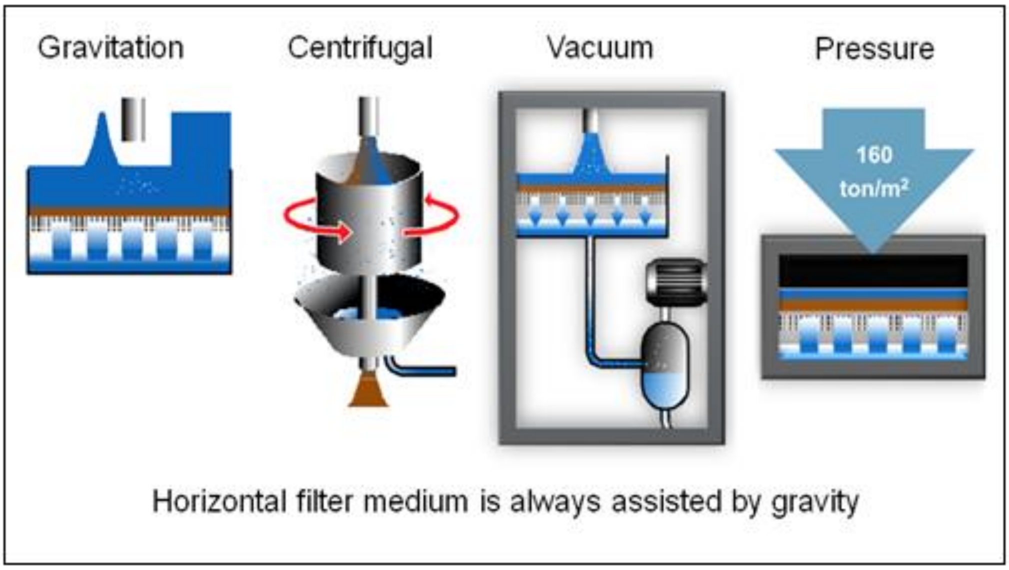


Figure 7. Filtration methods

PF60 filter separates the material with pressure, and gravity. “PF” refers to *Pressure Filter,* and the figure “60” is the size attribute, which also stands for the minimum filtration area of the filter in square meters. Different PF models which are currently manufactured by Outotec are PF1.6, PF12, PF15, PF48, PF60 and PF180.

Feed material of filtration is called *Slurry,* which is pressed between the horizontal plates of a pressure filter. The plates press together, and apply pressure to the slurry via a diaphragm inside the plate. The steps in filtration process are; Slurry feed, filtration, diaphragm pressing, optional solid washing, second diaphragm pressing (optional), air drying and cake discharge.

Figure 8. PF60 filter

The end result of the filtration, *cake*, is a dry product which is often ready for shipment. If the product needs to be even dryer, evaporation technologies are the next steps in the process.

The Outotec filtration plant is a facility, which holds from one to four PF60-filters. In this thesis, the filtration plant has four PF60 filters. The filtration plant consists of waste screen; slurry feed tanks with mixing, slurry pumps and pipelines, PF-filters, process water tank, pressing and drying air compressors & receivers, motor control center, air release tanks, filtrate tank and pumps, service area, control room and a cake conveyor. The heart of the filtration plant can be considered the filters, since they are the assets that produce the end product of the filtration plant – the cake. The future expansion area is also always designed and taken into consideration when designing a filtration plant. In this thesis, only the four filters of the filtration plant are under inspection. (Intro to filtration, Outotec marketing video)

Maintenance for a PF60 is made partly by the recommendations in the PF60 Scheduled Maintenance Excel spreadsheet. From this Excel-file, the generic structure for PF60 maintenance can be found, which is roughly applicable for any PF60 filter. PF60 is a highly technical and complex asset; the circumstances and purpose of use are always taken into consideration when designing maintenance for the filter. Different applications might require the filter components to be made of different materials.

Maintenance for PF60 filters are by default, divided into 5 steps; daily, weekly, monthly, semi-annually and annual maintenance. Semi-annual and annual maintenance can be replaced by maintenance done after 15 000 and 30 000 cycles, depending on the customer’s preferences, and other chosen maintenance procedures. These maintenance procedures consist of washing the filter and performing condition monitoring. A few spare parts are listed, which have a clear time-based replacement interval - these are amongst the most critical components of a PF filter. (Outotec PF filter preventive maintenance plan)

There are other variables too concerning the future maintenance of the filter. Customers quite often have their own way to do business, own maintenance personnel and requirements for the device financially. Every variable must be taken into notice when designing the optimum maintenance programs to satisfy the customer, but also to keep the filter working as it should. Quite often end users want the maximum capacity of out of assets, and it means that machines are overused constantly. In the short-term this may seem useful, but in long-term it will cause assets to become unreliable and increase downtime. (Naukkarinen, Partti, meeting)

5 Optimization process

5.1 Data acquisition for optimization process

The material collected for this thesis is mainly gathered via interviews. Acquiring data by interviewing is an effective way for obtaining extensive information on the subject. When interviewing people personally, the answers can be negotiated and follow-up questions can be asked. The negative aspect is that this method is rather time consuming. Spare part information has been collected, along with the failure behaviors of the assets.

The original goal of the data acquisition was to gather all the spare parts of the filtration plant. Since the information gathering took more time than expected, the scope was reduced to only optimizing spare part recommendations for the pressure filters.

Not being familiar with the PF60 filters caused some difficulties in the beginning steps of the process, since wrong questions relating to the needed import information were asked. Once the measurable quantities of the research targets were confirmed, gathering the information was more efficient.

5.2 Principals of optimization

The most constructive question to which optimization answers is whether it is cheaper and more reasonable to store the part on site, or to keep it in a distant warehouse. (Joel Turpela, meeting)

Spare part optimization brings the user the best possible evaluation on what spare parts to store and what not to store. Not having perfect information on asset behavior, the knowledge that operating conditions might change e.g. by changes in spare part delivery times, and the simple fact, that human error can often cause unexpected errors makes it impossible to give the precise values for spare part consumption. The software solution used can, however, provide justified estimations, along with deviations which should hold even the worst case scenario events on spare part consumption.

In this chapter, the term spare part availability is mentioned a few times. Spare part availability can be 100% at the highest, and 0% at the lowest. This means the likelihood of the spare part being in the warehouse when it is picked up. If the spare part availability is high, more spare parts are expected to be found at the warehouse at all times, which is positive for production, but also raises up the warehouse costs. By balancing different service levels with the financial figures received from optimization, a decision can be made on the optimal storage availability to work with.

Outotec PF60 filters spare part consumption can be divided into two categories; unexpected spare parts and preventive maintenance spare parts. The PF60 filter has regular maintenance intervals, when certain spare parts are changed. Since the reliability of the filter is not 100%, it will need spare parts for unexpected failures.

Having the unexpected failure and time-based maintenance spare parts along in the optimization process gives a good total amount of spare parts, which the four PF filters will need in future.

The spare parts are optimized according to different potential scenarios. For this thesis, optimization was chosen to be done so that the supplier waiting time would be 1, 2, 3, 5, 7, 14 and 30 days away from the site. The supplier can be the manufacturer of the spare part, or the distant warehouse mentioned earlier. Five different spare part target availabilities are inspected per each scenario to make the research conclusive. These spare part availabilities were 99%, 98%, 97%, 95% and 90%.

5.3 Criticality analysis on ELMAS

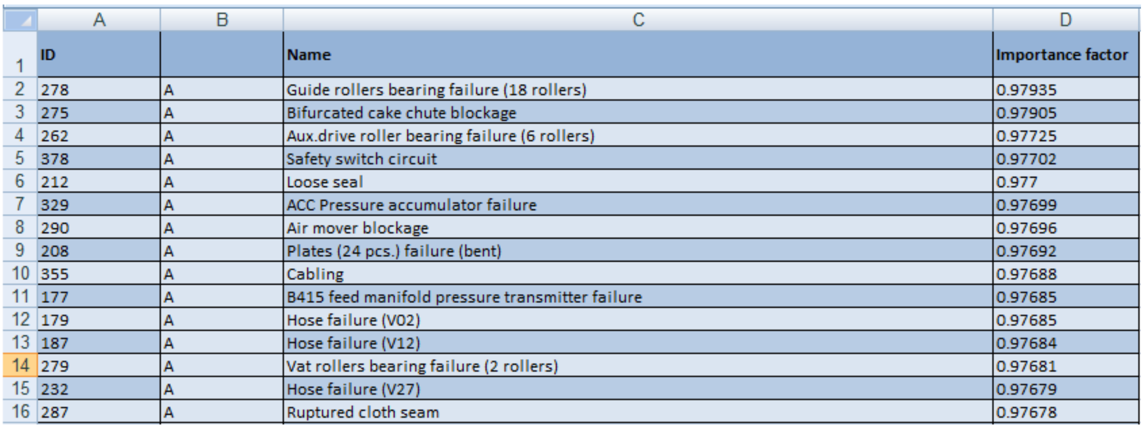
Criticality analysis for the PF60 filter was done on a three-day workshop in Lappeenranta, with filter specialists giving their best knowledge on how often, and by which mechanism, PF60 filters break down. This analysis was done to provide information for maintenance action planning, to locate big risks and bottlenecks in the process, to give the input data for this thesis and to estimate the overall availability of the Filtration Plant.

The asset architecture of the PF60 filter, along with auxiliary appliances, were displayed on the block diagram. A fault tree was built to locate all the possible failure modes. Each failure mode was given the MTTF, MTTR and personnel requirements information. RAM-software suits well for visualization of processes in this sense, and is also meant for optimizing the performance of the process. Downtime costs are also imported into the block diagram, and by consequence financial loss it can calculate how much production loss is most likely to cause during a year.

Event logic simulation parameters were inserted after the model was created, and a 10 year time period was simulated. The 10 year interval was simulated 200 times, to receive a comprehensive evaluation of the behavior. The results of the simulation showed the criticality of each component, downtime estimations and costs. At this stage the spare part consumption data is also created, if the spare part information is imported to the failure modes. This process is described in detail in chapter 5.4.1.

