FACULTY OF SCIENCE AND TECHNOLOGY

MASTER'S THESIS

Study programme/specialization: Master of Technology Operations Management	Autumn semester 2018 Confidential
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Title of master's thesis: Enhancing Lean implementation by introducing a paperless process from sales through planning and production: An investigation into preparations and changes needed.	
Credits: 30	
Keywords: Manufacturing, Lean, ERP, Paperless production	Number of pages: 66 *(i-xiv, 1-52)* Stavanger, 10 December 2018

Title page for Master's Thesis

Faculty of Science and Technology

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Enhancing Lean implementation by introducing a paperless process from sales through planning and production:

An investigation into preparations and changes needed.

By

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A thesis submitted in conformity with the requirements for the degree of Master in Technology Operations

Confidential

Universitetet i Stavanger

Faculty of Science and Technology

2018

Abstract

A Lean implementation project at a well-established manufacturer of electro-mechanical products reviews the internal supply-chain and associated functions from request of quotation through delivery.

During this work, it is discovered that an aging ERP system is not fully supportive to new work processes. As a result, a web-based paperless production system will be installed to enable the production planners to dynamically see capacities in various production departments and perform interactive planning for optimization of the production process. The goal is to create a better flow, improve quality, and minimize waste.

Methods chosen in the action research relate to an ABC analysis of sold products and tracking the corresponding production processes to discover constraints and areas of improvement.

The thesis is centered on the question on how to successfully implement a paperless production system, and it finds the answers by dissecting the pre-production and production processes, highlighting what should be adjusted prior to the implementation. The required improvements in processes will be both in the technical and human domain and are considered vital for a continuous growth and an improvement of customer support.

Sammendrag

En Lean-implementering ved en veletablert produsent av elektro-mekaniske produkter gjennomgår hele leveransekjeden og tilhørende funksjoner.

Gjennom arbeidet avdekkes svakheter ved en aldrende ERP-løsning, og bedriften velger å investere i et papirløst produksjonsstyringssystem som muliggjør en dynamisk og sanntids oversikt på kapasiteter i produksjonsavdelinger og forbedret planleggingsfunksjon. Målet er å øke flyten i produksjonen, forbedre kvaliteten i alle ledd, og minimalisere ineffektive kostnader.

Blant metodene som er brukt i denne aksjonsforskningen er en ABC-analyse av solgte produkter og de tilhørende produksjonsprosesser, med hensikt på å identifisere flaskehalser og forbedringspotensialer.

Denne masteroppgaven stiller seg spørsmålet om hvordan man går frem for å forbedre en virksomhet på vitale områder. Svaret finnes ved å gå dypt i prosesser i både forkant av og under produksjonsprosessene, og som derved påviser forbedringspunkter som bør forbedres før en implementerer et papirløst produksjonsstyringssystem. Dette vil være forbedringer både av teknisk og menneskelig art og som vil være vesentlige for videre vekst og forbedret kundeservice.

Acknowledgements

First I would like to thank my mentor, Professor Dr. Jan Frick at the University of Stavanger for his good advice, motivation, and patience during the work on the thesis. His guidance has been a journey where the goal is not simply crossing a finishing line, but the journey itself.

I would also like to thank my employer, R. Stahl Tranberg AS for allowing me to undertake the task of making a research into our main processes of delivering products to our customers. A special thanks to Terje Sørtun and Jean-Marc Bollmann for detail discussions of discoveries made during the project.

To my dear and patient wife Thorborg, who not only during this research had to see me disappear into my study, but whom also found me preoccupied and drifting away during casual conversations. Thank you.

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List of abbreviations

ATO – Assembly To Order

BOM – Bill Of Materials

CNC – Computerized Numerical Control (automated machining of components)

Company – R. Stahl Tranberg AS

ERP – Enterprise Resource Planning

ETO – Engineer To Order

IT – Information Technology

KPI – Key Performance Indicator

MTO – Make To Order

MTR – Manufacturing Test Record

MTS – Make To Stock

PN – Part Number

PO – Purchase Order

RFQ – Request For Quotation

SO – Sales Order

TEF – Tranberg Elektriske Forretning (company acronym)

Variant – A specific BOM

VSM – Value Stream Mapping

WIP – Work In Progress

WO – Work Order

Chapter 1 Introduction

1.1 The target group

The thesis is oriented towards an internal process change at R. Stahl Tranberg AS (the ‘company’), covering the value chain process from quotation until delivery. The terms and descriptions used in the thesis are to some extent internally oriented, at the same time supportive comments are provided for external readers.

1.2 Objectives and motivation

The background for this master thesis is an ongoing internal Lean project. This looks into several aspects of the company for identifying constraints and maximizing possibilities for improvements.

This internal Lean project also include a project for moving from a paper-based production Work Order (WO) system to using tablets throughout the production area (paperless production).

One of the key objectives of a paperless production system is to have a better planning functionality by visualizing need of materials and human resources for a WO, and to have an online status of all work in progress at the factory. This is dependent on correct estimates of materials, and that the required number of work hours is as correct as possible. The end result of combining the Lean activities with the paperless system would potentially be a significant improvement to the company.

1.3 Challenges

Introducing a paperless production system to the company is expected to have a set of challenges, technical as well as human. The technical issues relate to the computer systems and data quality, while the human aspects are related to habits, methods, and procedures.

A major challenge will be ensuring employees understand the need for a change. The second challenge is more technical in that we need an end result that is an improvement in comparison to the existing paper-based WO system. The third challenge is maximizing the “Lean” value of the end result in simplifying whatever is possible to make business processes more agile and prepared for disruptive changes in the market.

1.4 Research in brief

While reviewing and analyzing work processes and data from WO’s I realized that actual work hours for the same product varies to a large degree, and typically more work is needed than planned. Another observation is that customized products are very important for the business, but that they often have inadequately defined Bill Of Material (BOM), and an under-estimated workload. This discovery directly affect the main objective of the paperless production system as a driver for a Lean production, and my research point in the direction that a more rigorous process should be followed when handling customer-specific deliveries in order to perform more realistic production planning and cost optimization.

1.5 Structure of the report

The structure is arranged in 10 chapters as follows:

- Chapter 1 Introduction: A description of the paper.
- Chapter 2 Background: Presentation of the company presentation and challenges
- Chapter 3 Objective: The goal of this research
- Chapter 4 Theory: Three areas that need improvement for quality deliveries
- Chapter 5 Methods: Presentation of methods used, and why.
- Chapter 6 Analysis: Presentation of the data
- Chapter 7 Paperless production: A description of the paperless system
- Chapter 8 Validation/Discussion: Interpreting and discussing the analysis
- Chapter 9 Conclusion: A summary and suggestions for further research
- Chapter 10 References: List of references

The report is intentionally created in a way so that a preceding chapter prepares the reader for the next chapter. Furthermore, it is with intention made as short and fact-oriented as possible, without losing out important sections. Large tables are inserted in the Appendix section in order not to blur the vision of the reader.

Chapter 2 Background

This chapter gives an introduction of the company, products, IT systems, and production methods. It also introduces some themes that are being referred to later in the thesis.

2.1 Presentation of the company and its products

2.1.1 About the company

R. Stahl Tranberg AS is a Norwegian company established under the name Tranberg AS in Stavanger in 1901. Owned by the family Tranberg until 2005-2006, as the company became a part of R. Stahl Ag in Germany. The company develop and manufacture electro-technical equipment for the oil and gas, and maritime industry. In the summer of 2017 Tranberg AS acquired sister company Stahl-Syberg AS, and subsequently changed its name.

2.1.2 Main data about the company

- Offices and production sites: Stavanger (HQ) and Lørenskog
- Employees: 86
- Turn-over 2017: MNOK 243
- Financial result: MNOK 6

2.1.3 Products

Product areas with in-house production and assembly:

- Marine lighting: Navigational lanterns, signal lights, searchlights, floodlights, deck lights, and control systems.
- Helicopter landing decks: Perimeter lights, floodlights, windsock with illumination, status lights, Circle- and H-lights, and control systems.
- Electrical connections: Junction boxes, small to large in various designs, cable glands, cable protectors, cable clamps.
- High voltage: Junction boxes and termination equipment.
- Heat trace: Thermostats, junction boxes, protective materials, control systems.
- Anti-ice and de-ice systems: Junction boxes, protective materials, control systems.

The company delivers products and systems world-wide; approx. 30% exported, a number which is growing.

2.2 ERP systems and functionality

The company is challenged by two different Enterprise Resource Planning (ERP) systems; Visma in Lørenskog and Microsoft Axapta (Axapta) in Stavanger. This hinders a common purchasing and logistics handling, but also production planning and inventory handling. There exist plans to invest in a new and common ERP system.

This thesis is entirely focused on the production facility in Stavanger, where Axapta version 3.0 is the ERP system handling the following areas:

- Sales: Customer information, quotations, sales orders, etc.
- Product main data: Main repository for all products and components, Bill Of Materials (BOM), Routes (process lists), check points, etc.
- Product technical information: Separate archives for documents and drawings, all linked to part numbers and/or specific BOM.
- Production technical information: Archives for CNC (Computerized Numerical Control) programs, linked to part numbers and specific BOM's.

I will briefly describe some main areas and functions of the ERP system, as these are referred to several times in this paper.

Products

Overall there are over 21,000 live products, components, and materials in the Axapta ERP system. Active sales items are in the area of 5,000 products, with an additional 3,000 spares and components. Our owners want to reduce the number of valid items by as much as 30-40% over the next year, a fact which should be considered whenever discussing discontinuation of products.

Inventory

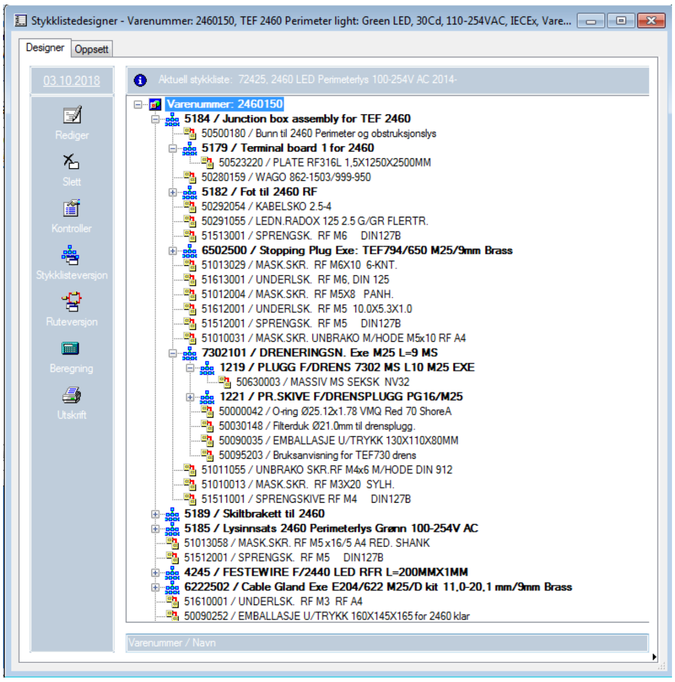
The inventory balance is always subject to optimization, both in contents of actual goods and its value. Hence, a continuous watch is kept on the validity of stock items, quantities, and inherent values. This is reflected upon by the suggested lot sizes from the ERP system, so that just the bare minimum is manufactured for each work order.

Net requirements

At the top of the hour, the ERP system runs a net requirement plan. This includes all new sales and other planned production items, and generates a complete breakdown requirement plan with part numbers and suggested quantities. This list is manually reviewed and adjusted with respect to quantities and date of delivery; thereafter this is broken further into WO's.

Bill Of Material (BOM)

All products except purchased items have defined BOM's. The BOM for product 2460150 helideck perimeter light (an example used later) is shown in Figure 1 below:



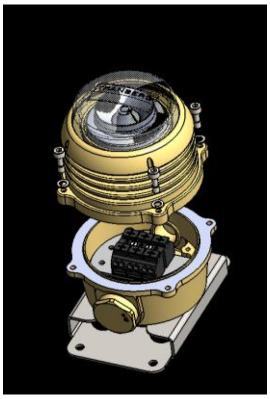
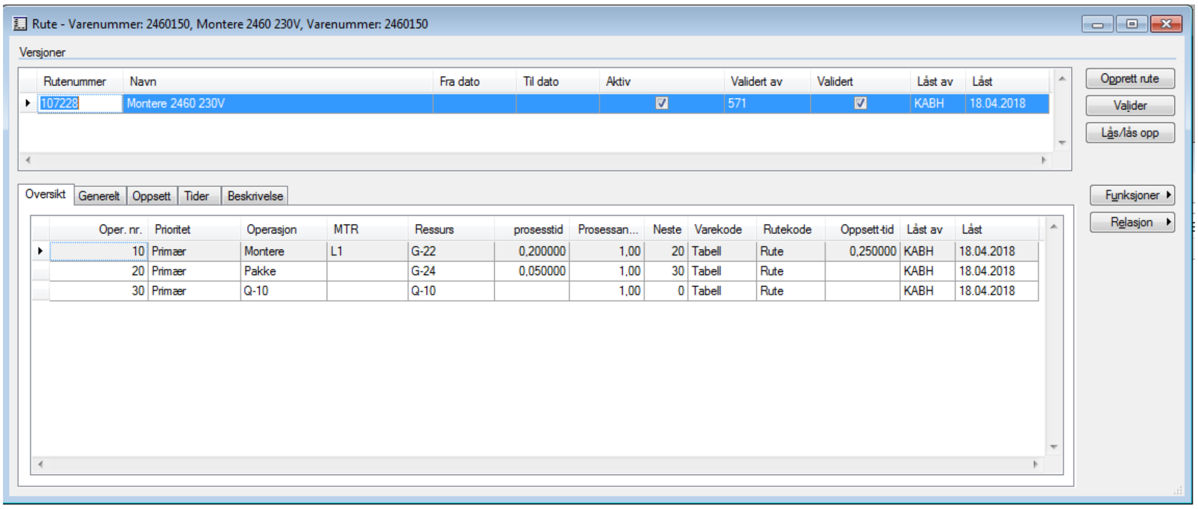


Figure 1 BOM and illustration of helicopter landing deck perimeter light 2460150.

