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Developing a Flexible Lead Time Model for the Order-to-Delivery Process

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This Thesis focuses on the improvement of the order-to-delivery process. The business problem of this study is the need for more agility and flexibility to handle the order-to-delivery process in the case company. Intense competition and tight situation in the economics have led to a situation where the lead times are one of the key factors to win or lose the competition. To address this challenge, the objective of this Thesis is to develop a new flexible process model in order improve the effectiveness of the order-to-delivery process.

This research uses quantitative methods to analyse the current state of the organization, the main data source being the company's information system. Combined with the knowledge from the organization and different key stakeholders, the right directions for the development can be chosen. This approach leads to the suggestion of a new process model. This initial model for the order-to-delivery process is tested to ensure that the planned changes and analyses are meeting the target. Based on the results, the finalized proposal model is presented.

The results of the Thesis are a new tool for analysing the work load and lead times for the engineering process, which enables the possibilities for more flexible lead time planning. These suggestions should make it possible to improve and to cut down the lead times of the order-to-delivery process.

The outcome of this study, the new process model and the new analysis tools, will help the case company in the implementation of a leaner order-to-delivery process with more exact knowledge of the actual workload in the office process. This will help planning for more flexible lead times, which should also enable shorter and more accurate lead time estimations to be given to the customers.

Keywords	Lean manufacturing, critical chain, process model, process development

Contents

Acronyms

*	motor type, xx
*	motor type, xx
BOM	Bill of Materials
SAP	ERP system
ERP	Enterprise Resource Planning
ETO	Engineered to Order
MTO	Manufactured to Order
OTD	On Time Delivery
MRP	Materials resource planning
WIP	Work in progress
OEE	Overall Equipment Effectiveness
JIT	Just-in-Time
APO	Advanced Planning and Optimization
TOC	Theory of Constraints

List of Tables and Figures

1 Introduction

This Thesis focuses on the development of a new process model for more flexible lead time planning in the case company. The manufacturing industry has been under severe challenges over the past few years in the Western world. Competition is fierce and the customers can be said to be in control of the situation. The competition takes place on all fronts, and the key attractions for customers are generally the cost of the product and the lead time that can be offered to the customer. As of the case organization, the main issues for these aspects are the length of the lead times, which also effects to the price that can be offered to the customer. If the process can be as agile as possible, it should also have an effect on the expenses of the company, thus releasing capital to the successful competition.

The current situation in the case organization is that there are few fixed length lead time models for order-to-delivery process, which leads to an ineffective usage of resources. With more flexible and accurate lead time planning models, this usage of resources can be utilized better and also the risk of missing the targets can be reduced. In addition, with these improvements the case company can adapt a more customer oriented approach for production planning as it is currently more focused to serve the manufacturing purposes and goals. Turnaround is needed as in today's business world the customers point of view should be the most important focus for all personnel.

1.1 Business Problem

Lead times and lead time planning plays an important role in manufacturing. From a customer's point of view, the lead time is often one of the most decisive factor for where the purchases are made from. There are lots of cases where, for example, the customer has broken down machinery at their own plant and any day or week is crucial for its replacement. In these cases, the case company has not always been able to compete successfully with its competitors when there is no exact knowledge of how long the lead time can take in each case. Due to not knowing it exactly, the way of working has been to play it safe and go with no-risk strategy when planning the lead time. This would result in too lengthy lead time forecast for the customer, and the competition may be lost.

All this means that there is a great need for more flexible planning model when scheduling the order-to-delivery process for each customer project. The current situation is that there are several non-flexible pre-determined lead time models, which are based on the degree of difficulty of each project. This degree of difficulty is determined on the basis of how much engineering hours are roughly needed and how long the lead time of the supplied components should have. Currently, the possibilities for these degrees of difficulties are only few, and there are from three to five degrees of difficulty for each machine type.

Thus, the goal of this study is to develop a new order-to-delivery process model that is more flexible, and re-define the office processes from the engineering, production planning, purchasing and ultimately the customer's point of view.

Next section includes a more detailed definition for the research and the estimation of the outcome planned for this Thesis.