5.3.1 Criticality classification

The criticality analysis received from ELMAS provided the information on the components, which failed most often. It is common, that 10% of the failures will cause 90% of the downtime. These components are obviously critical to the process, usually highly maintained and quite often rather expensive. In this thesis, definitions of the spare parts are given for these faults such as class A spare parts, in the criticality classification chart. The ID column in the following figure refers to the nodes on ELMAS fault tree. (Gulati 2009, p. 105)



	A	B	C	D
1	ID		Name	Importance factor
2	278	A	Guide rollers bearing failure (18 rollers)	0.97935
3	275	A	Bifurcated cake chute blockage	0.97905
4	262	A	Aux.drive roller bearing failure (6 rollers)	0.97725
5	378	A	Safety switch circuit	0.97702
6	212	A	Loose seal	0.977
7	329	A	ACC Pressure accumulator failure	0.97699
8	290	A	Air mover blockage	0.97696
9	208	A	Plates (24 pcs.) failure (bent)	0.97692
10	355	A	Cabling	0.97688
11	177	A	B415 feed manifold pressure transmitter failure	0.97685
12	179	A	Hose failure (V02)	0.97685
13	187	A	Hose failure (V12)	0.97684
14	279	A	Vat rollers bearing failure (2 rollers)	0.97681
15	232	A	Hose failure (V27)	0.97679
16	287	A	Ruptured cloth seam	0.97678

Figure 9. Criticality classification

Sometimes these expensive and critical components (A-class components) can be shared with different users, in order to save money. The risk of two similar breakdowns happening at once is rather minimal, so the risk is shared between the owners of the component. After the spare part is used, another one is ordered and is open for use again. (Gulati 2009, p. 104)

Spare parts are in this thesis defined into A, B and C class. A-class spare parts are the ones that cause downtime. If an A-class spare part fails, it means shutting down the filter, most likely calling in the maintenance personnel to change the part and report the incident, and restarting the filter. This will take time, even if the spare part is easy to change.

B-class components are the ones listed as criticality analysis failure modes, which do not usually cause down time. This sort of components can be for example supportive, health and safety related or user friendliness-related components, which might be mandatory according to various standards and regulations. Many of these spare parts are quite durable and are changed during a planned maintenance shutdown, so they do not cause any excess downtime on their own.

C-class components are the ones mentioned in PF60 preventive maintenance plan, which will break down gradually. They are not as critical as class A components, since with good condition monitoring unexpected downtime can be prevented, much like with the B-class spare parts. Some reduction in quality is possible to occur, but this is not taken into notice in this criticality analysis.

Having a criticality classification gives the users a quick way to determine the criticality of the component. These classifications can also be used for deciding on what spare parts to store in warehouses. The criticality classification can aid the creating of a spare part plan, since the spare parts are easy to categorize with the classification.

5.4 Information import and export

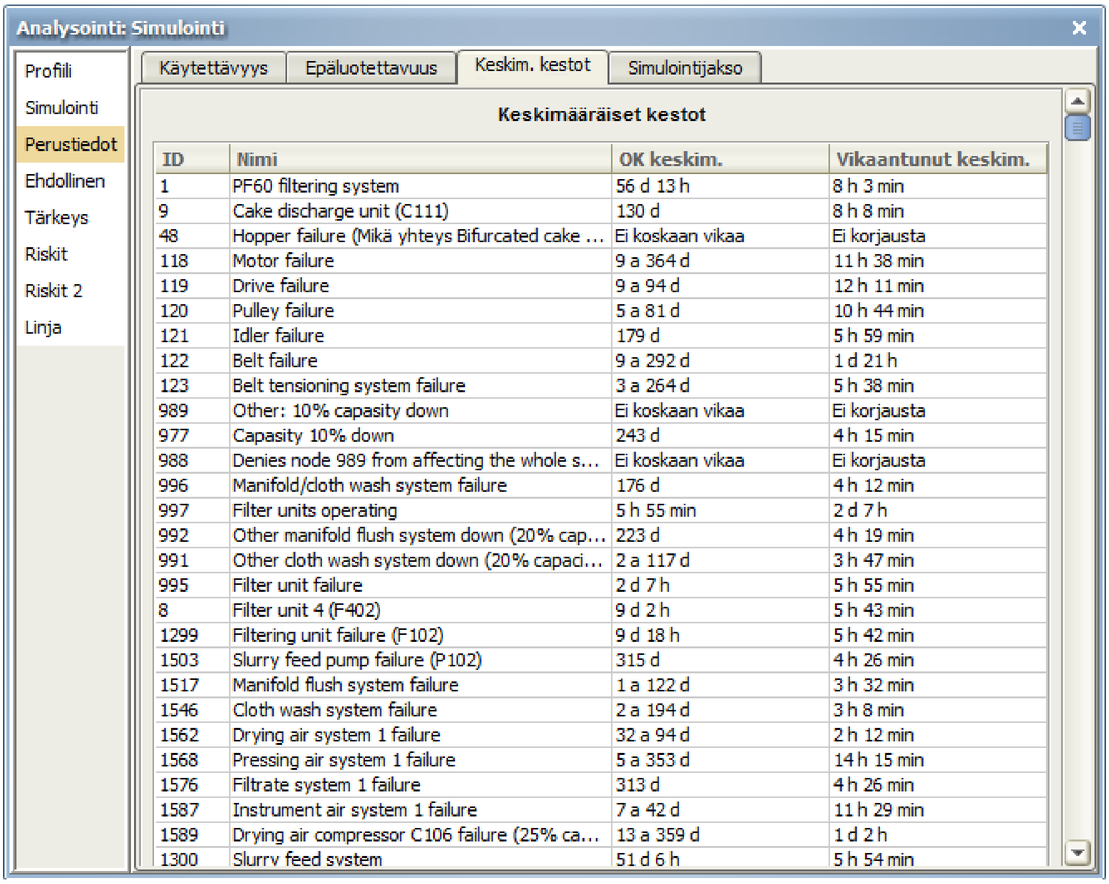
5.4.1 ELMAS

StockOptim requires spare part information imported in a specific form, in order to do calculations and estimate the optimum storage values. The ways the information is fed to StockOptim is presented in this chapter, and the form of the information is defined. This method requires an ELMAS criticality analysis to be done for an asset, which has to be done if the failure history is not in hand. First the spare part ID and failure data is imported into Block diagram, then into StockOptim.

The first thing is to perform the criticality analysis, and collect all the failure modes. Each failure mode is taken into inspection, and different spare parts are listed, which might have broken down along with the failure. The probabilities of which spare parts are likely to break down are also listed down. It is important to keep track which spare part concerns which failure mode, since the information has to be fed back into Block diagram at some point. The information can also be imported straight into ELMAS, but in this thesis for the sake of data management, the information has been maintained in an Excel spreadsheet.

For a single part, the ID code, name and failure data are required at this stage of the process. Failure data for a spare part means the probability on how the spare part will break down in case that failure mode happens. For example a hose might cause a failure due to normal wear, but the same failure mode can also happen, if the hose is loose and disconnects. If it is said that the chances on the hose disconnecting and breaking down are usually the same, the information is written down as follows; 0 parts used - probability 0.5. 1 part used - probability 0.5. In statistical mathematics, the likelihood of an event is always between 0 and 1; 0 presenting the 0% chance and 1 presenting the 100% chance. Percentages are often presented as 42%, 0.42 or 42/100. (ISO-standard 31-0)

This spare part information is imported into the Fault tree failure modes, which were created earlier. In this thesis, the information was written for a single PF filter, but the data was copied for the other filter units, as there are four PF filters in the Filtration plant. The copying does not take much time, as it can be done by “Copy and paste”. This feature did not work in ELMAS at first, but during this thesis it was fixed. Reducing the amount of hand writing is critical, since the spare part lists can be very long. Below there is a figure of the example simulation results gained from ELMAS.



Keskimääräiset kestot

ID	Nimi	OK keskim.	Vikaantunut keskim.
1	PF60 filtering system	56 d 13 h	8 h 3 min
9	Cake discharge unit (C111)	130 d	8 h 8 min
48	Hopper failure (Mikä yhteys Bifurcated cake ...	Ei koskaan vikaa	Ei korjausta
118	Motor failure	9 a 364 d	11 h 38 min
119	Drive failure	9 a 94 d	12 h 11 min
120	Pulley failure	5 a 81 d	10 h 44 min
121	Idler failure	179 d	5 h 59 min
122	Belt failure	9 a 292 d	1 d 21 h
123	Belt tensioning system failure	3 a 264 d	5 h 38 min
989	Other: 10% capasity down	Ei koskaan vikaa	Ei korjausta
977	Capasity 10% down	243 d	4 h 15 min
988	Denies node 989 from affecting the whole s...	Ei koskaan vikaa	Ei korjausta
996	Manifold/cloth wash system failure	176 d	4 h 12 min
997	Filter units operating	5 h 55 min	2 d 7 h
992	Other manifold flush system down (20% cap...	223 d	4 h 19 min
991	Other cloth wash system down (20% capaci...	2 a 117 d	3 h 47 min
995	Filter unit failure	2 d 7 h	5 h 55 min
8	Filter unit 4 (F402)	9 d 2 h	5 h 43 min
1299	Filtering unit failure (F102)	9 d 18 h	5 h 42 min
1503	Slurry feed pump failure (P102)	315 d	4 h 26 min
1517	Manifold flush system failure	1 a 122 d	3 h 32 min
1546	Cloth wash system failure	2 a 194 d	3 h 8 min
1562	Drying air system 1 failure	32 a 94 d	2 h 12 min
1568	Pressing air system 1 failure	5 a 353 d	14 h 15 min
1576	Filtrate system 1 failure	313 d	4 h 26 min
1587	Instrument air system 1 failure	7 a 42 d	11 h 29 min
1589	Drying air compressor C106 failure (25% ca...	13 a 359 d	1 d 2 h
1300	Slurry feed system	51 d 6 h	5 h 54 min

Figure 10. Filtration plant simulation, ELMAS 2013

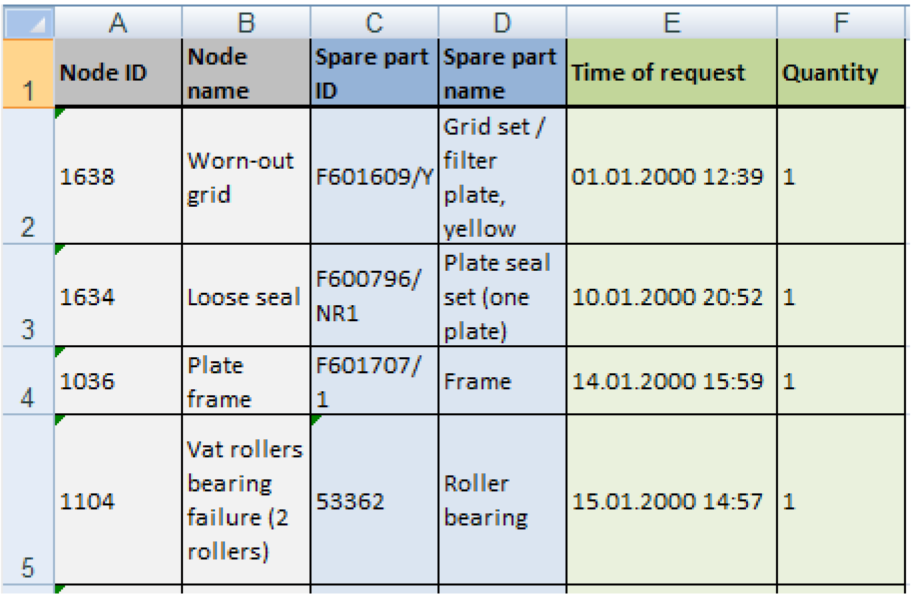
Once the spare part information is imported into the Block diagram, the consumption data can be generated. ELMAS calculates the potential behavior of the filter, by the MTTF and MTTR values given earlier. As a result from this simulation, the generated consumption data is created, where failures modes appear, along with the spare parts which are damaged, with the quantity of parts broken. In case a failure occurs, but no spare parts are needed, this failure event is not mentioned in this list.