What we see is a hierarchy of 5 levels, which describe the complexity and actual number of parts that makes up the product. Most of the components are also used in other versions of this product, thereby simplifying final assembly. Components and assemblies are discussed at later stages in this paper.

Route

A Route describes the various process-steps required for the production process. This is typically divided into a set of sequential steps, and includes a process time, and often a setup-time as a preparation for the task itself. The setup time is normally a definitive amount of time, while the process time is for each unit to be made. For low volumes the set-up time may therefore become dominant. For the example product 2460150 the following Route is valid:



Rutenummer	Navn	Fra dato	Til dato	Aktiv	Validert av	Validert	Låst av	Låst
107228	Montere 2460 230V			☑	571	☑	KABH	18.04.2018

Oper. nr.	Prioritet	Operasjon	MTR	Ressurs	prosesstid	Prosessan...	Neste	Varekode	Rutekode	Oppsett-tid	Låst av	Låst
10	Primær	Montere	L1	G-22	0,200000	1,00	20	Tabell	Rute	0,250000	KABH	18.04.2018
20	Primær	Pakke		G-24	0,050000	1,00	30	Tabell	Rute		KABH	18.04.2018
30	Primær	Q-10		Q-10		1,00	0	Tabell	Rute		KABH	18.04.2018

Figure 2 Route

We can see there are three operations steps in the assembly: 10 for assembly, 20 for packing, and 30 for rework (internally called Q-10). The setup time is 0,25 hours. This information is picked up and put on the applicable WO as this is printed out. It is also these estimates that are used and multiplied with the number of items to be manufactured, in order to calculate total production time, and subsequent capacity needs.

Variants

The ERP system allows multiple BOM's for each product, with one BOM always being the standard version of the product. The term 'Variant' is used for other versions of the BOM, and typically these are defined by the sales- or engineering department to configure customer-specific versions of a product. Variants are defined by using the Part Number (PN) with the extension which is the respective number of the BOM list within the ERP system, e.g. 2460150-62372.

Variants may also require more or less work during the manufacturing process, and which is why a dedicated Route also can be defined to align with the specific Variant. Subsequently, Variants can be calculated with their own cost prices, but also be planned with other manufacturing process times than the standard versions of a product.

Work Orders (WO)

The WO's contain the applicable BOM with quantities and inventory locations, a description of the processes (Route), relevant drawings, a MTR check list (Manufacturing Test Record), and also relevant information for CNC programs to be used in the machining and sheet steel departments. A WO is always put inside a flexible A4 red plastic folder. This is prepared by the planner and delivered to the various production departments at the Stavanger facility:

- Sheet steel and welding department
- Machining department
- Electronics assembly department
- Searchlight assembly department
- Ex-approved assembly department
- General products assembly department

In addition, and as a part of the sales department, the engineering department handles engineering of customer-specific products such as control systems, heat trace installations, anti-ice and de-ice systems, control cabinets, etc. They are also subject to planning and WO's for their involvement in customer projects, and is often the starting task as they will provide the production drawings.

Registration of working hours

Operators register start and stop of each activity on work orders by means of a bar code reader towards the respective WO's. Individual ID is available on a board next to the bar code reader, and this enables identification of person, work order, and activity. This system is called TimeCatcher, and used in every production department.

2.3 Planning and production

For the company it is important to deliver products on time, at the right quality, and correct quantity to its customers. Relatively small batches are run in the production area; we have therefore several change-over each day throughout the production departments.

Axapta has a rather poor graphical planning system and this result in the planner issues WO's on paper for further processing and detail planning in the production area. Drawings and test schedules are printed automatically as the WO is printed, and are included in the same folder. This leads to stacks of WO's in the respective production departments, and which are not interlinked with dependencies in order to assemble a complete product, e.g. sub-assemblies required.

As a way to identify and prioritize WO's for which a customer is waiting, the planner makes a copy of the applicable sales order. This is inserted as the front sheet of the folder with the respective sales order line highlighted with a yellow marker, along with additional information or instructions written to it. Sometimes additional information is added manually, such as copies of customer drawings. The two latter items may be described as "unconnected information", that is information for which there exist no database relations.

As the WO is distributed to the various production departments, the planner has little feedback to what happens next. The standing agreement is that WO's with a copy of the sales order, are to be prioritized by the group leaders. The foreman in the respective department makes the detail planning and issues the operators with the respective tasks to carry out. Figure 3 shows the desk of a group leader in one of the assembly departments. We observe that the front pages on most of them are a copy of the sales order, where the item to be made have been highlighted with a yellow marker. In addition we can see handwritten messages from the planner made with a red pen, and yellow stickers with further instructions.

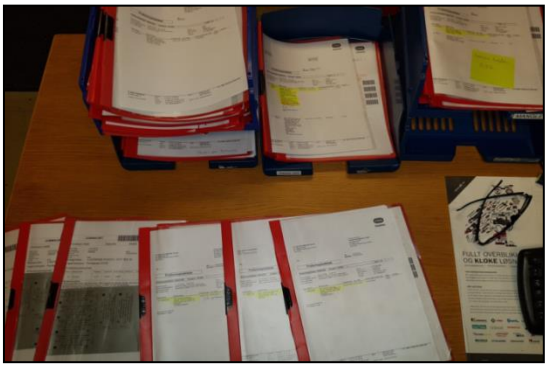


Figure 3 Group leader's office

As these WO's are handed out from the group leader to the operators, there is no 'receipt' left as a reference that the particular WO was handed out, with the exception of making several queries in the ERP system. Due to this there might be repeat WO's for the same product or component, with the result that multiple WO's will run in parallel.

2.4 Types of Work Orders

Typically products (and therefore WO's) are defined in three categories (Nicolas, 1998, p. 583-584):

- Make To Stock: MTS. These are products that are manufactured and put into the warehouse or sold as-is.
- Assemble To Order: ATO. Same products as for MTS, but which are only assembled once a Sales Order calls for it.
- Make To Order: MTO. Often the customer cannot use an existing product as is, and needs some modifications to it. Other times the customer needs a tailored solution and where very little exists as a standard solution. MTO's are defined as Variants in the ERP system (see chapter 2.2).

To cover the needs of our company, one more type needs to be included: ETO. Engineer To Order (ETO) is a Work Order issued to the engineering group in order to develop a specific solution for a customer. The results from the ETO could be delivered 'as-is' to the customer, or it could be used as a framework for a WO for MTO. This brings the total types to five as shown in Table 1:

<table>
<tr><th colspan="6">Definition of Work Orders</th></tr>
<tr><th>No</th><th>Type</th><th>Description</th><th>Explanation</th><th>Subject</th><th>Customization</th></tr>
<tr><td>1</td><td>MTS</td><td>Make To Stock</td><td>Manufacture and move to inventory</td><td>Components, sub-assemblies, spare parts, and finished products</td><td rowspan="2">No</td></tr>
<tr><td>2</td><td>ATO</td><td>Assemble To Order</td><td>Manufacture only when customer orders</td><td>Finished products or spare parts</td></tr>
<tr><td>3</td><td>ETO</td><td>Engineer To Order</td><td>Non-physical products</td><td>Calculations, analysis, drawings, documents</td><td rowspan="3">Yes</td></tr>
<tr><td>4</td><td>MTO</td><td>Make To Order</td><td>Customer-specific manufacture, and assembly</td><td>Finished products</td></tr>
<tr><td>5</td><td>ETO + MTO</td><td>Engineer To Order and Make To Order</td><td>Customer-specific design, manufacture, and assembly</td><td>Finished products</td></tr>
</table>

Table 1 Definition of WO's

The first two types are for standard products only, while the MTO is what identifies a customer-specific delivery. The ETO is a required process step to provide engineering work (review, calculations, drawings, programming, etc.) which either constitutes the delivery by itself, or whether the results from ETO is used to support a MTO delivery.

The ERP system does not discriminate between the types of WO’s, except that the part number itself may be assigned to be a stock item, or only made upon a customer request. This converts to MTS and ATO, respectively.

2.5 Summary of background

The company operates with two separate ERP-systems, which is a constraint in leveraging the production capacities in the two locations. There is a large overall quantity of various products registered in the ERP system in Stavanger, of which only a relatively small amount has a turn-over. Furthermore the aging ERP system provides very poor planning capabilities and a poor overview of active Work Orders, and this is a significant challenge in optimizing production capacities.

Chapter 3 Objective

The objective of this thesis is to identify ways to increase profit and quality by implementing a paperless production system that leverage on Lean processes. This is done by conducting an action research into some major areas of the company as listed below.

3.1 Lean work processes

The company continue the Lean introduction and need to improve both sales and production processes. New product development must be anchored at designs that result in simplified production methods and assemblies, but which also allow quick product updates.

3.2 Aligning data within the ERP system

While the company at one hand plans for introducing a paperless production system, the aging ERP system is to be replaced with a new system within a few years (probably SAP). It is considered good practice to perform a general clean-up of data within an existing system prior to migrating to a new system. In this case this includes voiding products which has a low turnover, or which is at a natural end-of-life. Of no less importance is ensuring that product and production data, such as relevant BOM’s and Routes, are as correct as can be. The integration to a paperless production system will require some important interfaces to the ERP system, and which will be highlighted and discussed.

3.3 RFQ (Request For Quotation) process

Over the years we have become aware of a lack of control in some work associated with quotations, engineering, and production for customized products. The outcome is very evident: Improper planning due to wrong initial estimates of work, delays due to materials not being available or growing amount of scrap due to incomplete drawings, or lack of detail richness lead to more scrap. Thus this directly affects the profitability of the company, and it may result in undesired customer service.

3.4 Summary of objective

The thesis tries to highlight that going deep into historic business data may lead to an identification of key areas that are critical to improve both customer support and profitability. With that in place, a paperless production system may become a strategic tool in aligning the ongoing projects for continuous improvements.

Chapter 4 Theory

Our parent company has a focus on implementing Lean in all affiliates. As such it would be a good match to ensure the paperless production system has a reference to Lean principles.

4.1 Lean at a glance

The traditional way of displaying the Lean activities is a house highlighting the main activities. The roof represents the customer focus, which is the primary objective. Everything else is subordinate, yet critical for a Lean process. There are two main pillars consisting of a Just-In-Time orientation for optimized production process, and Jidoka for how to handle variance. The joining part in the middle is headlined Involvement with a set of activities that is also present in other main parts of the Lean building.

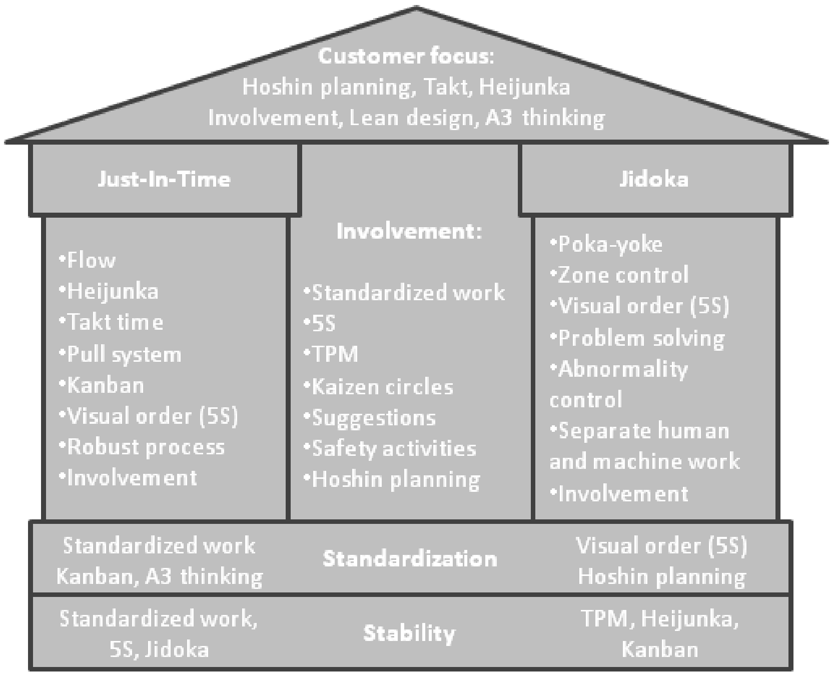


Figure 4 Lean production simplified (Dennis, p.19)

The two fundaments in the bottom are Standardization and Stability.

Although the core goal is to provide the highest quality, at the lowest cost, in the shortest time by continually eliminating waste, customers today have broader expectations. Dennis (2002, p.19) states that safety, environment and morale are added to core goals of lean companies.