1.2 Research Question and Outcome

This study focuses on the development of the new order-to-delivery process model. In the order-to-delivery process, most of the work phases are done after the previous phase has ended. But there could be possibilities to improve office processes so that there are more things done in parallel, instead of doing them subsequently, as in a chain.

Before any exact promises can be given to the customer for the lead time, there must be a defined model, for example, of how to calculate the engineering hours which are needed. Another key point is the time needed at the longest for the supplied components and the decision where in the production it is needed. All these questions need to be combined into a clear process model, which may also lead to a development of some sort of configuration tool at the end.

The outcome of this study is a new flexible order-to-delivery process model, where the lead times can be calculated more accurate than what is currently done in the case organization. This will also support the organization's current goals of shortening the lead times and generating possibilities for more flexible processes and resources. When the lead times are known better, the customer service could improve and the forecasts that are given to the customer can be trusted.

Another aspect is also the fact that some of the customers are not in a hurry for their orders. These customers’ orders might be part of a bigger project such as a larger industrial power plant, and in these circumstances, the given promise for a delivery date can be much more crucial than in some other cases. Thus, the new process models and tools to analyze the work load make an important focus point of this study.

2 METHOD AND MATERIAL

This section describes the research methods and materials that are used in this Thesis. First, there is a description of the research design and process. This is illustrated in a graphical form to visualize the research process progression. Secondly, there is a short description of the data collection and data analysis phases, and then finally there is an overview of the reliability and validity of this study to establish solid foundation for research.

2.1 Research Design and Research Process

This research is conducted for the case company in collaboration with the project team. The research starts from the definition of the business problem, which is shaped in the form of research question that this study will try to answer. Research process is designed before the work begins and crucial phases are formed into a visual form. The research design shows all of these phases and steps that are planned to carry out in this research process and also all data collection points. These data collection points are numbered from 1 to 3.

The research design for this Thesis is illustrated in Figure 1 below.