5.4.2 StockOptim

The consumption of the spare parts in *Brown field* cases is usually gained from usage histories from warehouse databases. If the information does not exist, it can be created based on a criticality analysis, like in this thesis. StockOptim accepts both forms of information, as each option has its positive and negative aspects. Warehouse history can be distorted, if the spare parts have not been used in the correct way.

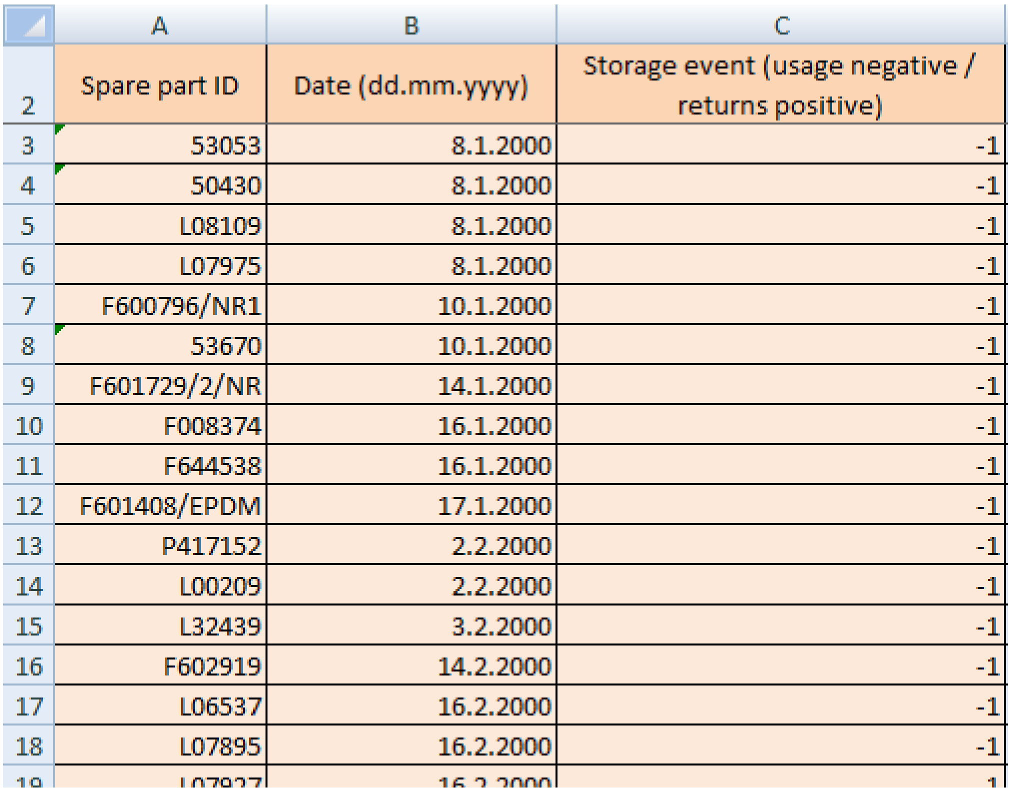
Maintenance personnel might have the tendency to pick up spare parts close to the assets, so that they are quickly usable in case of a breakdown. These “hidden storages” mess up the usage history on the databases, since some of the parts might not be used, or they will be used on different times than expected. Collecting the spare parts only when truly needed would support maintenance planning in EAM and StockOptim, since they need the correct data of the asset in order to perform correctly.

The consumption data was transformed to suit the StockOptim template. Below you can find a figure of both the original consumption data, and the StockOptim import sheet. Due to some Excel work done in between, the ID codes do not match up in the following figures, but the principle should be clear.



	A	B	C	D	E	F
1	Node ID	Node name	Spare part ID	Spare part name	Time of request	Quantity
2	1638	Worn-out grid	F601609/Y	Grid set / filter plate, yellow	01.01.2000 12:39	1
3	1634	Loose seal	F600796/ NR1	Plate seal set (one plate)	10.01.2000 20:52	1
4	1036	Plate frame	F601707/ 1	Frame	14.01.2000 15:59	1
5	1104	Vat rollers bearing failure (2 rollers)	53362	Roller bearing	15.01.2000 14:57	1

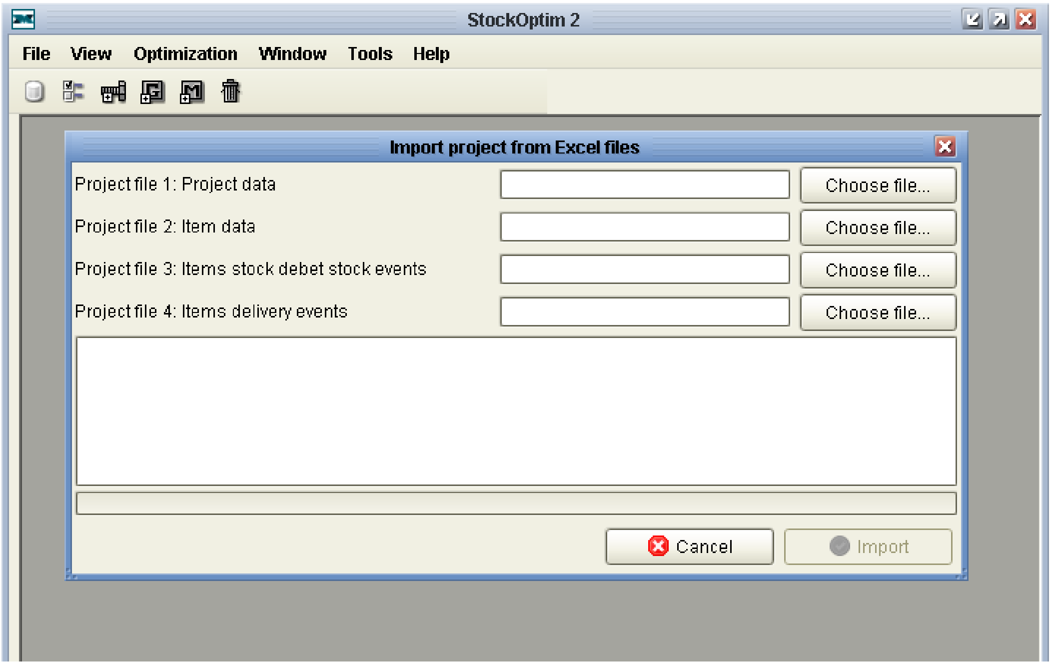
Figure 11. Spare part consumption data, ELMAS 2013



	A	B	C
2	Spare part ID	Date (dd.mm.yyyy)	Storage event (usage negative / returns positive)
3	53053	8.1.2000	-1
4	50430	8.1.2000	-1
5	L08109	8.1.2000	-1
6	L07975	8.1.2000	-1
7	F600796/NR1	10.1.2000	-1
8	53670	10.1.2000	-1
9	F601729/2/NR	14.1.2000	-1
10	F008374	16.1.2000	-1
11	F644538	16.1.2000	-1
12	F601408/EPDM	17.1.2000	-1
13	P417152	2.2.2000	-1
14	L00209	2.2.2000	-1
15	L32439	3.2.2000	-1
16	F602919	14.2.2000	-1
17	L06537	16.2.2000	-1
18	L07895	16.2.2000	-1

Figure 12. StockOptim consumption data import template, StockOptim 2013

Four other import sheets are needed in order to perform optimization in StockOptim, and these sheets are project basic information, spare part information, spare part delivery times and preventive maintenance plan consumption spreadsheets. Each spreadsheet is briefly described below, along with the data import view from StockOptim.



Import project from Excel files

Project file 1: Project data

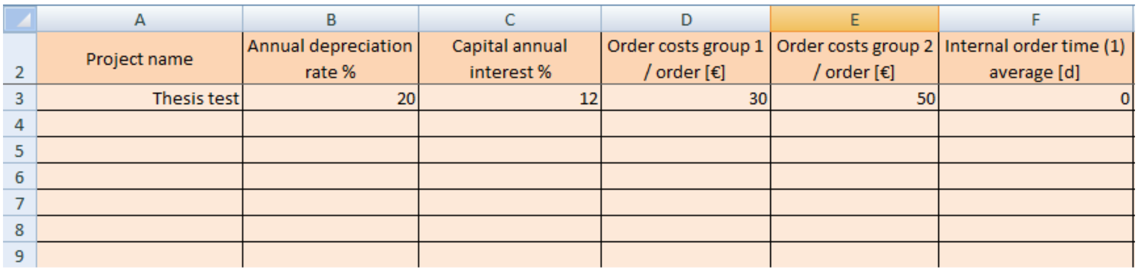
Project file 2: Item data

Project file 3: Items stock debet stock events

Project file 4: Items delivery events

Figure 13. StockOptim data import, StockOptim 2013

1. The basic information spreadsheet includes all the basic financial information, along with internal ordering time estimations and ordering cost prices. This data was collected by interviews, but in ideal situations it could be exported from ERP.

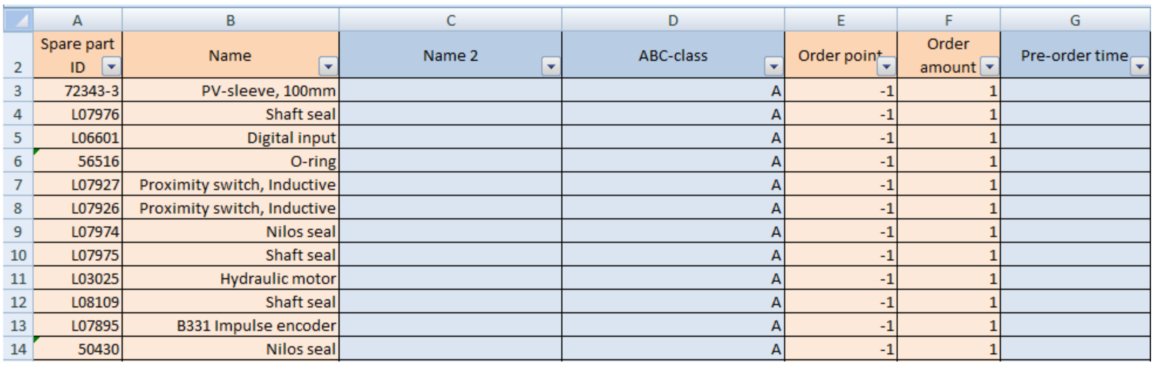


	A	B	C	D	E	F
2	Project name	Annual depreciation rate %	Capital annual interest %	Order costs group 1 / order [€]	Order costs group 2 / order [€]	Internal order time (1) average [d]
3	Thesis test	20	12	30	50	0
4						
5						
6						
7						
8						
9						

Figure 14. StockOptim project data import, StockOptim 2013

2. The spare part information spreadsheet is a much larger task to fill in, since it can hold many rows. If spare part information is stored in an information system in a flexible form, filling in this spreadsheet will be an easier task. Excluding the fields that are visible in the figure, ordering cost group information and the historical period of the spare part consumption