4.2 Lean production

In my opinion, having order in production related information is to high degree a part of the Lean thinking. Connected information, such as correct machining and assembly drawings linked to the respective part numbers, is vital in ensuring a correct manufacturing process. Drawings are typically subject to revisions, sometimes due to changes related to improvements, sometimes due to change in suppliers or for other reasons. It is therefore imperative that the correct drawings and revisions are presented to the operators in production.

Furthermore, BOM and Routes must be properly declared and correct. This ensures on one hand correct material supply, and to the other hand a good foundation for planning production processes correctly.

A third part is relevant and correct test procedures for the production process, and the ability to record correctly the performance and results. With a growing need for handling unique serial numbered items and individual follow-ups in case of later defects, individual items may be subject to testing with full digital logging of test sequences, personal identification, and test results.

Finally, and as a closing remark, recording the start and stop of each production step is of great interest. This is due to two reasons; identifying the progress in production, and verification of planned time spent versus actual time spent. This may subsequently be used to identify areas with problems, and may lead to improvement possibilities. With a non-stop flow of production data, we will have a very good starting point for analysis and continuous improvements.

4.3 Lean tools that are reflected in this thesis

It has already been mentioned that good and timely information is important for ensuring high quality. Furthermore, a well-prepared organization with respect to training and professionalism will help absorb required changes that occur in the marketplace.

The following key areas of Lean production are discussed and referred to in this paper:

4.3.1 Keeping things tidy: 5S

Keeping the workplace in a fit state with tools and surroundings may have a profound improvement of efficiency. This is the five terms that constitutes 5S:

- Sort
- Set in order
- Shine
- Standardize
- Sustain

4.3.2 Mura, Muri, and Muda: Irregularities, Overload, and Waste

The 3M of the lean thinking are all related to waste. The three elements focus on removing variability, balancing load on machinery and people, and removing the cause for direct waste. Dennis (2002, p. 36) states 5S training is a quick payback investment, but a focus on the 3M may well contribute with even greater financial benefits.

4.3.3 Continuous improvement: Kaizen

Kaizen is a strategy where all employees work together to improve the business. This is based on the Deming circle with the four activities Plan, Do, Check, Act (PDCA), as described by Liker, (2004, p. 264) .

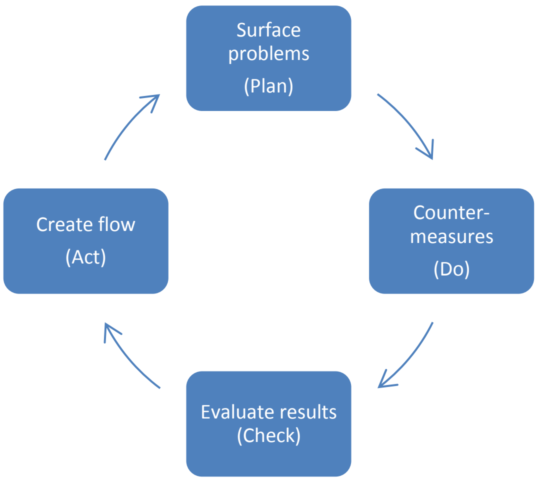


Figure 5 PDCA cycle

Having precise feedback from the production data regarding planned vs. actual time used is one way of using the PDCA-loop: Define the opportunity and plan the change, then test the change, follow up with a review of the test results, and finally implement the results from the test. If the test was unsuccessful, rerun the cycle.

4.3.4 Kanban

High volume components, such as screws, washers, and nuts, may be treated as commodities. Often such items are distributed throughout the various work cells in the production and assembly areas, and replenished as the volume decreases below defined limits.

4.3.5 One-piece flow

One-piece flow is a Lean method of letting a product flow through the production from beginning to end, with a continuous value-added process, and minimum Work In Progress (WIP).

There are 7 benefits of the one piece flow (Liker, 2004, p.95-96):

- Builds in quality
- Creates real flexibility
- Creates higher productivity
- Frees up floor space
- Improves safety
- Improves morale
- Reduces cost of inventory

One-piece flow should have minimum change-over times. It may fit well with low volumes of items to be manufactured, but requires a flow in production.

4.4 Summary of theory

Some key Lean tools are identified for guidance and positioning the company for the future. Combined with an improvement in sales- and production processes, this may be helpful to reduce variability and waste, and contribute to improved visibility and flow.

Chapter 5 Methods

5.1 Action research

Koshy (2005, p.3) states “Action research creates new knowledge based on enquiries conducted within specific and often practical contexts”. This thesis may be viewed as an action research within the company as it connects to an ongoing Lean implementation project. The results from the analysis of this thesis have as such been distributed, discussed, and partly used for other actions in that project. The advantage to this model is that it ensures a focus on important areas, and that it can express the need of more detail research.

5.2 Available methods

Both quantitative and qualitative methods have been used in this thesis. The quantitative methods include gathering information from 2017 as a calendar year, then various steps with ABC-analysis and further processing to bring forward relevant information.

The qualitative methods are represented through interviews, group work, and mapping of production processes. The interviews were made with relevant staff in order to highlight areas or functions that were unclear, or to validate findings.

The following paragraphs will further explain the details.

5.2.1 Gathering and use of existing information

As a part of the work with the thesis, a Microsoft Access database was set up and loaded with product and production data from the Microsoft Axapta ERP system. Data included BOM lists for all products, all Work Orders for 2017 (with part number references, quantities, date and planned vs. actual production times, and more). Some of the data was then exported to Microsoft Excel for more powerful data analysis and then imported back into the Access database for use as comprehensive data tables. This led to a number of queries and reports combining otherwise unrelated information, providing a rich data set for analysis.

In order to get a good overview of the current business as a whole, a natural starting point was gathering production and sales data for 2017. This was in many ways a year with positive financial results, no layoffs, and good utilization of the capacity of the company.

5.2.2 ABC analysis

The Pareto principle is used to divide sales value, inventory value, etc. into three classifications on the basis of annual value (Heizer, Render, Munson, 2017). This is often called an ABC-analysis. This puts products categorically in class A, B, or C.

An ABC-analysis was the cornerstone for this thesis. This outlined the categories of products that constitute 70% (A), 20% (B), and 10% (C) of the value of sold products. The analysis was further used to highlight products that had a high level of variance (overall number of BOM lists), but also a deeper study into the number of Work Orders in comparison to number of sold units.

As a control reference, an analysis was also done to a set of products which are deemed as standard products, and which are made repeatedly in batches of sizes from 30 to 50 units.

5.2.3 Interviews

A number of interviews were also made, either to support the findings or to sort out misunderstandings or inconsistent data used in the study. Results of interviews are blended on the relevant sections of this paper.

5.2.4 Process Mapping

As a graphical presentation of the process steps and dependencies, process maps of all deliveries were made to describe the current situation. This includes MTS, ATO, ETO, and MTO. These were quality checked with the respective departments, such as sales, engineering, production, and quality.

5.3 Summary of methods

Quantitative methods are used for the most of the analysis, and in particular with a reference to an ABC-analysis of sold products. Data and findings are discussed through qualitative group work with colleagues in the internal Lean project. As an action research project, the results from these discussions are brought back into the work on the thesis and drive the research as an iterative process.

Chapter 6 Analysis

The investigated data from the Axapta ERP system will be presented in this chapter, but also a review of the various work processes for the production area. I will start with some background information that will be referred to later.

6.1 Sales and products facts

The following data comes from the 2017 study:

- Unique part numbers sold: 1,909
- Total number of items sold: 271,924
- Sales value: 157 MNOK

Volume of items includes metrics such as pieces and meters. For instance, heating cables was sold in units of meters, and is included in the numbers.

6.2 Production facts

The following data comes from the 2017 study:

- Work Orders issued: 8,426
- Unique part numbers manufactured overall: 2,160
- Total number of items manufactured: 514,021
- Amount of Work orders with variants (MTO and ETO/MTO): 19%
- Planned work hours: 34,478
- Registered working hours on the job: 38,328 hours

6.3 Processing Work Orders

A WO is normally distributed to one department only, but in some cases it will pass through two departments before being completed. With reference to Table 1 in Chapter 2, I investigated which types of WO's in use at the company and found all types to be relevant; MTS, ATO, ETO, MTO, and ETO/MTO. I then made cross-functional process maps of the respective process flow and present these in the following pages. This not only shows the flow of the WO, but all work involved in the process, the responsibilities and the relationships (Damelio, 2011, p.88).

6.3.1 MTS: Make To Stock

Our company has no continuous production of the same product; thus the MTS is initiated upon inventory level dropping below a minimum level, or as a need from an overall production plan.

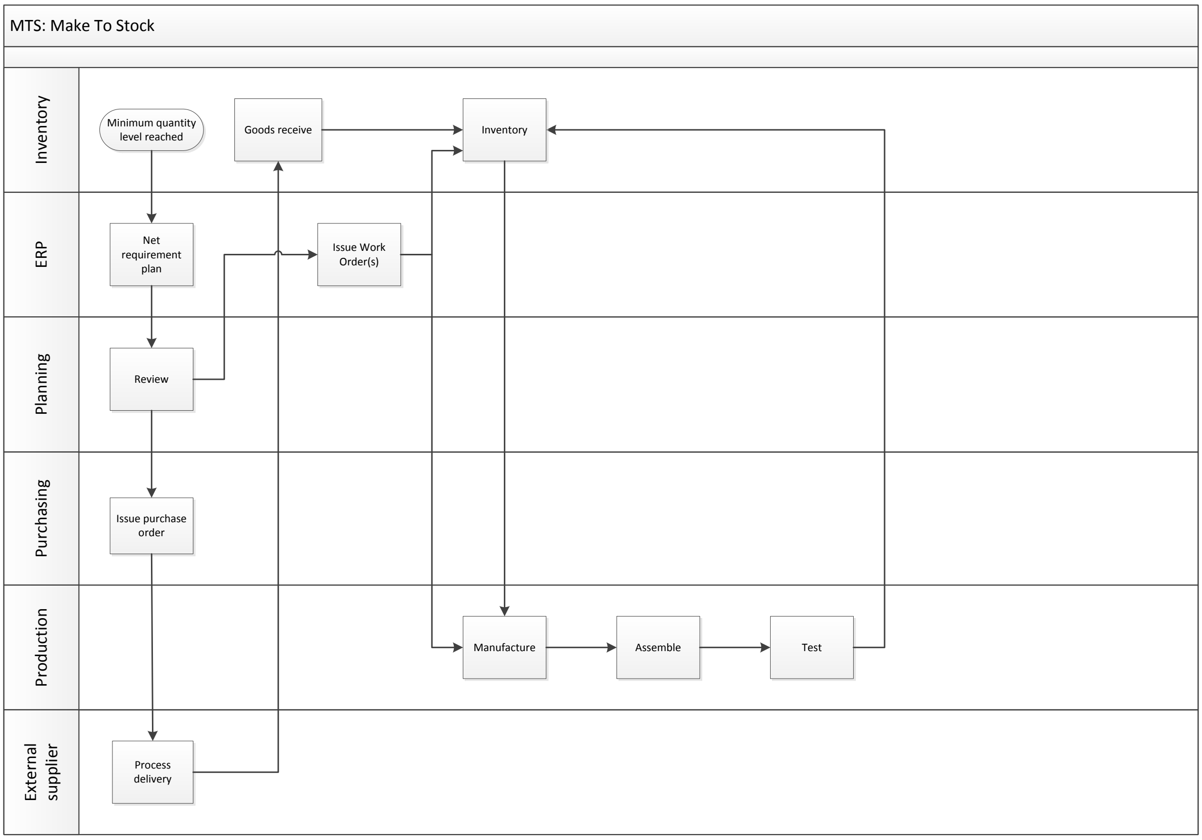


Figure 6 Make To Stock

The starting and ending point is inventory: First as a need, then as replenishment of physical products. The MRP II functionality within the ERP system handles the process as a batch process, based on a forecast, not as a pull system.

The supplier involvement is only relevant if some purchased items are missing, or will be below a minimum quantity in inventory.

6.3.2 ATO: Assembly To Order

This is very similar to a MTS, only that no work is started until a sales order is established and calls for the item. The benefit is that the said product is not in inventory withholding capital, but can be assembled in a relative short time. Normally it consists of standard components or pre-assembled units.