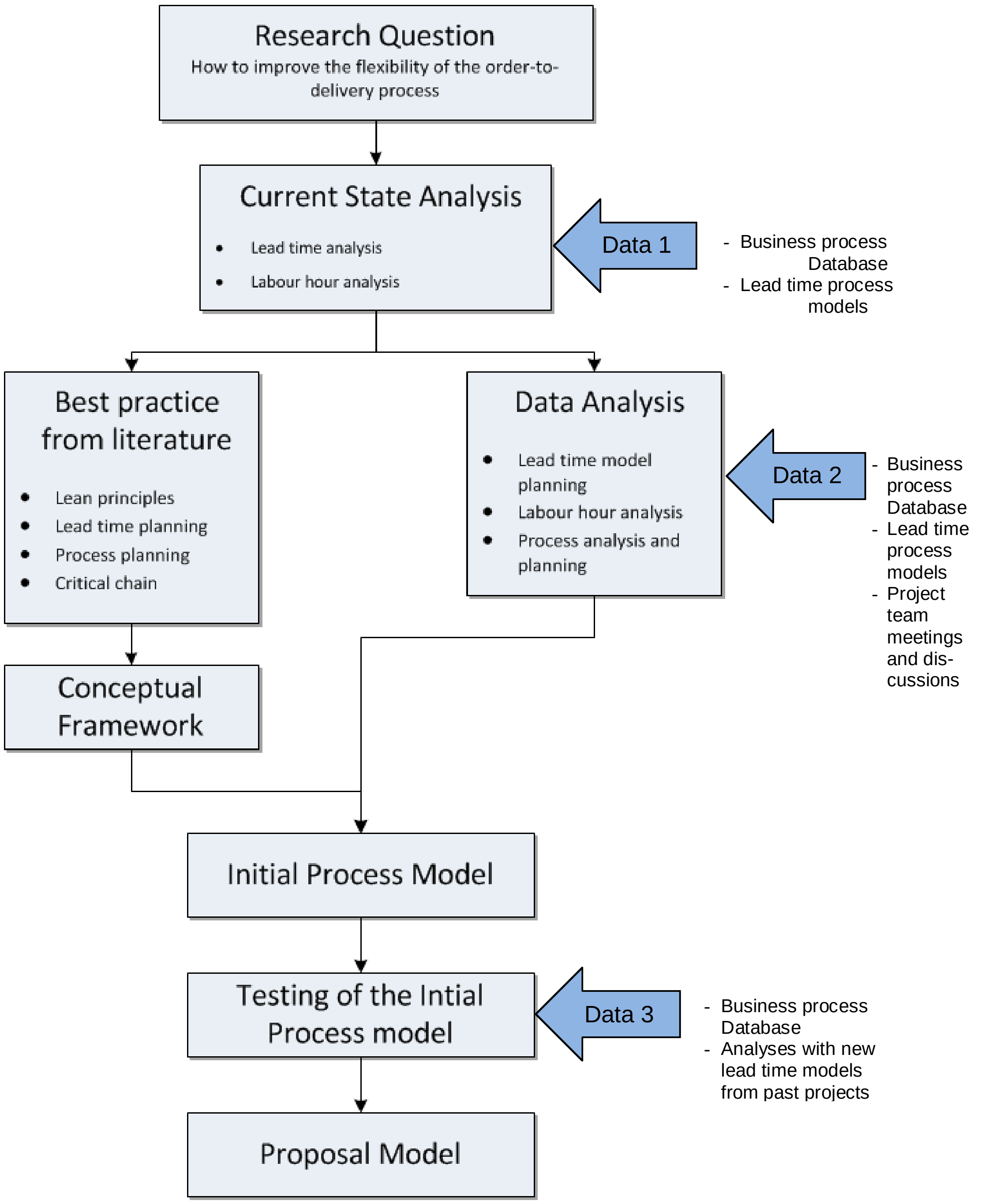

Figure 1. Research design of this study.

As seen from Figure 1, the research design is carried out in several steps. First, the current state analysis is conducted. The current state analysis is done to identify how the lead time models are generated currently in the case organization and what are the critical chain parts in the process. The current process model is then visualized, so that the most important phases and points in the process are made visible. Data for this analysis is extracted mostly from the case organizations data systems, and also from the team discussions and expert interviews. This data includes analyses of the key work phases, so that the main focus points can be recognized.

Secondly, the analysis of the engineering work is conducted. This is done in collaboration with the engineering department. This analysis should identify the elements which are generating the most demanding engineering work and suggest where that information could be gathered from. Simultaneously, the search is conducted in the existing knowledge and literature to find out the related best practice in the field. This best practice is collected into a conceptual framework, which then works as a guideline for the solution development process. Combining the aspects from the current state analysis and best practice in the team discussions provides input to start analyzing the new process model and develop the new tools for analyzing the engineering process.

In the third phase of this study, the initial model for the new process model is presented. This model is then be put to test which leads to the third data collection phase. This data is collected from information systems and the aim is to analyze the actual cases with the new tools and model. The project team brings their expertise to the data analysis and provides conclusions and suggestions. When the data is analyzed with the new tools and the results are positive, the research can proceed to the next phase.

In the last phase, the final model is presented. Before this stage, the results from the previous tests are analyzed and the adjustments to the process models and tools are made. When this is done, the proposal model is finally presented as an outcome of this study.

2.2 Data Collection

Data for this Thesis is collected from several data sources. The primary source of data is the information systems of the case organization. The study is conducted using both qualitative and quantitative research methods, and based on the actual numbers that extracted from the databases. The most important data source is the Enterprise Resource Planning (ERP) system of the case company. ERP systems are generally large software products that run almost all functions from sales and purchasing to production and financing.

Additionally, key stakeholders are interviewed to be able to interpret the collected data in a correct way. Some of the data is collected with analyzing engineering work during their work. Data is collected by taking notes and timing of each step that was conducted. This analysis is used to confirm the calculated and estimated labor hours are in a right direction. This data is then used to analyse the current situation of the case company. After this, with the help of existing knowledge and best practice identified from the literature, a new process model is developed.

The details of data collection are presented in Table 1 below.

Table 1. Data collection.