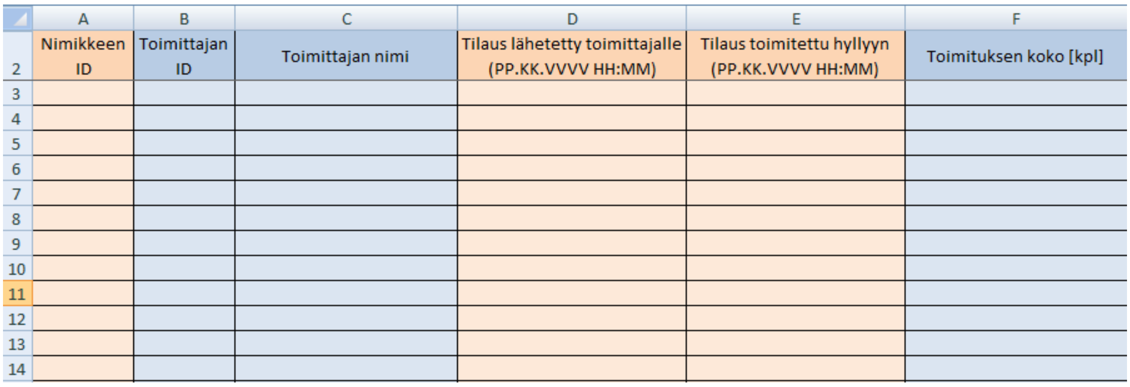
were defined in the spreadsheet as well. The estimated spare part delivery times and deviations were estimated on this spreadsheet, but they can also be estimated in the spare part delivery times spreadsheet separately. This method was followed, since different scenarios were investigated, and information on the optimum storage methods did not exist. If it were a real warehouse next to a facility or a factory, better information on the delivery times of individual spare parts would exist, thus receiving a more precise spare part plan, e.g. delivery times on some special components.



	A	B	C	D	E	F	G
2	Spare part ID	Name	Name 2	ABC-class	Order point	Order amount	Pre-order time
3	72343-3	PV-sleeve, 100mm		A	-1	1	
4	L07976	Shaft seal		A	-1	1	
5	L06601	Digital input		A	-1	1	
6	56516	O-ring		A	-1	1	
7	L07927	Proximity switch, Inductive		A	-1	1	
8	L07926	Proximity switch, Inductive		A	-1	1	
9	L07974	Nilos seal		A	-1	1	
10	L07975	Shaft seal		A	-1	1	
11	L03025	Hydraulic motor		A	-1	1	
12	L08109	Shaft seal		A	-1	1	
13	L07895	B331 Impulse encoder		A	-1	1	
14	50430	Nilos seal		A	-1	1	

Figure 15. StockOptim spare part data import

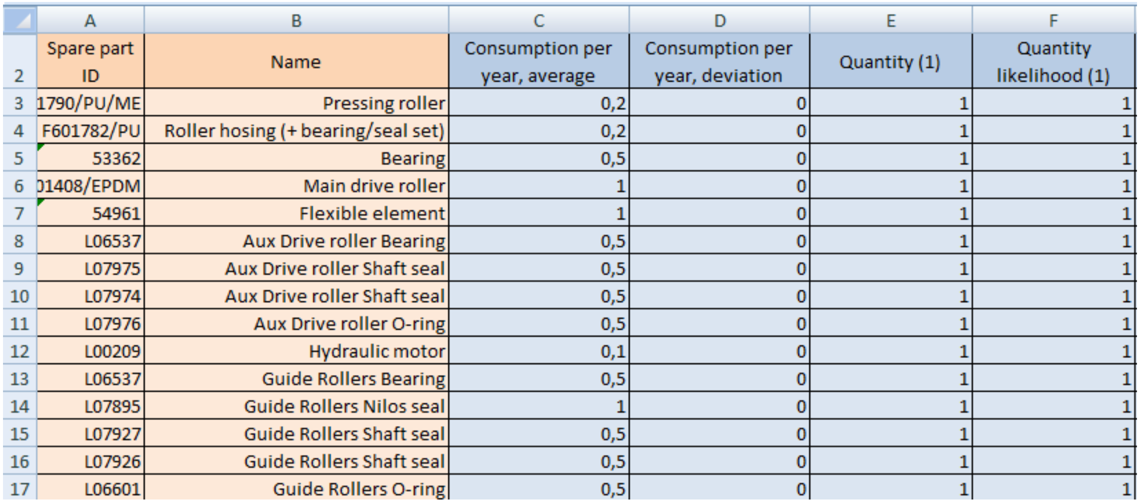
3. A figure of the consumption data import spreadsheet was reviewed earlier (Figure 12). This spreadsheet includes all the parts that were taken from the storage, along with the amount of parts used and consumption date.
4. The spare part delivery spreadsheet is used to fill in the specific order times for spare parts, if they are known. Recorded history of the delivery order and receiving times is necessary to have, in order to fill in this spreadsheet



	A	B	C	D	E	F
2	Nimikkeen ID	Toimittajan ID	Toimittajan nimi	Tilaus lähetetty toimittajalle (PP.KK.VVVV HH:MM)	Tilaus toimitettu hyllyyn (PP.KK.VVVV HH:MM)	Toimituksen koko [kpl]
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						

Figure 16. StockOptim delivery data import

5. This function for StockOptim was created for the thesis. The ELMAS model gives the estimated unexpected spare part consumption, but a PF filter also has a list of spare parts it needs for time-based maintenance.



	A	B	C	D	E	F
2	Spare part ID	Name	Consumption per year, average	Consumption per year, deviation	Quantity (1)	Quantity likelihood (1)
3	1790/PU/ME	Pressing roller	0,2	0	1	1
4	F601782/PU	Roller hosing (+ bearing/seal set)	0,2	0	1	1
5	53362	Bearing	0,5	0	1	1
6	01408/EPDM	Main drive roller	1	0	1	1
7	54961	Flexible element	1	0	1	1
8	L06537	Aux Drive roller Bearing	0,5	0	1	1
9	L07975	Aux Drive roller Shaft seal	0,5	0	1	1
10	L07974	Aux Drive roller Shaft seal	0,5	0	1	1
11	L07976	Aux Drive roller O-ring	0,5	0	1	1
12	L00209	Hydraulic motor	0,1	0	1	1
13	L06537	Guide Rollers Bearing	0,5	0	1	1
14	L07895	Guide Rollers Nilos seal	1	0	1	1
15	L07927	Guide Rollers Shaft seal	0,5	0	1	1
16	L07926	Guide Rollers Shaft seal	0,5	0	1	1
17	L06601	Guide Rollers O-ring	0,5	0	1	1

Figure 17. StockOptim preventive maintenance data import template

Consumption data is based on the preventive maintenance plan of the PF60 filter (PF60 Scheduled maintenance.xlsx). Each maintenance task was inspected separately, and the potential spare parts which the maintenance procedure might consume were listed down. These spare parts were listed in several workshops with Filters product line specialists. A question of how often each spare part was consumed during a maintenance overhaul was answered, and the results were fed into StockOptim as follows; if a spare part is used e.g. once every 5 years, the likelihood that it is used per single overhaul is 0,2, if the preventive maintenance is performed annually. That means on average that in every five years one part is used.

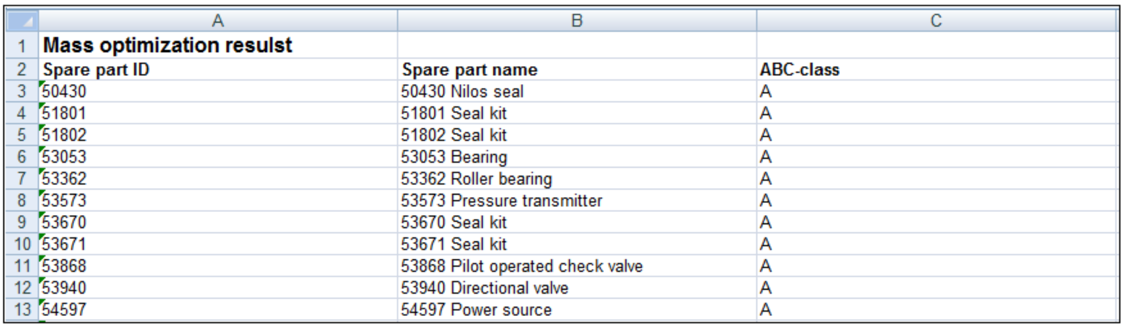
After all the spreadsheets are uploaded into StockOptim, the optimization process can be done. This so far is a simple step, for it only consists of picking out which spare parts will be optimized, and on what service levels. As mentioned before, the optimization calculation takes several hours, and it was found out that the best method was to perform the optimization, when the computer was not otherwise used – at night. The optimization process can be a challenge for older computers, if other software is used at the same time.

The information gained from StockOptim can be exported into Excel spreadsheet, or XML-file. When choosing the Excel file to output the results, the spare parts will be listed in the order as they were chosen to be optimized in the first place. This requires the user to remember, in what order he picked the spare parts. This sounds like a simple task, but it can be surprisingly challenging. A recommendation was given to Ramentor about adding the information of service levels into the Excel spreadsheet, instead of simply having all the parts listed.

A collective Excel spreadsheet was created, which holds the necessary information for a user to start preparing his/her spare part plan. The creation and content of this spreadsheet is reviewed in the chapter Optimization results.

5.5 Optimization results

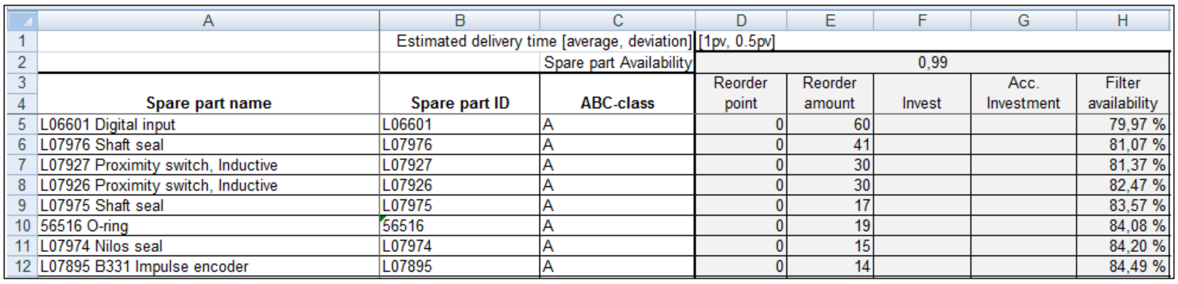
The results from optimization can be exported into Excel spreadsheets, where the chosen information fields are listed. The list received holds every optimized value below each other, so some modification of the list is needed. Once again caution is needed, since typing errors can occur very easily, and disrupt up the entire list. When sorting columns and rows, a single mistake can realign the figures, in such a way that they are not usable. A figure of this export spreadsheet is below this chapter. This particular spreadsheet holds 873 rows and 31 columns of data, so it is far from readable; and these are just results from one scenario.