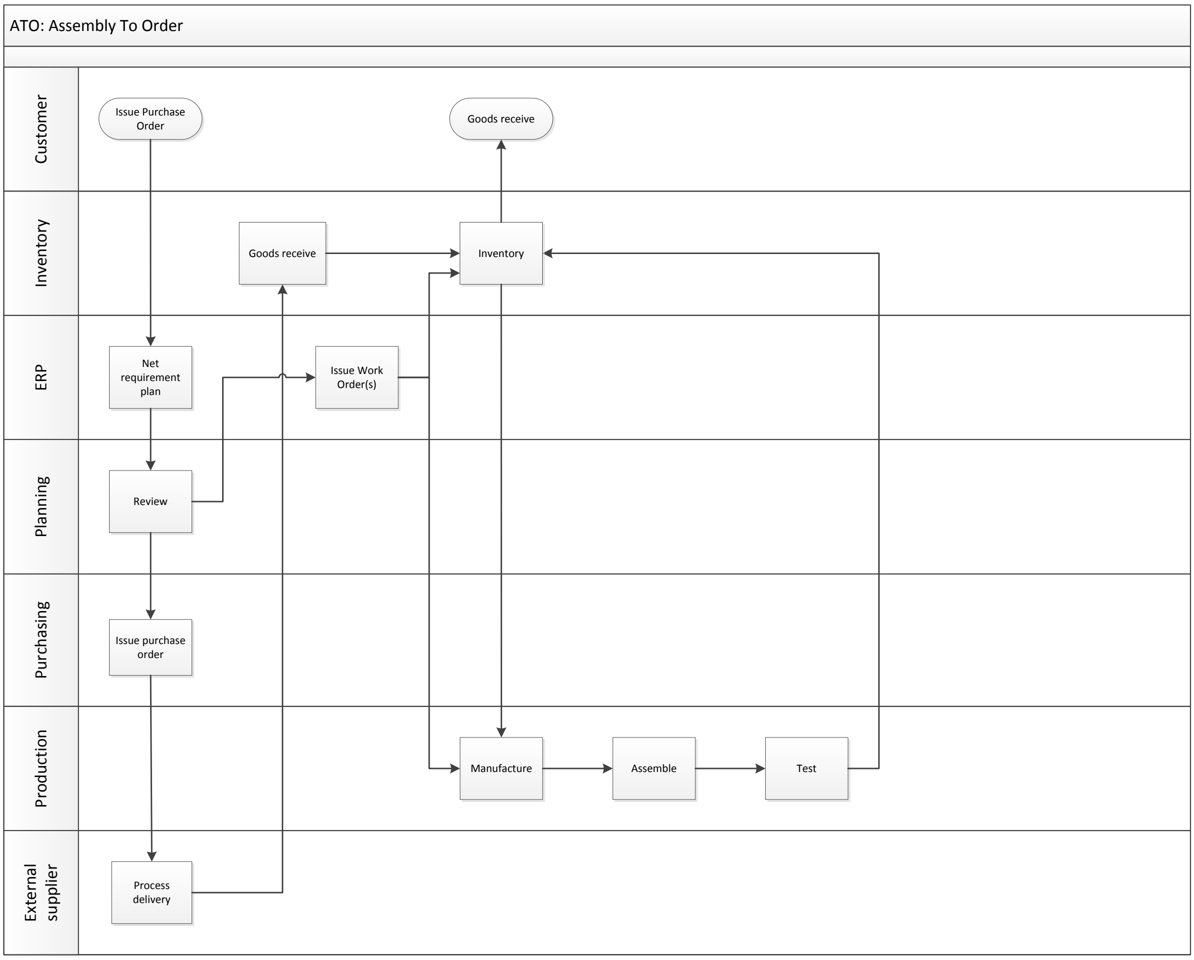


Figure 7 Assemble To Order

Referring to Figure 3 we see that the WO binder contains the copy of a Sales Order to identify that the WO is of type ATO.

6.3.3 ETO: Engineer To Order

A distinct category, ETO is an engineering job done for a customer where no additional products or systems are included. The results from the ETO are typically sent the customer as electronic information: Drawings, calculations, test documents, etc.

Figure 8 Engineer To Order

6.3.4 MTO: Make To Order

A simpler control system with a level of variance that could be assembled without specific drawings or other engineering activities can be addressed as MTO.

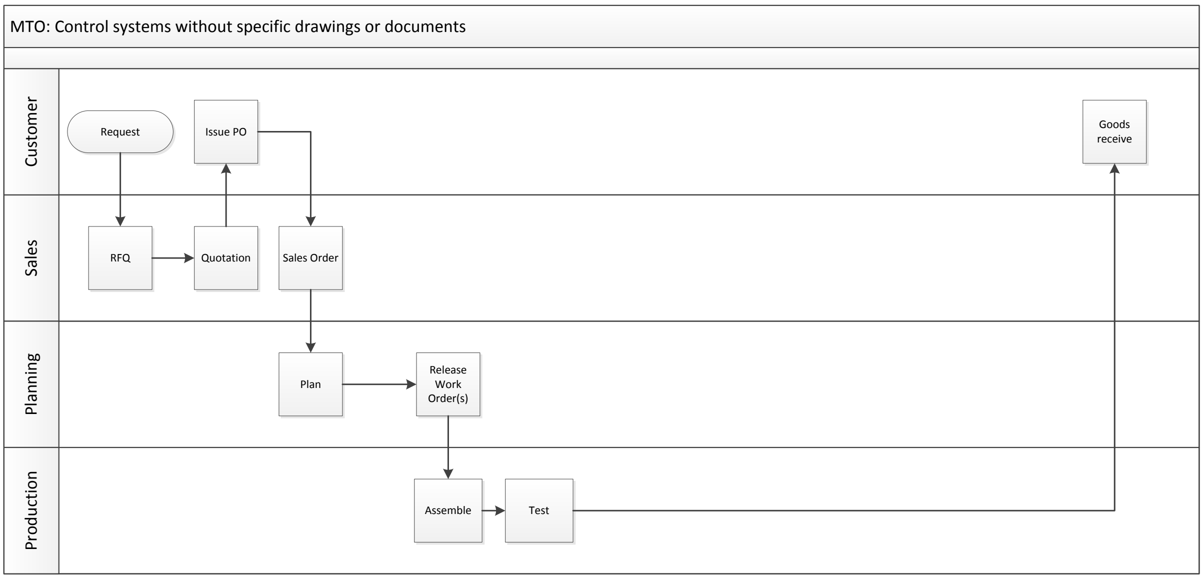


Figure 9 Make To Order

A MTO is a customized product with a small change or modification which does not require a set of drawings or complex pre-processing.

6.3.5 ETO/MTO: Engineer To Order and Make To Order

Some products, such as enclosures and larger cabinets, are subject to customer modification in three dimensions or other requirements. Common for this is that the customer modification requires a specific product at the very start of the manufacturing process, which includes engineering. Thus I refer to this as Engineer To Order and Make To Order (ETO/MTO).

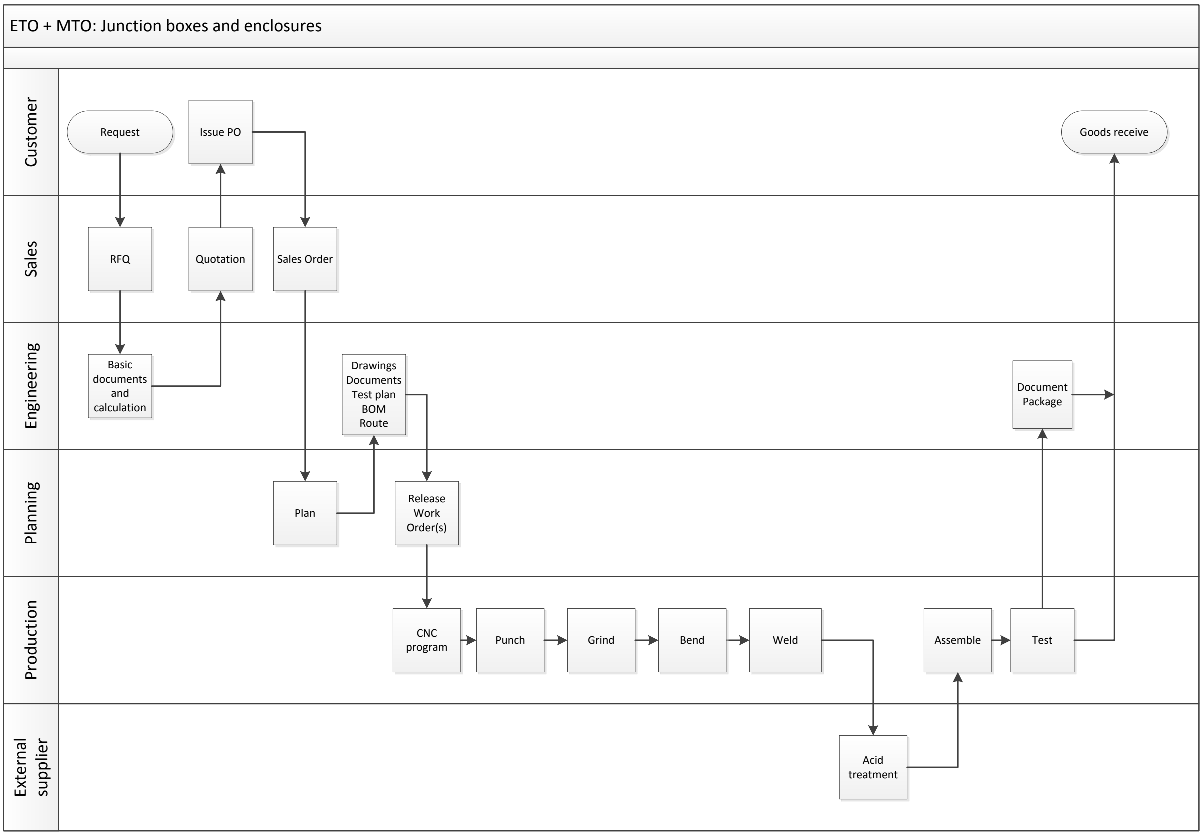


Figure 10 Engineer To Order + Make To Order

This type of Sales Order is often split as one WO for the ETO and another one for the MTO. It is important that the engineering output from the ETO, such as drawings and documents, are made available in due time for the production phase of the equipment (MTO).

6.3.6 Process description of rush orders

With reference to Figure 10, I will also include a description of a rush order. This is typically products that may be delivered on short notice, e.g. same day or next day.

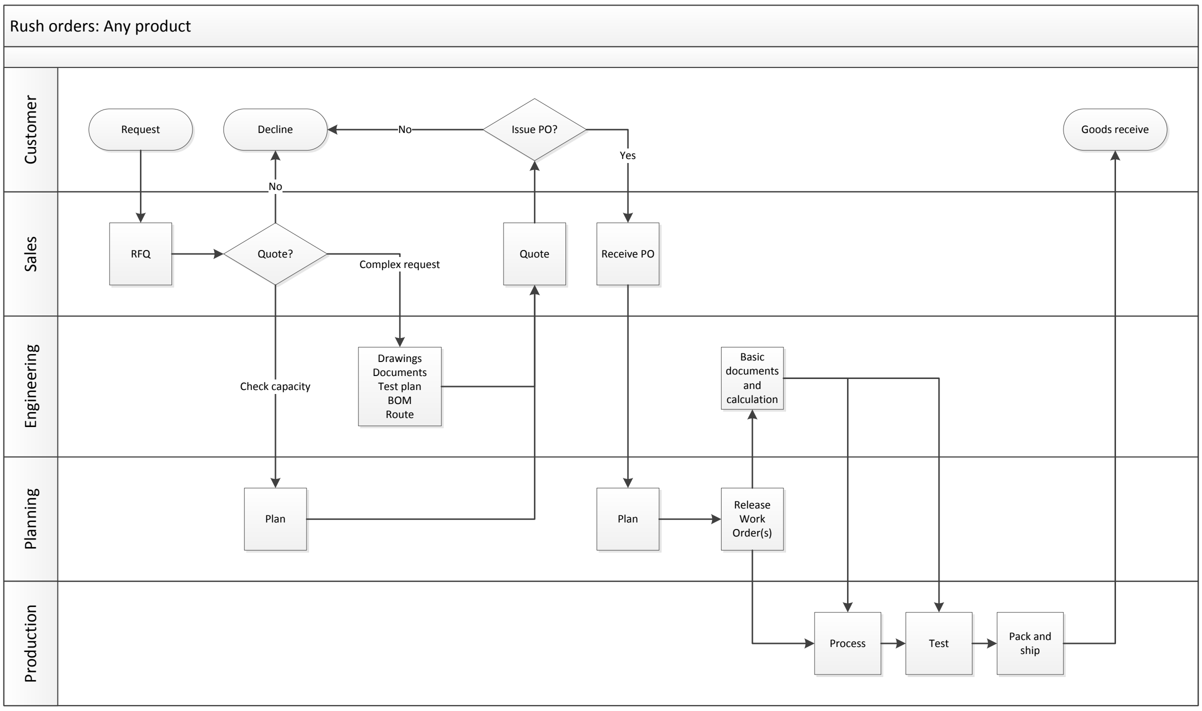


Figure 11 Process description rush orders

Common for this kind of orders is the short delivery time, and where all materials should be in inventory in order to deliver at the agreed time. If materials are not in inventory, rush orders may lead to serious variance due to additional purchasing activities, additional WO's for sub-assemblies, or re-planning of production schedules.

Rush orders are very often MTO deliveries and production is done at the expense of other planned or ongoing WO's.

6.4 ABC analysis of sold products

To understand the sales value, volume, and product mix of 2017, I ran an ABC-analysis of the products sold, and populated the table below. This includes quantities of unique part numbers in each category, and a split of products made, and those that are trading products.

ABC analysis of products sold 2017: Value and type of products					
Category	Grade	Value	Qty unique Part Numbers	Of which has a BOM	Trading products
A	70%	110 MNOK	87	68	29
B	20%	31 MNOK	239	178	61
C	10%	16 MNOK	1,453	874	579
Sum	**100%**	**157 MNOK**	**1,779**	**1,120**	**669**

Table 2 ABC analysis of 2017 (value and types)

It is observed that as few as 68 unique part numbers of manufactured products represent category A, in comparison to 874 unique manufactured products representing category C.