Data	Collected from	Type	Analysis
Data 1	SAP ERP database	Lead time data from previously confirmed cases	Section 3.3
Data 1	SAP ERP database	Labor hours from previously confirmed cases	Section 3.3
Data 1	SAP ERP database	Basic machine analysis from database data	Section 3.4
Data 2	SAP ERP database	Engineering work analysis from database data	Section 5.2
Data 2	Project Team Meetings	Engineering work analysis	Section 5.2.1
Data 3	SAP ERP database	Engineering labor actual hours	Section 5.4
Data 3	Project Team Meetings	Engineering labor hours analysis	Section 5.4

Table 1 shows where the data is collected in Phases 1, 2 and 3. These steps correspond to the data collection points as visualized in the research design in Section 2.1. The quantitative data is collected from the ERP system in a numerical format, while the data from the meetings is mainly suggestions and estimations for different aspects that are affecting the engineering work and aspects associated with the overall order-to-delivery process planning.

The first data collection rounds, Data 1 and 2, are related to the current state analysis and analysis of the engineering work load. This data includes both the lead times and the labor hours from the databases. The last data collection round, Data 3, is connected to the testing phase of the new principles and tools developed in this Thesis.

Finally, the key personnel and stakeholders are involved in the project by attending the regular meetings for this project. The project team is arranged to comprise the experts from the mechanical engineering and project management departments. The information, data and improvement suggestions received from these departments are used in developing the new tools and analyzing the results of the new principles.

2.3 Validity and Reliability

Validity and reliability of research should be considered to achieve trustworthy results. Generally, the objective of research should be conducted with thorough planning and rigorous research design. This should be done in such way that occasional mistakes or errors are minimized and the researcher’s bias is avoided. These principles also ensure that same results would be achieved if the same research is conducted by another person, using different data collection methods, or at a different point in time. (Yin 2003)

In quantitative research, data can be considered *reliable* if the results are consistent over time and significant representation of the population and also the repetition of the research in a similar methodology with similar results is possible. (Golafshani 2003)

Validity, on the other hand, relates to addressing the research question and finding answers to this question. In valid research, the data is accurate, correctly interpreted and answers the research question. Furthermore, it should be ensured that the results are actually measuring what they are supposed to measure. (Golafshani 2003)

In this study, the reliability is planned to be ensured by making the sample size of the data adequate and ensuring that the time line from which the data is collected reasonably wide. The calculations and methods that are used to interpret the data apply standard statistical methods. This will also ensure that the repetition of the research with similar methodology is possible.

Finally, the data in this study will also be collected from multiple sources, both qualitative and quantitative. These include discussions and interviews with the project team and key personnel in the organization. The validity of this research will also be improved by involving the project team that will help to interpret the results and secure the validity of the calculations.

The validity and reliability of this study will be further evaluated in Section 6.5, at the end of the report.

3 CURRENT STATE ANALYSIS

This section discusses the results of the current state analysis of the order-to-delivery process of the case company. The current state analysis is a comprehensive analysis of the current situation in the case company. This section consists of five stages covering the most important phases of the order-to-delivery process. Based on this analysis, focus points and directions to proceed are identified and further analysed at the end of this section. Additionally, this analysis helps to ensure that the improved process fits the requirements and the stakeholders' views are taken into consideration.

3.1 Case Company

(Section removed)

3.2 Order-to-delivery Process in the Case Company Manufacturing Process

The order-to-delivery process in the case company works on the so-called Engineered-to-Order (ETO) basis. This means that most of the machines that are sold are also engineered from scratch and they make a sort of unique products each time. Some replication of the earlier ordered projects is done occasionally but still in these cases basic engineering needs to be done at some level. However, the time needed for the engineering changes radically when replications or repeats of the previous machines are ordered as compared to totally new designs.

The order-to-delivery process of the case company manufacturing process consists of six major stages. These stages are order *booking/project management*, *electrical engineering*, *mechanical engineering*, *production planning*, *purchasing* and *manufacturing*. Besides these, there are also other important stakeholders such as research and development, quality management, and production development, but these are not handled in this study because they represent more of the supporting functions in the case organization.