	A	B	C
1	**Mass optimization resulst**		
2	**Spare part ID**	**Spare part name**	**ABC-class**
3	50430	50430 Nilos seal	A
4	51801	51801 Seal kit	A
5	51802	51802 Seal kit	A
6	53053	53053 Bearing	A
7	53362	53362 Roller bearing	A
8	53573	53573 Pressure transmitter	A
9	53670	53670 Seal kit	A
10	53671	53671 Seal kit	A
11	53868	53868 Pilot operated check valve	A
12	53940	53940 Directional valve	A
13	54597	54597 Power source	A

Figure 18. Optimization results export, StockOptim 2013

A new report spreadsheet was made to hold the optimized data in a more user-friendly form. This report lists all the spare parts, ID codes, criticality classes, and scenarios. In each scenario, all the service levels are listed, with the optimized reorder point and amount, and the initial investment costs. A figure of the tailored report spreadsheet is below this chapter.



	A	B	C	D	E	F	G	H
1		Estimated delivery time [average, deviation]		[1pv, 0.5pv]				
2			Spare part Availability	0,99				
3				Reorder point	Reorder amount		Acc. Investment	Filter availability
4	Spare part name	Spare part ID	ABC-class			Invest		
5	L06601 Digital input	L06601	A	0	60			79,97 %
6	L07976 Shaft seal	L07976	A	0	41			81,07 %
7	L07927 Proximity switch, Inductive	L07927	A	0	30			81,37 %
8	L07926 Proximity switch, Inductive	L07926	A	0	30			82,47 %
9	L07975 Shaft seal	L07975	A	0	17			83,57 %
10	56516 O-ring	56516	A	0	19			84,08 %
11	L07974 Nilos seal	L07974	A	0	15			84,20 %
12	L07895 B331 Impulse encoder	L07895	A	0	14			84,49 %

Figure 19. Optimization results tailored

The formula to calculate the initial investment cost is:

$$Investment\ cost = (Reorder\ amount + reorder\ point) * \ Unit\ price \qquad (2)$$

One important thing to keep in mind is how to deal with the optimized figures in the report. There might be some really inexpensive parts, like O-rings for example, when the reorder point is optimized at 0. In theory this would mean that when O-rings run out, a set amount of new ones is ordered. In actuality, O-rings are quite important, but inexpensive parts; this means that we can store them in large quantities, without affecting the financial costs that much, and not having to bother and order them constantly. StockOptim optimizes the values, with what the service level can be reached, by storing the minimum amount of spare parts. All the figures are valid, but some might not be very practical. The results should be hand-tailored in the end, before implementing the warehouse plan for use.

The combined amounts of initial investment costs per scenario were calculated to the end of each spare part list. When the spare part availability drops, so does the amount of spare parts. This quite obviously means that the price drops as well. What is interesting to see is the behavior of the curve, and to check whether it is exponential, or linear. The curve does not show financial figures used in this thesis, but relative figures were used to present the curves as the same.

The most expensive curve is the 30 day delivery scenario, with 99% availability. In the figure, this is the point 1. There is a significant change between the 1 day and 30 day scenario, as can be seen in Figure 20.

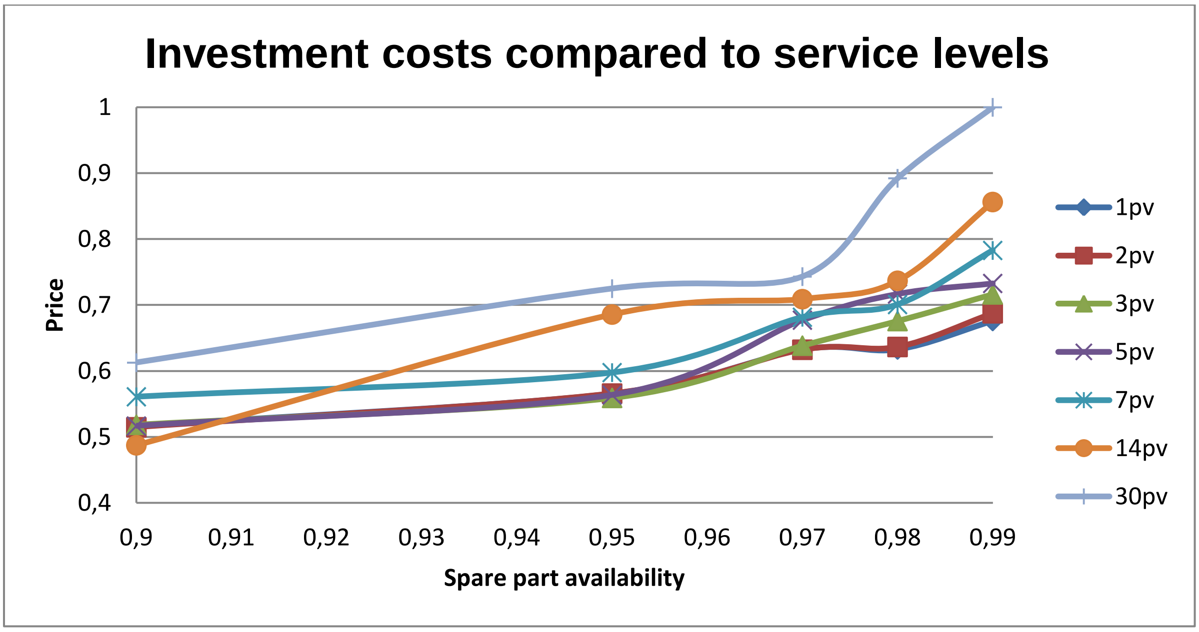


Figure 20. Investment costs compared to service levels

An investment efficiency list was also created for the A-class spare parts. This list shows how downtime can be avoided with the lowest possible costs. A customer might not have sufficient funds to purchase all of the recommended spare parts, so some compromises have to be made. This list shows where to invest the money that the customer has, if all of the parts cannot be purchased. The formula for the investment efficiency spare parts is described below (Formula 3). Current lacking time means the given scenario which was suggested (spare parts not stored in site warehouse due to distant warehousing scenarios) and optimized lacking time means the best potential results that can be reached by optimization.

$$Investment\ efficiency = \frac{Spare\ part\ initial\ investment\ cost}{Current\ lacking\ time - Optimized\ lacking\ time} \qquad (3)$$

The listing of the most efficient spare parts to be stored was first done by calculating the 1 day delivery scenario, with 99% availability. This task was relatively time taking, so it was not done for all of the scenarios. However, it was done for 14 and 30 day delivery scenarios. The order of the spare parts did not change much. Some spare parts jumped up on the list by few places. The changes were so minor, that the 14 day scenario was chosen to be the one used for availability calculations further on in this report sheet.

As mentioned earlier, a big topic while doing this thesis was the scenario, where a customer has limited amount of finances, and the decision to be made; what spare parts should be bought? Now that the spare parts are listed in the investment efficiency order, one may order which spare parts are most vital, if all cannot be afforded.

The spare parts are sorted so that the most investment efficient spare parts are at the top. The prices also accumulate downwards, so the optimum spare parts can be seen, if only a certain amount of money is in use.

To make the spare part plan even more comprehensive, the availabilities for each spare part scenario were calculated. The ELMAS criticality analysis estimates that the unavailability time for PF60 filter per 10 years is 88 days, as the simulation was done with 10 year parameter. Since currently a single year is researched, this number is divided by 10 and used in calculations. This unavailability parameter for spreadsheet calculations was set in the “Settings” tab of the report spreadsheet, where the parameters can be completed. A Settings-tab was created to ease the changing of the parameters in the report spreadsheet.

Further adjustments for the spreadsheet should be done, to set more parameters to this tab; this would allow more flexibility for the spreadsheet. The formula to calculate the availability for each scenario is:

$$A = 1 - \frac{\text{Acc. TLT per spare part} + \text{Acc. LT per filter} + \text{Annual un. A per filter}}{365} \quad (4)$$

In cases where the distant warehouse is further away than 2 days, the delivery time for the spare parts which are not stored in site warehouse is 2 days, with 0.5 days deviation. The parts which are not stored are the parts, which are not included in the recommendations for each scenario. Since the reliability of the PF60 filter is not 100%, as is the case with every asset anywhere, it will consume more spare parts than these recommendations suggest, and some unexpected scenarios will rise up. In this case, the delivery time is the 2 days, as mentioned above. In case of a failure and a shutdown, a long waiting time for a spare part is unacceptable. The loss in production will exceed the logistical costs of the spare part fast, so any means of transport is taken into use. Two days delivery scenario might not be possible for all of the spare parts, since some of them are manufactured on order. This fact should be taken into notice when designing and integrating an optimized spare part plan into use.

With the 2 day emergency order scenario, we can have the accumulating availability figures for each spare part. This means that the list contains the availabilities per single spare part, and how the availability will rise if more spare parts are stored near the site. The behavior of the availabilities on the 30 day scenario with the spare part availability level at 90% is quite interesting. The calculations give better results when less spare parts are bought. This is because the calculations assume, that if we choose to store the part, it will arrive to us at the given scenario delivery time - which is 30 days in this case. This lowers the availability immensely. The reason why the figure drops is that if the spare parts are not bought, the delivery time would be faster, due to the emergency delivery. The logistical costs would be vastly more expensive if the emergency delivery would be used constantly, and thus is not the method of how any facility should be run.

The availability calculations can be seen as the worst case scenarios case per case, and it is likely that the actual availability is higher than the estimation. At the moment the calculations do not take into consideration that when a failure occurs, several spare parts might be needed, and the waiting time of these spare parts overlap. Thus, some of the unavailability times should not be added together, since they occur at the same time.

The calculations also do not take into account that the filter is not used constantly. Some part of the time used in calculations is actually part of the time when another spare part is on its way to the site, and the filter is unavailable – in other words not able to consume any more spare parts.

The total availability of the filter starts reaching its potential maximum, when more spare parts are stored close to the filter, with high service levels. The maximum availability for a single PF60 filter is the ELMAS simulated 356,2 days per year, or 97,6% Availability, subtracted by the preventive maintenance overhauls.

Division of the amounts of different spare part classes was researched, and three figures were made to present how the amounts of spare parts per class vary between scenarios. Categorization can be seen from the bottom of the page 17. Figures 21, 22 and 23 present the results.