By reviewing the Work Orders in combination with the ABC analysis (assigned to the various part numbers) I distilled an overview that shows the volumes in each category, as well as the distribution of the products as standard or customer-specific MTO:

ABC analysis of products sold 2017: Volume view			
Category	Products sold		
A, B, C	Total volume sold	Total volume sold as MTO	% as MTO
A	82,777	31,714	38%
B	73,616	43,320	59%
C	115,530	88,607	77%
Sum	**271,924**	**163,641**	**60%**

Table 3 ABC analysis of 2017 (volume view)

This is interpreted to that an average of 60% of everything sold is a MTO, thus proving this is an important area for the company.

6.5 ABC analysis of manufactured products

The ABC analysis of sold products clearly shows that the sales are divided into two categories; Standard products (MTS/ATO) and Customized products (MTO). The analysis also shows that both are vital for the business as a whole. What the analysis does not show is the level of customization that is represented, and how this affects the manufacturing process. For this I will go into more depth of both categories and try to identify distinguishable differences.

I set up a query in the Access database for all WO's in light of the ABC analysis of sold products. This provided me with a view of the overall numbers of WO's, the ABC-categorization, and whether they were for a standard product version, or a customized version (Table 4).

ABC analysis of products made 2017: Work Orders in total - Finished goods and components				
Category	Work Orders			
A, B, C	Share	Sum of all	As standard (MTS and ATO)	As variant (MTO)
A	11%	917	427	490 (53%)
B	16%	1,330	922	408 (30%)
C	27%	2,259	1,801	458 (20%)
Components and Assemblies	46%	3,920	3,708	212 (6%)
Sum	**100%**	**8,426**	**6,858**	**1,568 (19%)**

Table 4 ABC analysis of 2017 (Work Orders)

This shows that more than half of the WO's for the category A products are customer-specific. Components are sub-assemblies to the ABC-products, and not sold as finished goods.

As an example of complex customization we find enclosures and cabinets made of sheet steel that are equipped according to customer's needs. In this category an entirely new enclosure must be designed and manufactured prior to the equipment being installed. As such, this needs to pass through more than one production department: Engineering, sheet steel department, and assembly department. This is clearly involving more unknown elements, as we are no longer dealing with an off-the-shelf product being slightly modified.

6.5.1 Deeper analysis of Work Orders

As a final investigation into WO's for 2017, I reviewed all 8,426 and classified them according to batch sizes for each WO. This is shows in Table 5 below.

ABC analysis of Work Orders and quantities being made: All types (MTS, ATO, MTO)						
Work Order details			Category and distribution			
Batch size	Number of WO's	Percentage of all WO's	A	B	C	Components and Assemblies
No limit	8,426	100 %	917	1,330	2,259	3,920
<100	7,469	88 %	904	1,223	2,017	3,325
<10	4,961	58 %	744	911	1,351	1,949
<5	4,224	50 %	685	786	1,163	1,590
1	2,305	27 %	477	422	672	730

Table 5 Work Orders and quantities made (all types)

The result is surprising to the fact that a large share of the WO's is for a quantity which must be classified to be quite low.

This result triggered the need for an analysis of how the MTO WO's were represented. Table 6 is the corresponding quantification of Table 5 only that this is exclusively for the MTO orders.

ABC analysis of Work Orders and quantities being made: MTO only						
Work Order details			Category and distribution			
Batch size	Number of WO's	Percentage of all WO's	A	B	C	Components and Assemblies
No limit	1,568	19 %	490	409	457	212
<100	1,548	18 %	487	402	454	205
< 10	1,326	16 %	448	325	385	168
<5	1,249	15 %	428	306	366	149
1	904	11 %	347	193	276	88

Table 6 Work Orders and quantities made (MTO only)

The observation made is that a large share of WO's for MTO products has a volume of one item only.

To complete this part of the analysis, I defined a query of unique manufactured P/N’s as presented in Table 7. This show a total of 2,160 P/N’s was manufactured in 2017. These are distributed as a mix of A, B, C, and Components and Assemblies over varying lot sizes.

ABC analysis of unique Part Numbers manufactured and respective distribution					
Data		Category of Part Numbers and distribution			
Batch size	Unique P/N’s	A	B	C	Components and Assemblies
No limit	2,160	65	175	874	1,046
<100	1,884	64	151	695	974
< 10	1,194	56	118	482	538
<5	1,043	54	110	425	454
1	666	42	91	280	253

Table 7 ABC analysis of unique P/N’s manufactured and respective distribution

One observation is that 30% (666 of 2,160) of all P/N’s were manufactured with a batch size as low as 1, and where the majority of products are classified as C products or Components and Assemblies.

6.6 An investigation into the differences of MTS/ATO, and MTO

With the observations made, I found it required to investigate and analyze how these Work Orders were carried out through our production. I divided this work into the two categories as shown in the next sub-chapters.

6.6.1 MTS/ATO - Standard products

For the standard product assembly process, a set of products were selected. A first review was made to identify the number of WO’s, and a second to find the respective time used for final assembly.

The chosen products run in reasonable production lots, and which rely on much the same basic components, only in different quantities: Navigation lanterns and helicopter landing deck lights. In addition I included a few sub-assembly components used in other products.

Furthermore, the products are normally run in stable batches, are not subject to customization, thus they should represent a relatively constant use of assembly hours. The following product groups were chosen:

Navigational lanterns:

Product: Type 2870 Navigation lantern in 5 versions				
Part Number	ABC classification	Total number of Work Orders	Total quantity made	Sales value NOK
2870001	B	5	100	171,605
2870510	B	5	105	179,770
2870515	C	7	34	43,890
2870611	C	4	13	18,909
2870711	B	4	80	100,572
Sum		**25**	**332**	**514,746**

Table 8 ABC classification of type 2870

Aviation lights:

Product: Type 2460 Helideck lamp in 5 versions				
Part Number	ABC classification	Total number of Work Orders	Total quantity made	Sales value NOK
2460150	A	11	298	1.005,312
2460160	B	7	138	229,380
2460162	C	6	16	18,117
2460165	B	5	36	85,825
2460166	C	4	18	22,966
Sum		**33**	**506**	**1.361,600**

Table 9 ABC classification of type 2460

The third category is sub-assemblies for medium volume lights:

Product: Type 2440 lamp inserts (sub-assemblies) in 3 versions				
Part Number	ABC classification	Total number of Work Orders	Total quantity made	Sales value NOK
2440995	No class	3	67	Not for sale
2440996	No class	3	5	Not for sale
2440997	No class	15	514	Not for sale
Sum		**21**	**586**	**0**

Table 10 ABC classification of sub-assemblies

We observe from the first review that neither the production lots, nor the volumes are very high for these three groups. The second part of this review was made for the various WO's for each product to analyze the repeatability of the work involved in the assembly.

Details from WO's

Type 2870 is a standard navigation lantern that has been in production for more than 15 years. The graph corresponds to Table 8. The vertical bar indicates -38% to +100% more time than planned for final assembly. A cut-off was made at +100%.

Type 2870:

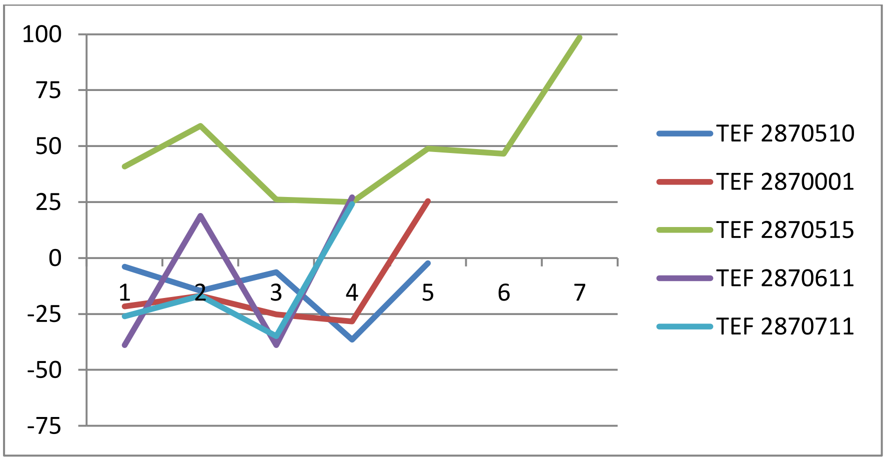


Figure 12 Navigation light type 2870 production hours

I then reviewed two types of lights for offshore helicopter landing deck. Type 2460150 is a perimeter light, and type 246016x constitutes four variant of an obstruction light of obstacles. All types have been in production since 2015. Again, a cut-off was made at +100%.

Type 2460:

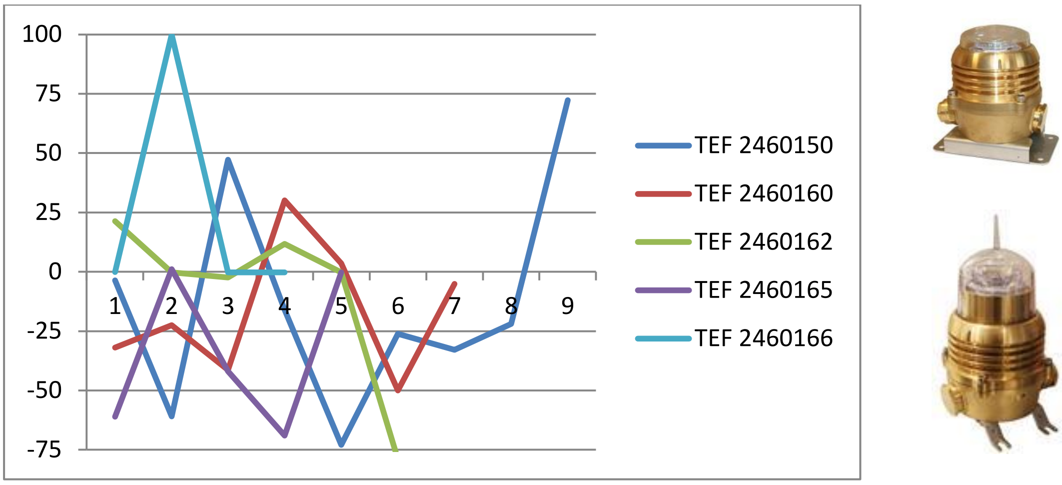


Figure 13 Helideck light type 2460 production hours

Finally, a review of the lamp insert Type 2440995/2440996/2440997, which is a sub-assembly (lower part) used in finished products for the past 20 years. Again, a cut-off was made at +100%.

Type 2440:

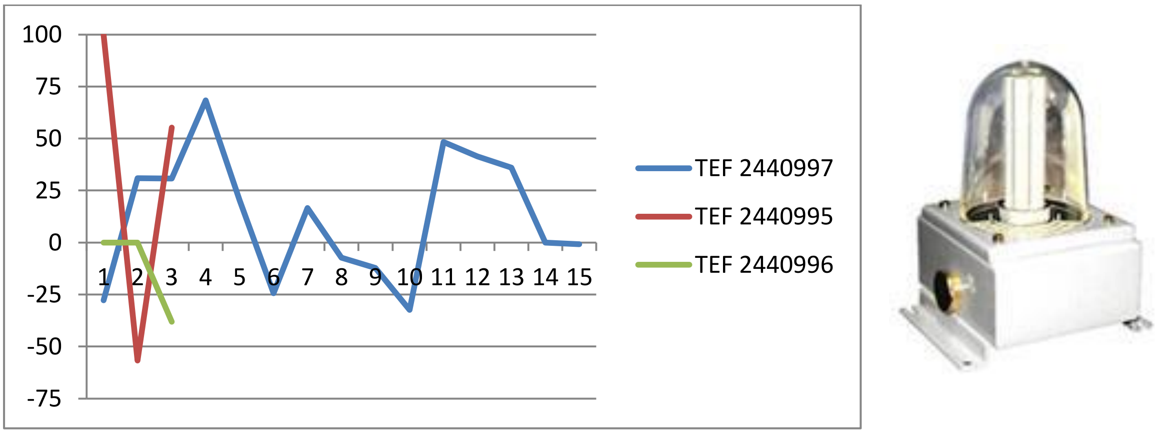


Figure 14 Helideck light type 2440 production hours

Observation: What I found was a surprisingly very large swing in actual assembly hours with respect to what was planned.

6.6.2 MTO - Customized products

The ABC-analysis show that not less than 53% of the WO's for products in the category A was for customized products. It is therefore not a small and unimportant part of the business that is defined as MTO.

There is no definition within the Axapta ERP system for MTS/ATO/ETO/MTO/ETO+MTO. Therefore I reviewed the A category products by defining a query in the Access database, and established an overview to highlight the distribution as seen in Table 11. The categorization is done by reviewing the respective WO's, and whether it was the standard BOM or a customized BOM that was used. The data is sorted by total sales value in descending order.

ABC analysis of part numbers and respective number of WO's (Class A only)				
Part Number	Description	Value NOK	MTS/ ATO	MTO
9980000	TEF 9980 HELIDECK STATUS LIGHT - MAIN LIGHT	3 329 648	10	
92080003	TEF 9208 Enclosure Heater 230VAC 300W T4 With flying lead	2 738 429	11	
2650425448	TEF 2650 SØKELYS M51 XF 2000W/230V ARCTIC VERSION -52 C	1 895 221	1	4
2000082	Project services Winterization Marine	1 867 450		2
92060001	TEF 9206 Enclosure heater 230VAC 100W, T5, flying lead	1 616 502	18	
1063200	TEF1060 HV Hengslet/Skrudd lokk. Kundespesifisert	1 610 384		18
2650425440	TEF 2650 SØKELYS M51 XF 2000W/230V COMMANDER	1 541 301	11	
2650415430	TEF 2650 SØKELYS M51 HF 2000W/230V COMMANDER	1 388 783	22	
1060210	TEF1060 Hengslet/Hurtiglås. Kundespesifisert	1 315 970		22
2650323440	TEF 2650 SØKELYS M41 XF 1000W/230V COMMANDER	1 274 588	6	1
2440150	BEL.IND GRØNN 30cd. SIDE EMITTING 230 VAC	1 196 900		14
4900000	CONTROL SYSTEM COMMANDER SERIES	1 046 498		24
10540501	JB IND. 316L Beiset 100X80X50	1 041 020		17
10581618	TEF1058-16 Heat Trace JB Wallm Bright ch w/Glands	1 025 789	14	4
Listing continues – See Appendix Table A for full listing				

Table 11 ABC listing divided into Work Order type

It is observed that there is a good mix of the two main types of product categories, except ETO (e.g. P/N 2000082). What the table also show, is that there exist customization of several MTS/ATO products.

6.6.3 Analysis of actual work hours versus planned

In order to analyze how the category A products flow through our production, I ran an analysis of all WO's, and grouped these by the respective part numbers.

At the same time I summed the actual work hours and the respective planned work hours, and logged the discrepancy. This is presented in Table 12 which sorts the data by Actual Work Hours *minus* Planned Work Hours in descending order.

ABC analysis of part numbers and accumulated more work than planned for WO's (Class A only)					
Part Number	Description	New Product	MTS/ ATO	MTO	Actual hours *minus* Planned hours
1060210	TEF1060 Hengslet/Hurtiglås. Kundespesifisert			22	438,80
4900000	CONTROL SYSTEM COMMANDER SERIES			24	306,86
1063200	TEF1060 HV Hengslet/Skrudd lokk. Kundespesifisert			18	236,07
8150210	8150 JB w/bolted lid. Kundespesifisert			15	129,6
92080003	TEF 9208 Enclosure Heater 230VAC 300W T4		11		96,77
4600199	4600 Helideck control panel SPECIAL 100-240VAC	X		8	87,69
9980020	Control Cabinet for TEF 9980 - INDOOR 100-240V AC	X	7	1	59,23
9980000	TEF 9980 HELIDECK STATUS LIGHT	X	10		48,73
4600171	4600 Helideck control panel complete	X	4		40,97
104	Kobl.Boks / Bygging ExD/Ex de (DOV)			1	28,74
9964010	110 V XENON HELIDEKK FLOMLYS EEx de II T5		14		25,65
10581638	TEF1058-16 Heat Trace JB Wallm El-pol w/Glands		29	2	23,63
9950900	TEF 9950 CHLITE Control Cabinet Non-Ex 230V	X	4	2	21,25
2650425440	TEF 2650 SØKELYS M51 XF 2000W/230V		11		15,37
4720010	KONTROLLER 1X8 24V INNFELT			58	14,16
10582581	TERMOSTAT F/VEGG 0/+120 KAPILLAR Elpolert		17		12,47
Listing continues – See Appendix Table B for full listing					

Table 12 Actual work hours versus planned

The table shows that both MTS/ATO and MTO products have a discrepancy in actual versus planned work hours, but where MTO products are dominating the top items in the list. The column 'New product' indicate products that has been in production for less than a year, and where the planned hours within the ERP system may not have been adjusted to actual hours.

6.7 Waste in Lean Manufacturing: Mura, Muda, Muri

6.7.1 Mura

The observations in the analysis point to a variability in the related departments depending on type of product and WO: MTS/ATO for standard products, and MTO and ETO/MTO for customized products. This is interpreted as shown in Table 13:

Variability as a result of having incorrect or insufficient information in regards to the function		
Function	MTS/ATO	MTO and ETO/MTO
BOM	Medium	High
Route/Process	Low	High
Drawings	Low	High
CNC programs	Low	High
Test procedures	Medium	High
Operator preparedness	Medium	Medium
Product documentation	Low	High

Table 13 Mura

MTS and ATO may be viewed as the same when discussing variability. For such products the BOM, route, drawings, CNC programs, test procedures and applicable documentation is standard and altered very little. This I interpret as having little impact on variability. However, if the operators are not prepared for the job, e.g. due to lack of training, it may affect the variability.

This is very different from MTO and ETO/MTO production scheduling. As observed in Table 11 and 12, for MTO the number of products may be high and volume for each low. Nicholas (1998, p. 595) claims this obstructs level production, thus the goal must be to reduce waste. According to Nicholas, this could be done as follows:

1) Simplify the BOM
2) Use group technology and standard parts
3) Make only what is needed
4) Produce in lot sizes that are small and easy to count
5) Use simple visual control systems
6) Do not overload the workshop or particular operations

7) Use days or hours for planning lead times

Simplifying the BOM (number 1 on the Nicholas' list) is interpreted as reducing the number of levels, which results in less pre-assembled products or components. This could be linked to a target of more one-piece-flow in the production.

Of the other elements, (2) is related to a standardization phase and/or new product development, (3) is related to Muda, (4) is related to a pull-methodology, (5) is related to Kanban and Andon signals, and (6) are related to Muri.

6.7.2 Muda

It is observed that the MTO and ETO/MTO products due to variation in size, complexity, and content are more challenging through the entire supply chain. Through the process maps and interviews, I found that I can map most of the 7 Muda's in relations to the inaccuracy in three main functions BOM, Route/Process, and Drawings.

Consequences of waste due to inaccurate data in BOM, Route, and Drawing			
Muda	BOM	Route/Process	Drawings
Motion	X		
Waiting	X		X
Inventory	X		
Over-processing		X	X
Over-production	X		
Defects	X		X
Transport	X		

Table 14 Muda

This shows that having incorrect or missing information set up in the ERP system prior to planning and releasing a WO, may have direct consequences to the quality and deliverability.

6.7.3 Muri

Muri translates into overburden, which means unnecessary stress to employees and processes. This is caused by Mura (variability). I viewed the consequences of various conditions and mapped these to types of WO's as shown below.

Overburden as a result of various functions			
Condition	MTS	ATO	MTO
No training for work processes	High	High	High
Cluttered workplaces	Low	Low	Medium
Unclear instruction	Low	Low	High
Lack of proper tools and equipment	Low	Low	Low/Medium
Unreliable equipment	Low	Low	Low
Unreliable processes	Low	Medium	High
Poor communication	Low	Medium	High

Table 15 Overburden

Compared with MTO, MTS and ATO are standard products, thus the workforce is expected to be better trained and experienced and a more resilient working situation should exist.

6.7.4 Summary of sub chapter

An observation is made in that Work Orders for MTO products may have a higher probability of waste than that of MTS/ATO products. This can also be related to the RFQ process as a whole, where an improvement in the dialogue between customer and the company can result in improvements for both parties (Womack, James P., Jones, Daniel T. (2005, p.86-87).

6.8 Tools and methods for an improved RFQ process

Processing a request from a customer and providing a quotation is important in many ways: The customer expects a quotation quickly, but the process must check out several key areas: Is the solution technically feasible? Is the solution safe and in accordance with rules and regulations? Is the estimated price correctly calculated?

There are several ways of safeguarding this process, such as using a predefined and validated Excel spreadsheet to make the calculations. Under all circumstances it is important that the tool is easy to use, and that the core is protected from alterations, as that may change the calculations. One tool I developed for calculations of larger enclosures were submitted for internal test mid-October 2018. Developed in Microsoft Visual Studio it runs as any general Windows program.

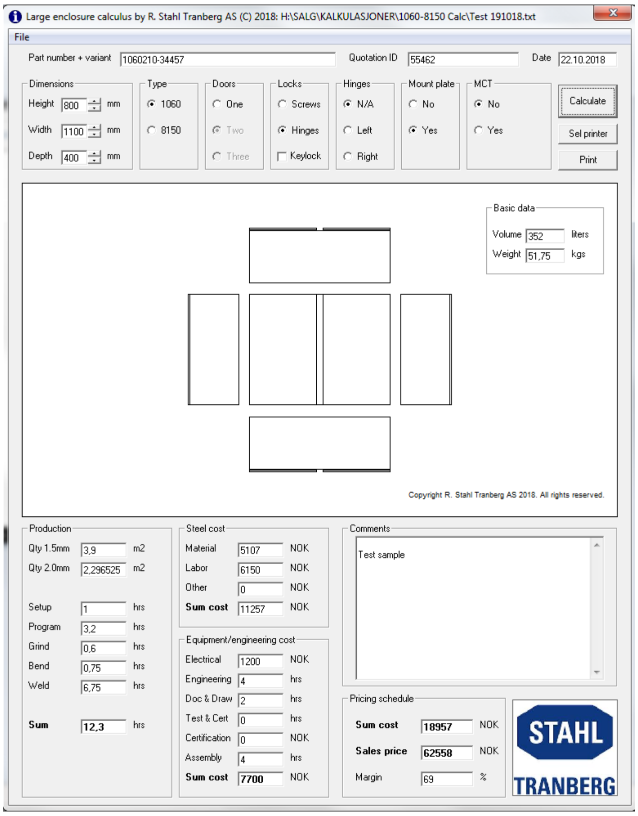


Figure 15 Screenshot of calculation tool for larger enclosures

Entering the dimensions, and selecting type of enclosure with relevant fittings, provides an immediate calculation or recalculation. The tool is currently in test to remove any bugs, but also to verify that the coverage and applicability is as expected.

6.9 Summary of analysis

The analysis shows that:

- Logging work hours per WO are only interesting in obtaining a better understanding of standard production times (Takt), and as a measure to improvement. It is documented that the quality of the registration of value-created work could be more consistent.
- A large portion of what constitutes the turnover is made as MTO. As this is important for the business, and delivery times are often short, it is worthwhile improving the flow of material for such deliveries.
- Work Orders for MTO are likely to have few numbers of units to be made, in general less than 5 units per WO.
- Often MTO products tend to have fewer hours planned than what is actually used.
- Products that are designed to be standard products are in fact also represented as MTO.
- The RFQ process is vital in providing a best estimate for pre-production needs, such as planning and procurement.
- Newer products may not have correct time estimates, but what should be improved over a few runs of production.

This may be summarized as insufficiently reliable and inconsistent information from the production processes. On the other side, it is also shown that relatively complex product structures that are handled as customer-specific products are not sufficiently processed in the quotation process.

Chapter 7 Paperless production

7.1 The paperless production system

A paperless production system is by definition a pure digital system, relying on all data and information to be presented in a digital way on a board or tablet for operators. This implies no “manually” added information will be possible, such as including an undefined drawing or sketch into the production folder, or any other cross-related combination of information that is not electronically linked.

One reason for such a strict policy is the chance of missing out once, and with the implications that would lead to. Examples of such possibilities are job hand-over during vacations, stress or overload of individuals, or similar. Another reason is that by ensuring all-digital input and output, a much better method of analysis can be put in place Key Performance Indicators (KPI), thereby increasing continuous improvements.

The company has decided to implement a paperless production system called diRect, developed by the Norwegian company AMS AS. diRect is already in operation by several midsize Norwegian companies, such as Ekornes, one of the leading Norwegian furniture makers. The diRect implementation started early 2018 and is currently in test mode. The intended setup allows the system to act as a ‘piggy-back’ to the ERP system, leveraging on the rich data structure of part numbers, BOM’s, related documents and drawings, etc. This will function in parallel to the existing paper-based WO system, enabling safety in the implementation phase, and in case of intermittent problems.

7.1.1 Principle of work flow

The functionality is shown in Figure 16. The ERP system initiates needs as a result of stock levels reaching a trigger point, or new sale orders. This net requirement generates suggestions to purchases and WO’s. The main planner releases new WO’s while also ensuring that the purchasing department are informed about particular needs.

A functional requirement for information screens as described in 7.1.4 is the need of linking one WO to a ‘parent’ WO, and/or a Sales Order. This functionality is missing in the ERP as of today, and must be implemented as a new function. The planner then needs to add the required ‘parent’ data upon planning a WO, a simple task that will lead to a huge improvement for many other employees.