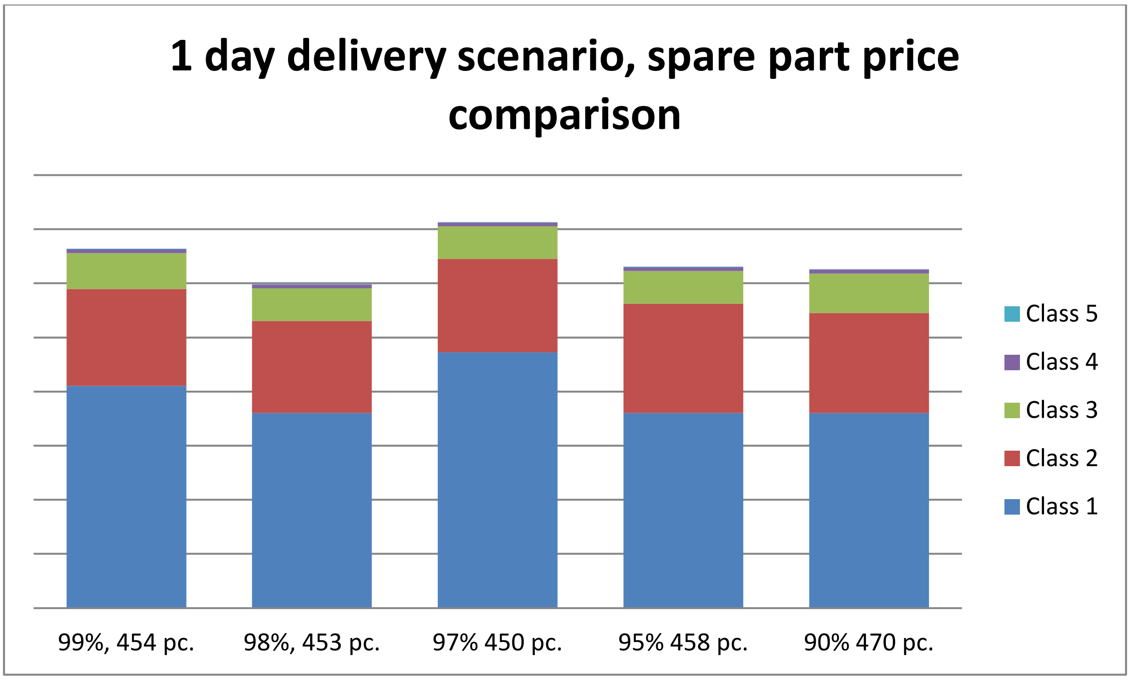


Figure 21. 1 day delivery spare part price comparison

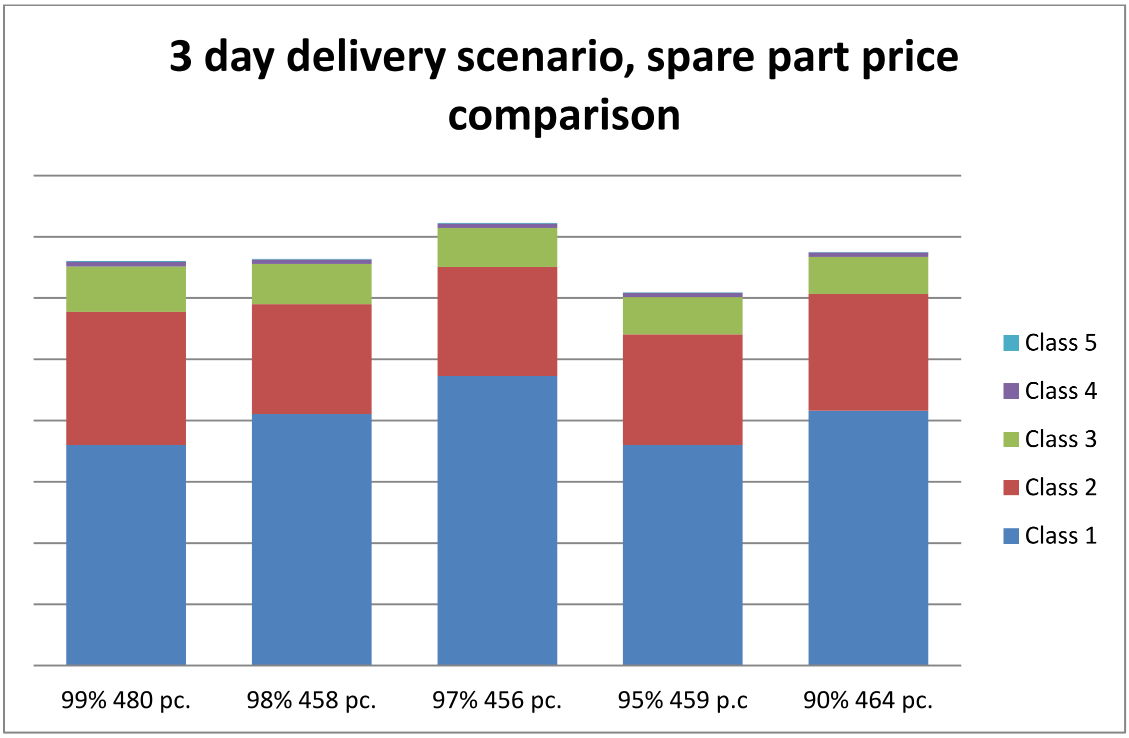


Figure 22. 3 day delivery spare part price comparison

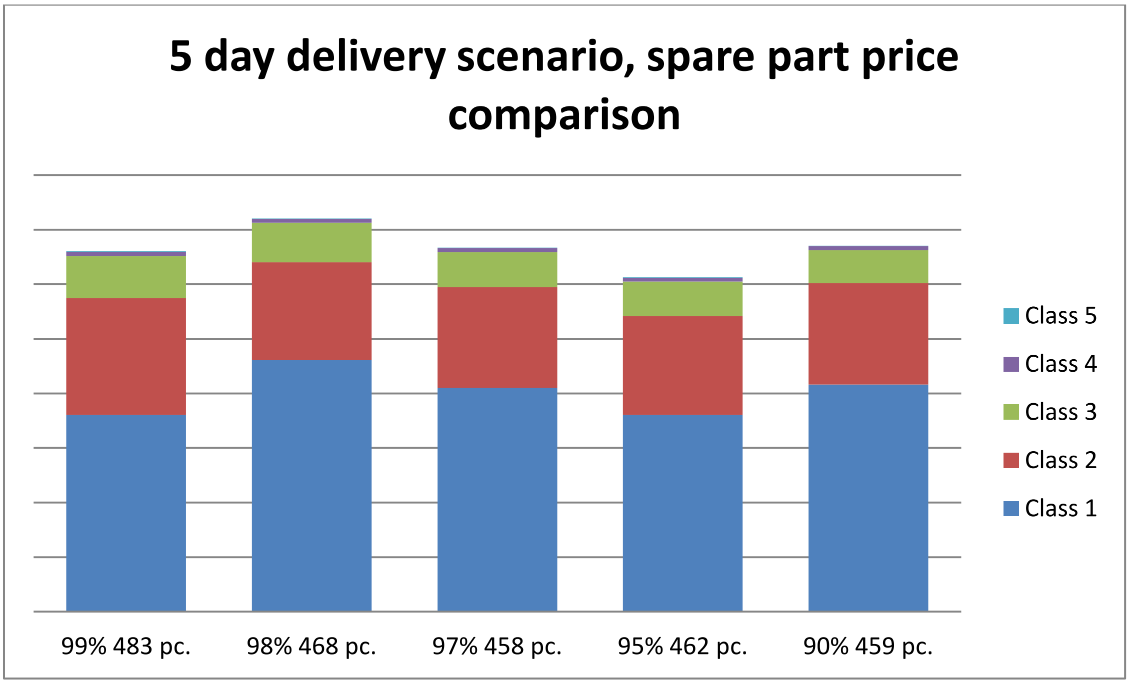


Figure 23. 5 day delivery spare part price comparison

An interesting result from these graphs to see, is that the spare part amounts compared to each other do not drastically change between scenarios. If very expensive components are included in these figures, as is with the case of Class 1 components of the PF-filter, the bar presenting the spare parts can vary a lot.

The spare part costs were also examined between different scenarios, with the same spare part availability level. Most of the changes in the bar levels are due to reduction of the amount of expensive spare parts. The less expensive spare parts do not alter the results that much. The amount of the spare parts rises, when the delivery time extends.

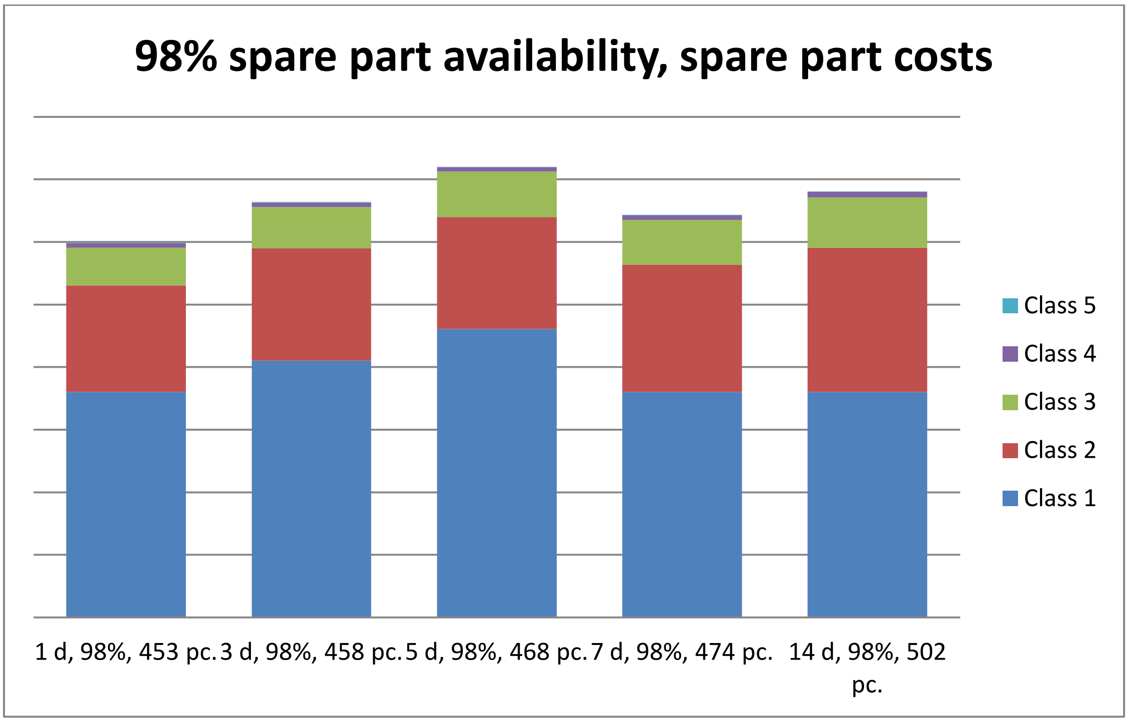


Figure 24. 98% spare part availability, spare part costs

5.6 Work process description

This chapter is a revision of the work stages involved in the optimization process. This list can also be used for a guideline for a new spare part optimization case. The figure below presents the main steps of the process, which are opened up afterwards with more detail.