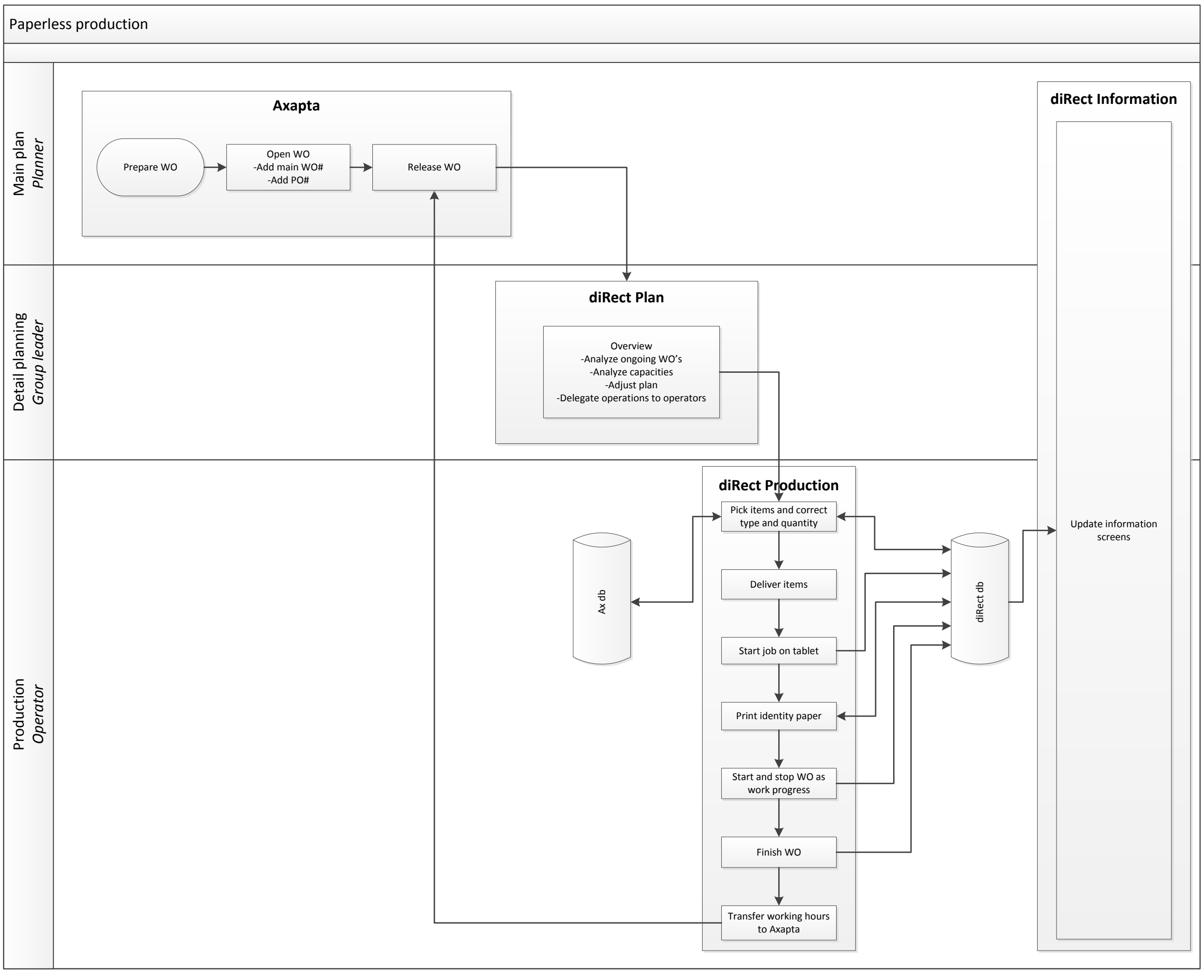


Figure 16 Paperless functionality

7.1.2 Foreman's office

The picture below shows the paperless system in use at a foreman's office. This web-based system is dynamically updated and uses simple objects to show information and states.

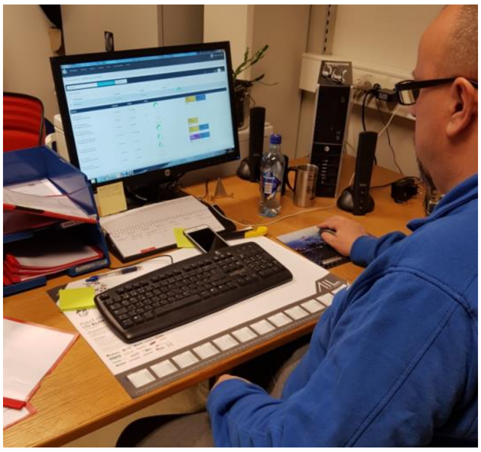


Figure 17 Foreman's office

The main dashboard window for the foreman is an overview of all ongoing WO’s, and newly released WO’s that need detail planning. The foreman has also a direct view of the workload for each employee, and status of each operation. Upon a new WO, she or he can assign part or all of the related work to one or several operators in the assembly/production area by simple drag-and-drop method. This immediately recalculates the workload and remaining capacities in the department.

One key factor in making this work properly is that the planned work is realistic in setup time and process times, as it otherwise will not have a meaning in planning towards capacities. Figure 18 shows planned WO’s, and status of each, as well as capacity for each employee for the given day. Color codes and symbols make it simple to get a quick status of the operations.

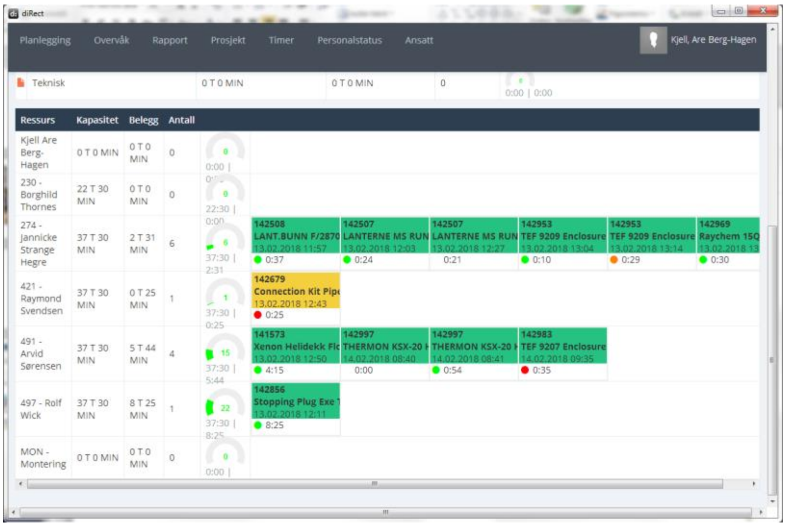


Figure 18 Paperless: Viewing personnel assignments

7.1.3 Operator’s environment

As the foreman assigns WO (more specifically tasks) to operators, this will within minutes appear on a tablet as shown in Figure 19. The operator has all the information required at this device. She or he will also start and stop WO’s by a simple press on a symbol, and view all relevant drawings and other documents. It will also be possible to view status of inventory levels of all parts in the BOM, and even correct the quantities or types of parts.

The intention is that it will lead to a quality improvement of actual working hours and a more timely transfer of information between the two systems, such as inventory pick. The outcome of hours used versus hours planned, as well as the value of %C&A (percent Complete & Accurate) may be used for continuous improvement.

Figure 19 Paperless: Operator's workplace and tablet in use

The operator can directly check out the number of finished products, and also raise a deviation note upon a faulty product or not being able to produce the intended quantity. This enables an online and graphical presentation of the current status in each department, and finally for the entire factory itself.

For explosion-protected equipment, test procedures are a strict part of the assembly process. New regulations require testing to be done with a higher sampling rate, and some products require testing of each unit. The paperless system allows all test procedures to be presented as a descriptive part of the assembly steps, with direct entry of test results onto the tablet. This requires a serial-numbering of each unit made, and which may be discussed as a next step of the paperless production system.

7.1.4 Information screens

The various departments is planned to be equipped with large online information screens to show which WO's are being handled and the respective progresses. This may be informative for other departments and be helpful in obtaining a better flow of products and materials.

As previously shown, a WO may have dependencies to a Sales Order or to another WO. Such information may be shown on the information boards with simple color coding, indicating where material are to be transported internally.

7.1.5 Individual tracking

A growing requirement from customers is a tracking function for serialized equipment. This is planned as a next phase to the paperless system, and will provide an individual tracking option during production, inventory handling and shipment. This is planned as a QR-code or RFiD chip that is printed, registered and labeled to the product, and that will stay with the product throughout its lifecycle.

This will be used to connect a unique item to a customer order and optionally can be used as a way to bond with the customer over a longer time. It may also be used to provide specific information to the customer by allowing a secure logon to a dedicated website, and where the customer can allocate specific (serialized) products to its locations. As such this web site could act as a data repository for small business, and where one could establish inspection or maintenance functions that tie the customer close to the company for an extended period of time.

7.1.6 Personnel issues

Data collected from the WO's will contain personal performance information, e.g. through who is given a specific WO. This must be handled and presented in a way that is not in conflict with rules or regulations, and which does not result in lowered motivation.

7.2 Summary of paperless production

The paperless system relies on the background data from the ERP system, and is therefore restricted to the main functionalities of the ERP. Still, some minor upgrades of the ERP system are identified for improved visibility and usability of the paperless system.

With the ability to register detail information, the paperless system will be valuable as a decision support tool and for continuous improvements. Due to its very nature, it introduces a need for electronic-only information, an area that influences the human aspects of planning and associated documentation for successfully carrying out the production.

Chapter 8 Validation/Discussion

8.1 Data model used in analysis

The quality of data extracted from Microsoft Axapta and restored in the Microsoft Access database is considered proper. This included a table covering all part numbers along with related technical information, BOM, Routes, and more. Furthermore the database consists of one table for all work orders for 2017, the ABC analysis, and actual time recording from our TimeCatcher system.

To filter out the details required, a number of selections were made and data exported to Microsoft Excel for summary, better analysis, and presentation. This amount of data cannot be replicated into this thesis, but it is considered that data are accurate. This process has been run twice to verify data consistency.

8.2 The large swing in actual vs. planned working hours

As presented in chapter 6.7.1, there is a large and inconsistent variation in actual working hours versus planned working hours for standard products. This may be due to four reasons:

1) Missing parts, tools, or instructions for the job, causing unnecessary movement and delays.
2) Use of students or other under-qualified operators that increased the production times.
3) Incorrect standard times are set up in the ERP system.
4) Improper register of working hours.

After reviewing data from Work Orders and production documentation, I have identified the following possible causes:

1) It is assumed all parts were made available prior to the assembly, as no deviation reports was linked to any of the total 79 WO's. Furthermore, no rework hours was registered. <u>This is unlikely to be the reason.</u>
2) The WO's are run all-year and no signs point in direction of other than the standard operators was used. <u>This is unlikely to be the reason.</u>
3) The swing of actual hours is both negative and positive to the planned number of hours (except for P/N 2870515 which tends to have an average of 40-45% more registered working hours than planned). <u>This is unlikely to be the reason.</u>

4) The clock in the assembly department is fixed to a wall and the operators need to start the WO by use of a bar code reader to read the WO number off the papers, and then assign their personal identity with that WO. The clock starts ticking. When finished, the operator stops the clock in the same way. Any time spent for lunch or bathroom is not registered. Other events, such as meetings, a visit to the doctor, or halts in production area registered by due use of predefined barcodes next to the clock. This stands out as the most likely reason.

This point in the direction of having correct time registration is of the outmost interest in order to be able to plan correctly. It is also important in order to have a correct estimate for cost analysis and setting a standard cost price, followed by a standard sales price.

8.3 Three stages of production

The analysis shows that customization of products is an important part of the business, but it is also documented that the process around customization is subject for improvements. I will discuss this in three stages of production: Pre-Production, Production, and Post-Production, and align this with the introduction of a paperless production system.

8.3.1 Pre-Production process

With a relatively high number of different products being manufactured, the data structure and relevant information for each must be at its best. This is summarized in Table 16:

Pre-Production				
Area	Goal	Today	Paperless	Advantages
Poka-Yoke	Minimize errors that can be avoided	Handwritten instructions on WO or inadequate documentation following WO. Sometimes conflicting.	Need all information and documentation to be electronically linked to product or WO	Improved information, which will be made available for each operator.
Standardization	Less variation	Many products are using variants. Real opportunity to simplify and standardize both on components and processes.	Information must be added in paperless system.	Advantage in standardization, less risk of errors made due to habits.

Table 16 Pre-production activities

As an example, the RFQ process is difficult to make perfect, as there will always be elements that are hard to describe at the quotation time. A predefined calculation tool as described in chapter 6.8 could be a way to align many RFQ processes the same way. This will be reasonably precise, and provides both a qualified price estimate, and estimates that may be used later when making BOM and Route descriptions for a MTO delivery.

8.3.2 Production planning and execution

The paperless WO enables the operator to work in a dynamic and online environment. The possible improvements are shown below:

Production activities				
Area	Goal	Today	Paperless	Advantages
Waste	Minimize waste	Inadequate recording of materials used, rework, transportation and delayed reporting	Online reporting, using exact part numbers. Categorization of time spent.	More rapid update of incorrect BOM's. Online inventory.
Takt	Short, but optimized	Uneven and poor standard times.	More precise recordings as the operator push Start and Stop of each WO.	Better standard times. Improved probability of identifying improvement areas
Continuous flow	Optimized batch quantities	High chance of multiple work orders for same product	More visibility and better chance to see other WO's for same product, and to combine several WO's into one	Reduced setup times, larger overall batches
Level production	Utilize work force	Disconnected from ERP. Delay and inaccurate time recordings. Poor data for improvements.	Visual control of workloads, capacities, and statuses	Better chances of leveling production

Table 17 Production planning and execution

Habits of users and a mistrust to detail insight to each operator may result in negative responses. This should be addressed prior and during the implementation phase.

Removal or mitigating the effects of Mura, Muda, and Muri is an important task in order to prepare the organization for a paperless production.

8.3.3 Post-production process

With a higher quality of data from the production, an opportunity raises for more analysis and continuous improvements. This is described in the Table 18.

Post-Production				
Area	Goal	Today	Paperless	Advantages
Continuous improvement	Always better	Inadequate data for highlighting improvement areas	The tablet may be used to directly enter and record deviations	Better data from each step in the process
Cost control	Always better	Inadequate data and time-consuming activity	Better time recording of activities, and material usage	Improved planning of Work Orders

Table 18 Post-production activities

Even though the amount of data will increase, it is still the habits of sales staff, engineers, and operators that control the accuracy level of data entered into the system. Potential errors are described in the Table 19, along with possible consequences.