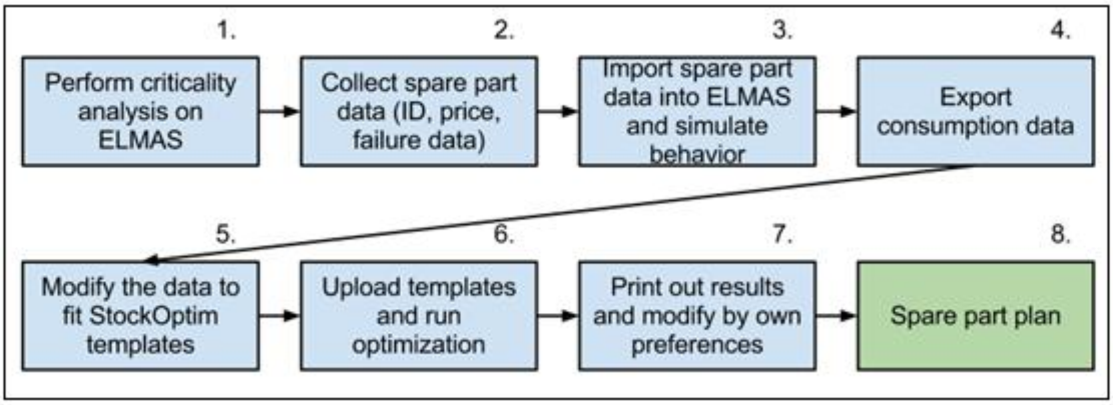


Figure 25. Work process

1. Performing the criticality analysis involved half a dozen of employees, along with consultants from Ramentor. A thorough criticality inspection always takes time, and is needed to be done in case the spare part data does not exist, or is not reliable. The criticality inspection only needs to be done once per asset or a process, so the results are valid for similar processes or assets as well and as long as the scenario will be similar.
2. Collecting the spare parts was done by interviewing PF60 filter specialists, who recognize the most vital components, which relate to the failure modes received from the criticality analysis. The spare part information is not at the moment in a printable form in any of Outotec's information systems, but this task, like the criticality analysis, must only be done once per asset or process.
3. The spare part data is imported to the nodes on ELMAS, which takes some time, since it has to be done one node at a time. After this the simulation parameters are assigned, and the simulation performed.
4. Once the simulation is done, the consumption data is printed onto a spreadsheet. The criticality classification can be assigned for spare parts at this point, since the downtime values are seen from ELMAS simulation results. The consumption data from is fitted to into the StockOptim template.
5. The four remaining StockOptim templates are filled with general project and delivery data. The project data was collected with an interview. Several scenarios on different delivery times were used for the

optimization, since the filtration plant does not yet exist, and different scenarios for it were researched.

6. The import spreadsheets were uploaded into StockOptim case by case, and assigned with five different service levels to be optimized with. The optimization process for one scenario took one night, so roughly a week was spent on the optimization itself.
7. The modifying of the report spreadsheet took quite a great deal of time, since the layout and content of the spreadsheet was not yet defined. The formulae used to calculate availability and the item investment efficiency were also defined, and used in the report. Since the template for the report is done, doing it again for another case would take much less time.
   The figures should be hand-tailored to meet real-life practicality issues (see page 38).
8. The report spreadsheet can be used for warehouse planning and sales negotiations, since it shows the optimum storage methods and prices. Showing the gained availability values should be a good sales claim, to justify the importance of spare parts.

Further researches on the validity of the results are performed with asset specialists, after the entire Filtration plant has been optimized. The spare parts collected for this thesis might also lack some spare parts for the PF60-filter, since the information was gathered with interviews, and human errors might have occurred. The spare part list must be verified, before taking the spare part plan into use.

5.7 Communication with other software

In this thesis, StockOptim mostly had to communicate with ELMAS, ERP, Aton PDM and Excel. The following figure clarifies the route through which the information traveled in the thesis. The criticality analysis precedes Figure 26.

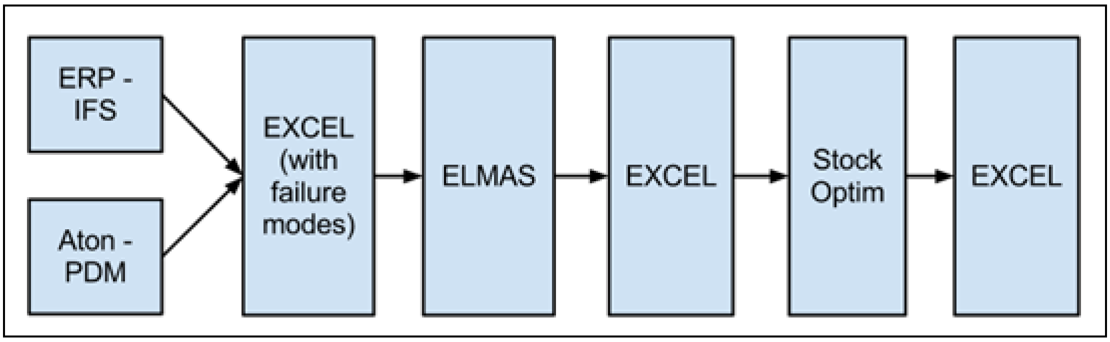


Figure 26. Information flow, present model

Information was modified numerous times in this thesis during different stages, which means that the current IT systems do not support the use of StockOptim too well. The information should be stored in such a way, that it can be exploited without too many additional modifications. The following figure represents the way the information should go, in order to provide a swifter optimization process.

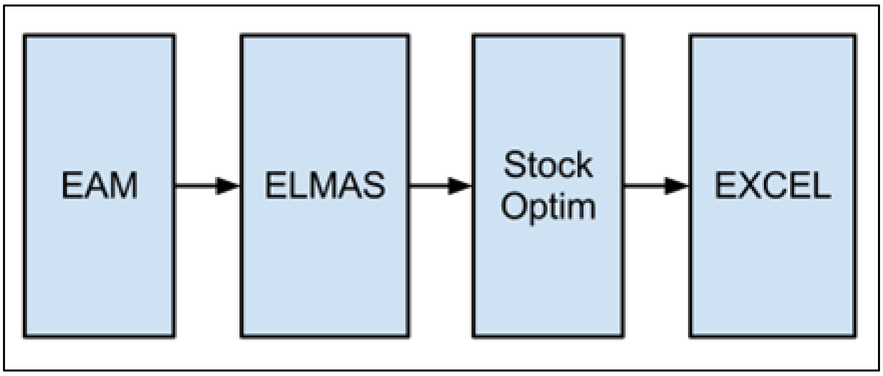


Figure 27. Information flow, future landscape, Brownfield

In Brownfield cases, the spare part information, holding the name, ID, asset hierarchy, failure behavior and delivery data should all come from a single information system - EAM. The failure modes of assets need to be listed on the same system, so that the spare parts could be assigned for the correct failure modes in ELMAS criticality analysis.

Improvements are to be made with Ramentor tools also. The consumption data which ELMAS exports should be in such a form that it could be imported into StockOptim without modifications. ELMAS could also determine the criticality classes automatically – if not done before – based on the downtime values received from simulation.

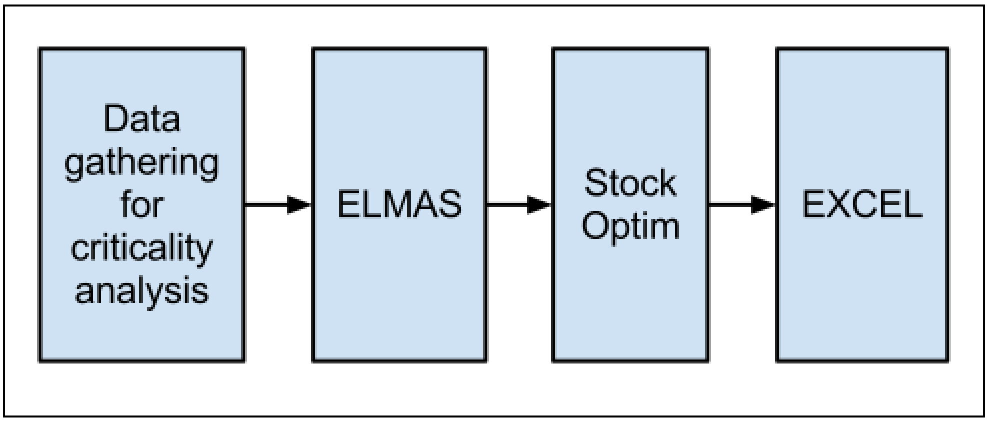


Figure 28. Information flow, future landscape, Greenfield

In Greenfield cases as in this thesis, the information must be created. A good way to gather the data is to interview asset and process specialists, and perform the criticality analysis. After this, the spare part information is also gathered, as well as the optimization process

StockOptim templates would be easy to fill, if the information stored in Outotec's systems held the same needed data in Brownfield cases. Definitions of the spare part and project information form should be made so that they support spare parts optimization.

Once the optimization is done, the results could be exported to the final form of the report spreadsheet. An Excel macro would be a useful tool to do the calculations needed to transform the optimized results from the current state to the final report form. The report spreadsheet holds a *Settings*-tab, which would allow the use of other variables, such as emergency delivery time and availability figures. Currently the tab only holds the unavailability figure for a single filter.

6 User experience

6.1 Key issues

StockOptim and ELMAS are relatively simple software to use. What was challenging in the thesis was modifying the information to fit each purpose. Now that all the main stages of this process have been done and are listed down, performing the optimization again would be a much easier task.

Some knowledge on warehousing, logistics and maintenance terminology is mandatory to have when dealing with storage optimization. Most of the work can be done by a person who is not an expert on the asset itself, except for the criticality analysis. If the analysis is done, and the spare part and project data is collected, the optimization process is a simple task.

The optimized results can be used for two purposes; to warehouse planning, or to sales negotiations. Being able to optimize and estimate these values is a strong advantage for Outotec, and the method on how the results were gained is not revealed to customers. Outotec's relationship towards customers is based on trust, and the quality of the services must always stay high. Thus, being able to provide the optimum storage values supports the core competence areas of Outotec and improves Outotec's image for customers.

6.2 Personal experience

According to my experience StockOptim is useful software, which can be used to turn simple spare part data into a decent warehouse plan. Creating supply chain models and warehouse plans based solely on user experience and interviews is not the best method for long-term maintenance planning. If the knowledge on assets improves and the storage plans are refined, storage optimization could be a method to create really accurate storage plans in the future.

The feedback from sites to monitor the true behavior of assets is the next step after implementing an optimized warehouse plan. As mentioned in the previous chapter, this is needed to improve reliability, availability and maintainability of assets, since the information has to be updated and monitored. In Outotec's case, these tasks should be planned and performed with APM and RAM tools.

If the optimized values turn out to be far from the actual consumption, it is vital to locate the cause. The reason for the mismatch of information could lie on an error on the optimization process or in the use of the asset.

All of the parameters should be checked in this case that the correct scenario information was used. There might be several other reasons why the information does not match, some of which might be because of errors done in spare part optimization, and some due to errors on the use of assets.

One important issue to keep in mind when following these maintenance and spare part recommendations is to remember the human error factor, in other words *Human Reliability*. In order to reach the theoretical reliability and availability requires strict following of the recommendations, and running assets & warehouse in the intended way.

Errors in the use of assets are common, and might be caused from perfectly normal reasons, e.g. lack of knowledge, emotions, and state of health or simply accidents. It is challenging to take these mistakes into consideration when designing maintenance plans, even though they are a daily part of processes. Most of these problems occur on *Brownfield*-cases, where the personnel might be re-trained to use new maintenance software, or new methods to apply maintenance.

Reaching the potential availability figures is a delicate task, since the amount of variables which can go wrong is huge. Aiming for the best possible reliability, availability and maintainability is a good goal, regardless of the challenges. Finding out the optimum ways to handle assets can save lives, protect the environment and be financially beneficial.

A lot of learning happened during this thesis to the writer himself, e.g. on maintenance theory and various angles on how to approach and plan spare parts for assets. Supply chain management is also a large part of reliability-engineering, and according to my experience it goes hand in hand with spare parts. The overall figure of how facilities are maintained became a lot clearer during this thesis.

The entire Filtration plant was not spare part optimized, which is a deficiency in this thesis. On the other hand the original scope was rather large, taking in note the given amount of time to work.

Spare part optimization was performed, and the process for Outotec was developed in this thesis. Some new solutions, e.g. the preventive maintenance spare part optimization and tailored results spreadsheet were created, so new features also rose up. The integration requirements were also defined, so all in all this thesis reached its set goals.

6.3 Competing software solutions

In the field of maintenance engineering various tools are available to improve maintenance and reliability procedures. Numerous storage optimization software are on the market, some of which are listed in this chapter. Research on such software could reveal the best choice for Outotec’s purposes. A quick browse through the internet also shows that there are several consulting offices which provide item optimization.

Figure 29. SOS logo

Strategic Corporate Assessment systems Pty is a company which provides maintenance planning for its customers. They are located in

Australia and North America, and provide a similar tool as StockOptim. Their product is called Spare parts Inventory Optimization - S.O.S.

S.O.S evaluates stock levels, and provides to bring the user the optimal spare part levels. S.O.S gathers information by asking questions, e.g. relating to spare part criticality, failure patterns, usage, costs and lead times. What S.O.S does differently is balancing the cost of a possible out of stock situation, versus the stocking costs. S.O.S also uses a mathematical algorithm to evaluate its results. (Strategicorp homepage)

Figure 30 A.L.D logo

ALD Reliability Engineering Ltd. is another company that works in the RAM-industry. They claim to be world leaders in reliability engineering, safety and quality solutions. They provide training, consultation and software for maintenance planning. A software called RAM Commander is a competitor to both ELMAS and StockOptim.

Like the name suggests, RAM Commander can perform a RAM analysis, including reliability and maintainability prediction, spare part optimization, FMEA-analysis, FTA and safety analysis. RAM commander works with two principals - Total no shortage principal, and with Availability. This software has the same functions as ELMAS and StockOptim, but further comparison is not in the scope of this thesis. (ALD Reliability Engineering Ltd. homepage)

SPARES CALCULATOR

Figure 31. Spares calculator logo

Spares Calculator software is a storage optimizing tool from London Web Factory Ltd., located in the United Kingdom. Spares Calculator uses a logarithmic Poisson distribution to optimize the spare parts. That mathematical method is commonly used in other spare part optimization software as well.

Spares Calculator demands some knowledge on the behavior of the asset. For example, the MTBF values, and that the asset must not be on the infant-mortality stage, or wear-out region (Failure behavior type B, page). Spares Calculator has lots of major customers, such as Phillips, Fujitsu and Siemens. (Spares Calculator homepage)

7 Future research recommendations

7.1 Current status of spare part optimization work in Outotec

Currently, storage planning is done by supply chain developers, who also control Supply Chain Management (SCM) as a whole. Supply chain planners use Excel mostly to plan the storage levels, since there are no better tools available in the company. To help manage the storages in different locations, a very large spreadsheet has been made. The information in the spreadsheet is gathered in a large study done in 2011 of the spare part sales done in that year. The information was gathered from all the ERP systems which Outotec uses.

This spreadsheet estimates storage values, by asking similar questions as StockOptim does. The spreadsheet is provided with supply lead times, transportation times, targeted service levels, supplier locations and deviations of these values. The spreadsheet provides the user with the re-order points and amounts, along with the prices of the stocks.

The storage levels are assigned by taking notice of the demand in each location separately. The general guideline is that if some parts are not consumed within one year, they are not stored; unless they are of some special criticality, by some customer’s preferences. This is the way the planning is done at the moment, in *brownfield sites*.

If the case is a so-called *Greenfield Site*, the storage levels are decided by gathering estimations from asset experts. Within time, the storage levels are fixed to meet the real-life needs. StockOptim could be fit to this purpose well, and used to create the warehouse plans. What StockOptim requires is a criticality analysis to be done with ELMAS, before it can be used. Using this method could provide more accurate storage levels right from the start. More user experience from using StockOptim is needed, to better justify the benefits for Outotec.

7.2 Future scenarios

Whilst writing the thesis, some topics came up which were too large to solve within the scope of this thesis. These issues are presented in this chapter. A big question for Outotec is managing the supply chain management as a whole. Outotec's Service Centers might have to deal with several customers, thus the flexibility of StockOptim is under heavy inspection. A couple of possible scenarios rose up, which could possibly be subjects of future research on their own.

A very relevant question is managing a multiple users and warehouses scenario. Outotec Service Centers (SC) might be dealing with many customers, and the Service Center is supported by the Service Product Center (SPC). In the following figure, *Global warehouse* refers to SPC, and *Regional warehouse* refers to SC's. Managing a multilevel storage plan is something StockOptim cannot do automatically. Defining the methods on how StockOptim can be used to plan the complete supply chain is a future subject for research.

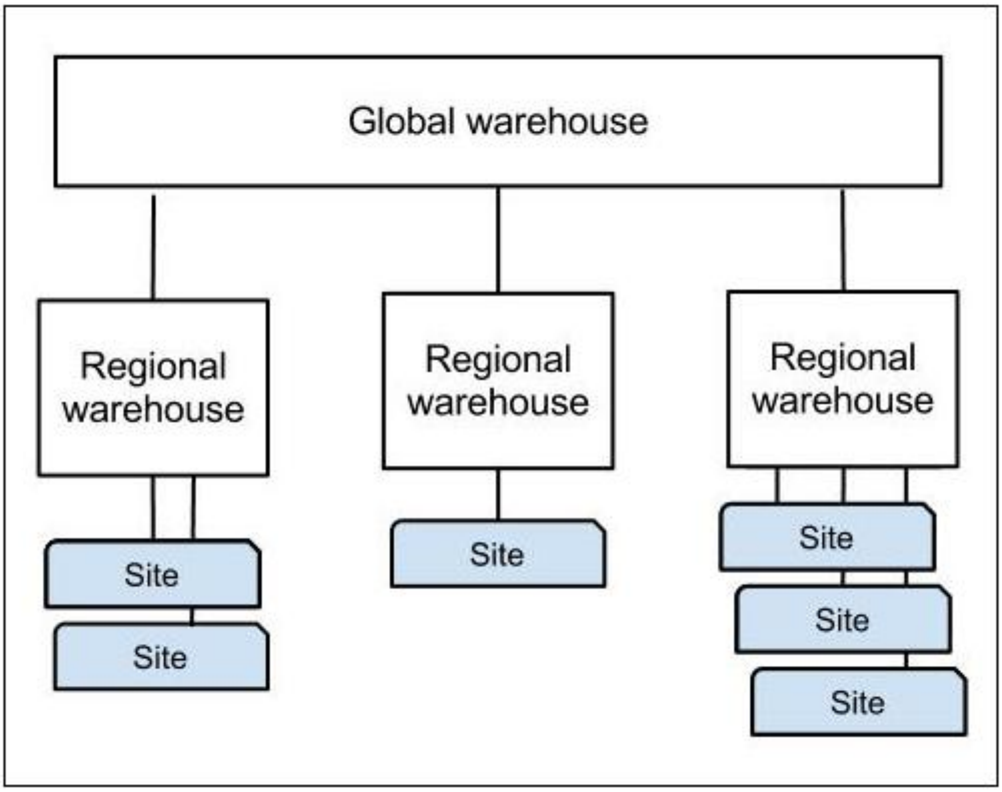


Figure 32. SCM model

A Ramentor specialist suggested that this sort of scenario can be optimized with StockOptim, but it has to be done one stage at a time. Each site has a number of assets, which consume spare parts. Once these amounts have been planned, the total consumption of the site is known. After all the consumption data from sites is known, the optimization for the regional warehouse can be done.

In theory this sounds like a possible task to perform, if all the variables are taken into notice. What if the consumption of a single site changes? What if another site appears? What if the *Global warehouse* has to be moved to another location? There are several questions, which need defining.

One thing related to supply chain management is researching the financial effects and the effects on availability, when some spare parts are stored in regional warehouses instead of sites. Studies should be done, if there are major differences on the production, if spare parts are stored by Outotec. This way Outotec could tell the client the actual effects it will take, if some spare parts are not stored close to the assets.

The reason why all of the spare parts should not be stored in the sites is the same reason why storage optimization is done in the first place – to reduce costs. Calculating the risks when choosing different storage methods for expensive spare parts should be a quick task to perform. If it is known that an expensive component will most likely last 5 years in use, the customer might not see any reason on storing the component before the first three years, for example. There is always a risk that the component might fail at any time, and in that case the shutdown costs will very likely exceed the storage costs for five years.

A study should be done, whether StockOptim could be used to swiftly examine reliabilities and prices of different storage options, as suggested above. This would allow the customer and Outotec to compare prices versus reliability on different options on warehousing.

The *Settings*-tab in the report spreadsheet should be fitted with all the possible variables, which can be changed in the final report.

8 Conclusions

Storage optimization software StockOptim can be used for Outotec warehouse planning, if some pre-requirements are met. The criticality analysis on ELMAS has to be done before the optimization, unless the warehouse data is usable, e.g. from a Brownfield site. The data also must include certain information, including spare part name, ID, price, asset hierarchy and failure behavior information.

Since the work stages of optimization are defined, the optimization process does not take very long, once the data is gathered. An optimized spare part plan should also be completed for the rest of the Filtration Plant. In the case of the thesis, the data gathering turned out to be a larger task than the optimization itself, so actions should be made to make the data more accessible. The surrounding IT architecture should support Ramentor tools to access the information which they need.

StockOptim could benefit Outotec and its clients both in Green- and Brownfield sites, where the warehousing is not at an excellent level. Performing the ELMAS criticality analysis for any plant can help on raising the availability, reliability and maintainability, and it will allow the use of StockOptim as well. Ramentor tools can be a powerful duo for Outotec, if measures are taken to support the use of them. With a bit more research, and a few actual case studies, StockOptim could turn out to be very useful software for Outotec.

9 Figures

10 Formulae

Formula 1. Availability definition, RAM Roasting case powerpoint
Formula 2. Initial investment cost
Formula 3. Investment efficiency
Formula 4. Availability calculated for each scenario

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