Production cost and possible implications: Standard products (MTS/ATO)				
Cost area	Production process	Departmental requirements	Possible consequences	Consequences to customer
Bill Of Material	Correct inventory level	Purchasing ordering in due time	Production not being able to assemble product correctly	Possible delays in delivery
Process or Route definition	Available resources and proper training	Planning to be as good as possible	Wrong assembly times	

Table 19 Possible consequences of errors with MTS/ATO due to incorrect BOM or Route

For customized products this goes one step further and includes documentation which must be specific for the delivery. This is shown in Table 20.

<table>
<tr><th colspan="5">Production cost and possible implications: Customized products (MTO)</th></tr>
<tr><th>Cost area</th><th>Production process</th><th>Departmental requirements</th><th>Possible consequences</th><th>Consequences to customer</th></tr>
<tr><td>Documentation</td><td>Providing relevant and descriptive documents</td><td>Engineering department to be involved</td><td>Standard documentation may be used instead of delivery-specific documentation</td><td rowspan="3">Possible delays in delivery

Incorrect use of product and potentially hazardous situations</td></tr>
<tr><td>Bill Of Material</td><td>Getting an early overview of needs</td><td>Purchasing additional parts to complete WO</td><td>Production not being able to assemble product correctly</td></tr>
<tr><td>Process or Route definition</td><td>Available resources and an understanding of what to be done</td><td>Close follow-up by project manager</td><td>Incorrect assembly and rework</td></tr>
</table>

Table 20 Possible consequences of errors with MTO due to incorrect BOM, Route, or drawing

8.4 Summary

The analysis shows the data structure and RFQ processes must be improved for all types of deliveries.

Any WO being processed must follow clearly defined rules to manufacturing in order to deliver an end result that is corresponding to product certification, and/or other norms and standards that are applicable. It is therefore no difference to whether the product is in the one or the other category: What is passing through production must be correct with regards to planned work hours, BOM, and documentation. Deviations in one or the other way may directly impact waste, productivity, and the ability to deliver on time.

All employees must be included and provided an understanding of the reason for the significant change and improvement in the process from RFQ to delivery (Womack, James P., Jones, Daniel T., 2005, p.183).

Chapter 9 Conclusion

A Lean perspective sets the frame of the work of this thesis, where the main view was on the improvement of the supply chain for deliveries of products. As it is documented that habits and methods must be changed and improved, the human aspects are very important. A first natural step would be Lean training for all, as this will help ensuring participation and embrace in the change process.

On the technical side, a paperless production system as described in this thesis will support many of the needs of the business, but most of all it will improve the expediting of WO's during planning and production. The paperless system depicts it must be kept simple to operate, but at the same time it must provide a detail richness in order to define reliable Takt times. In general, a higher quality of production data will also be beneficial for decision support, and for continuous improvement of operations.

With the findings in the analysis and later discussions, I argue that a limitation of the high amount of valid products in the portfolio will both help increase volumes of more standard products, and to reduce inventory levels. This will further help improve standardization of processes and in achieving a one-piece-flow with less time spent on unproductive change-over between jobs. Cleaning up the portfolio will also improve focus on core products and free up time for new product development.

MTO deliveries are documented to be an important part of the business, and it is vital to see the continuation of this through its own assembly line, so that its activities do not conflict with the more streamlined main production. However, it is documented that the broad range of products that are allowed as MTO should be limited, and that the RFQ process must be improved to better reflect the actual cost of delivery to customers.

Among the recommended future steps is considering a move to a pull-system in order to further reduce WIP and overall delivery times, and implementing a traceability method on products for after-sales service. Both initiatives have a direct and positive effect on customer support. The paperless system will support other ERP systems, and may therefore be a valuable bridge in a migration process to SAP.

Chapter 10 References

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Appendix

Table A. Manual classification of part numbers

Explanation: A product can both be manufactured as standard (MTS/ATO), and as customized (MTO). This listing identifies category A products and shows number of Work Orders for each respective type.

Sorted in descending order of overall sales value.

ABC analysis of part numbers and respective number of WO's (Class A only)				
Part number	Description	Value NOK	MTS/ ATO	MTO
9980000	TEF 9980 HELIDECK STATUS LIGHT - MAIN LIGHT	3 329 648	10	
92080003	TEF 9208 Enclosure Heater 230VAC 300W T4 With flying lead	2 738 429	11	
2650425448	TEF 2650 SØKELYS M51 XF 2000W/230V ARCTIC VERSION -52 C	1 895 221	1	4
2000082	Project services Winterization Marine	1 867 450		2
92060001	TEF 9206 Enclosure heater 230VAC 100W, T5, flying lead	1 616 502	18	
1063200	TEF1060 HV Hengslet/Skrudd lokk. Kundespesifisert	1 610 384		18
2650425440	TEF 2650 SØKELYS M51 XF 2000W/230V COMMANDER	1 541 301	11	
2650415430	TEF 2650 SØKELYS M51 HF 2000W/230V COMMANDER	1 388 783	22	
1060210	TEF1060 Hengslet/Hurtiglås. Kundespesifisert	1 315 970		22
2650323440	TEF 2650 SØKELYS M41 XF 1000W/230V COMMANDER	1 274 588	6	1
2440150	BEL.IND GRØNN 30cd. SIDE EMITTING 230 VAC	1 196 900		14
4900000	CONTROL SYSTEM COMMANDER SERIES	1 046 498		24
10540501	JB IND. 316L Beiset 100X80X50	1 041 020		17
10581618	TEF1058-16 Heat Trace JB Wallm Bright ch w/Glands	1 025 789	14	4
2460150	TEF 2460 Perimeter light: Green LED, 30Cd, 110-254VAC, IECEx	1 005 312	10	1
92080002	TEF 9208 Enclosure Heater 230VAC 175W T4 With flying lead	988 733	11	1
9950910	TEF 9950 CHLITE Control Cabinet Ex 230V 8+10 Circuits	949 767	5	
104	Kobl.Boks / Bygging ExD/Ex de (DOV)	931 800	1	
9980020	Control Cabinet for TEF 9980 - INDOOR 100-240V AC	918 342	7	1
2650413430	TEF 2650 SØKELYS M51 HF 1000W/230V COMMANDER	907 379	17	3
4600199	4600 Helideck control panel SPECIAL 100-240VAC	894 032		8
1060702	Thermostat TEF1060-NGC-20 - Controller/Limiter - AISI316	870 024	1	3
7000081	CONDUIT 22,3MM 25 MTR TRANBERG, AISI316	834 590	4	
9964000	XENON HELIDEKK FLOMLYS EEx de II T5 254V	769 577	6	
92080001	TEF 9208 Enclosure Heater 230VAC 100W T4 With flying lead	758 044	21	
2430150	TEF 2430 PERIMETER LIGHT GREEN LED 30Cd 230/254VAC, 50/60Hz	742 635	10	
9980005	TEF 9980 HELIDECK STATUS LIGHT - REPEATER LIGHT	739 242	10	
9964030	XENON HELIDEKK FLOMLYS EEx de II T5 230V	684 804	6	
4720011	KONTROLLER-1X12 24V INNFELT	658 835		43

(Table A continued)

3173	BRAKETT, MONTERT TIL 9964 230/254V	614 442	9	
99686122	WS Ø600 L2400, 100-254 VAC, Intern 32Cd, Obstr 32 Cd	613 100	10	3
9970100	TEF 9970 Ex-LED Helideck Floodlight Wide	609 878		2
9950280	TEF 9950 CHLITE-28 Circle & Cable Mounting System	607 219		42
4720010	KONTROLLER 1X8 24V INNFELT	602 174		58
2655021445	TEF 2655 SØKELYS M25 XF 150W/230V COMMANDER	545 585	9	
92070005	TEF 9207 Enclosure heater 230VAC 500W, T3, w/flying lead.	537 945	17	2
9970200	TEF 9970 Ex-LED Helideck Floodlight Medium	537 066	2	
9964010	110 V XENON HELIDEKK FLOMLYS EEx de II T5	529 128	14	
9950500	TEF 9950 CHLITE - H Mounting System Green/White	527 702	46	2
4730012	KONTROLLER-2X16 24V INNFELT	526 598		30
2613381100	MASTERPANEL FOR TEF 2650 COMMANDER HALOGEN/XENON 8 SØKELYS	522 610	6	
9964230	Xenon Helidekk Flomlys 9964230, 230V, Industri	495 451	8	
28700019	LANTERNE MS NAVIGASJON ZONE 2 TOPP	485 484	12	
7210002	KANTBESKYTTER, 16X65 TRANBERG	444 174	1	
8150210	8150 JB w/bolted lid. Kundespesifisert	442 190		15
9950900	TEF 9950 CHLITE Control Cabinet Non-Ex 230V Indoor	432 540	4	2
2000084	Project services General Marine	427 498		5
99686111	WS Ø600 L2400, 24V DC, Intern 32Cd, Obstr 10 Cd	413 751	2	
1060201	ENCL 316L Beiset 400x400x200 Skrudd lokk Mont.plate	413 093		20
4600171	4600 Helideck control panel complete	400 443	4	
2430160	TEF 2430 OBSTRUCTION LIGHT RED LED 32Cd 220-254VAC, 50/60Hz	388 768	7	
2650415439	TEF 2650 SØKELYS M51 HFHE 2000W/230V HENGENDE MONTERING	382 125	2	2
99683122	TEF 9968 Windsock Ø0,3 L1,3 obstr. light 32Cd, 100-254VAC	377 560	6	1
303	SALG AV TJENESTER	367 992		34
10582581	TERMOSTAT F/VEGG 0/+120 KAPILLAR Elpolert	360 136	17	
10581638	TEF1058-16 Heat Trace JB Wallm El-pol w/Glands	356 965	29	2
10581511	JB 316L El.polert 112X140X70	343 356	1	46
4900100	CONTROL SYSTEM COMMANDER SERIES	340 232		7
10582511	JB 316L El.polert 140X218X100	337 458		47
2438501	BELYSNING KLAR 2438 N SKJ. 1	336 740	3	1
99686112	WS Ø600 L2400, 200-254 VAC, Intern 32Cd, Obstr 10 Cd	329 866	3	2
9178236	Connection Kit f/Wall Mounted JB 5x11/5x13/5x15 M28x1	320 970	10	
2000081	Project services Heat Trace	317 434		1

Table B. List of A-items and accumulated number of assembly hours minus planned hours.

Explanation: This identifies the part numbers that have the largest difference in actual working hours versus planned working hours. Sorted in descending order.

ABC analysis of part numbers and accumulated more work than planned for WO's (Class A only)				
Part number	Description	MTS/ ATO	MTO	Actual hours *minus* Planned hours
1060210	TEF1060 Hengslet/Hurtiglås. Kundespesifisert		22	438,8
4900000	CONTROL SYSTEM COMMANDER SERIES		24	306,86
1063200	TEF1060 HV Hengslet/Skrudd lokk. Kundespesifisert		18	236,07
8150210	8150 JB w/bolted lid. Kundespesifisert		15	129,6
92080003	TEF 9208 Enclosure Heater 230VAC 300W T4	11		96,77
4600199	4600 Helideck control panel SPECIAL 100-240VAC		8	87,69
9980020	Control Cabinet for TEF 9980 - INDOOR 100-240V AC	7	1	59,23
9980000	TEF 9980 HELIDECK STATUS LIGHT	10		48,73
4600171	4600 Helideck control panel complete	4		40,97
104	Kobl.Boks / Bygging ExD/Ex de (DOV)		1	28,74
9964010	110 V XENON HELIDEKK FLOMLYS EEx de II T5	14		25,65
10581638	TEF1058-16 Heat Trace JB Wallm El-pol w/Glands	29	2	23,63
9950900	TEF 9950 CHLITE Control Cabinet Non-Ex 230V	4	2	21,25
2650425440	TEF 2650 SØKELYS M51 XF 2000W/230V	11		15,37
4720010	KONTROLLER 1X8 24V INNFELT		58	14,16
10582581	TERMOSTAT F/VEGG 0/+120 KAPILLAR Elpolert	17		12,47
9964000	XENON HELIDEKK FLOMLYS EEx de II T5 254V	6		9,52
2440150	BEL.IND GRØNN 30cd. SIDE EMITTING 230 VAC	14		8,43
4720011	KONTROLLER-1X12 24V INNFELT		43	8,07
4730012	KONTROLLER-2X16 24V INNFELT		30	7,19
9970200	TEF 9970 Ex-LED Helideck Floodlight Medium	2		6,96
28700019	LANTERNE MS NAVIGASJON ZONE 2 TOPP	12		5,9
9964230	Xenon Helidekk Flomlys 9964230, 230V, Industri	8		4,74
7000081	CONDUIT 22,3MM 25 MTR TRANBERG, AISI316	4		4,39
10581618	TEF1058-16 Heat Trace JB Wallm Bright ch w/Glands	14	4	4,01
10582511	JB 316L El.polert 140X218X100		47	3,37
92080002	TEF 9208 Enclosure Heater 230VAC 175W T4	11	1	2,87
4900100	CONTROL SYSTEM COMMANDER SERIES		X	2,63
2430150	TEF 2430 PERIMETER LIGHT GREEN LED 30Cd	10		1,38
2	DIVERSE		X	0,95
9178236	Connection Kit f/Wall Mounted JB 5x11/5x13/5x15	X		0,01