The ETO process creates several challenges in the case organization, since the unique designs need unique components that are requiring sometimes extra time, for example, for the purchasing process. As the manufacturing process itself is mostly similar in all of the cases when speaking of the lead time, the main emphasis in this Thesis is placed on the process preceding this stage.

The simplified order-to-delivery process of case company manufacturing process is presented in Figure 2 below.

Figure 2. Order-to-delivery process.

As seen from Figure 2, the main tasks before the manufacturing are the engineering, production planning and purchasing. These tasks are conducted in a chain in the current process, next task begins when the previous has been ended.

In the current process, *the production planning* is responsible for the levelling and scheduling of the production. This is done basically in two stages, before the mechanical engineering stage and right after it. Production planning is also attending the order booking meeting at the beginning, but the role in this stage has been relatively small. Further analysis of the production planning tasks is explained in Section 3.2.2.

The actual lead time planning is currently done automatically based on the fixed lead time models. These models are used based on relatively basic calculations done in the sales configurator during the order booking. The more detailed explanation of these calculations are presented in Section 3.2.3. The lead time models in this case are ranging from * week up to * weeks between different models. For example, the longest lead time always includes several weeks long engineering lead time, whether it is needed or not. This would also suggest that there should be significant differences in the actual labour hours of the engineering work and the lead time that have been planned for engineering for such cases. This analysis will follow in Section 3.3.

In this process model, the distance between *the mechanical engineering* and manufacturing is the time that can be used to purchase all the sales order specific components from the suppliers. In the current model, this time is also fixed, and the length is determined with the selection of the lead time model. This time ranges from just a few weeks up to * weeks on the lengthiest models. This time range remains the same regardless of the need for such time, meaning that even if the actual time needed for purchasing the components specific to a particular sales order takes * weeks, the time given to the suppliers is the maximum * weeks, if another reasons but the time for purchasing decides the need for longest lead time model.

Next sections describe some of the basic tasks which the production planning and order booking departments are going through when a new project is booked.

3.2.1 Order Booking

New orders from customers are booked in *the order booking* which is part of the project management department. Orders are booked by using the *-configurator program, which also functions as a tool for sales organizations. This tool is described in more detail in Section 3.2.3. The sales tool offers the basic lead time model for each case. However, as further described below, this lead time model is based on only on rough estimations utilizing a few parameters and the data is not up to date.

When a new order is booked, the current procedure is to have a pre-booking meeting with all the key stakeholders and, based on the decisions and instructions in this meeting, the actual booking can be done. These estimations and instructions can include, for example, the estimations from the purchasing for the needed delivery times for supplied components, estimations from the engineering for the needed labour hours or the work load for design, and eventually the lead time model suggestion from the production planning based on all this information. However, the feedback of the key stakeholders collected in this study reveals that about half of the new order bookings are done without this procedure.

The decision of the lead time model is, therefore, most often done before any investigation has been done about the capability of the process to handle each case. The decision is often made by the people who might not have any of the information they should have. Furthermore, currently the people making these decisions quite often might not actually understand that they should need such information, but rather rely on the data the sales tool is offering them.

After the new order is booked, the actual office process begins, from the electrical engineering, through the production scheduling to the purchasing.

3.2.2 Role of the Production Planning

The production planning has an important role in defining the overall lead time for each booked project. The overall lead time models are maintained by the production planning team, and they are also responsible for scheduling the actual work phases, both the office phases and production phases. In the case company, the production planning has gone through several changes over the years, where the key focus points from the production levelling principles and the production planning general work description has been modified.

One of the main tasks in the production planning is also to maintain and control the free capacity for new bookings. This should, in the optimal situation, work automatically, but in practice the situation has been that the sales people come to the production planning if they have any requests for slots for new orders. However, these requests are not maintained or followed after the requests, so that the situation is not always in control. When the new orders are booked after the sales person has received their answers from the customers, the same slots for free machines might have already been booked for another case. This means that the role of the production planning in the order booking phase is considerably important, but it is done somewhat loosely in the current situation.

The most visible current role of the production planning is strictly related to scheduling and levelling of the production load. Since Work in Progress (WIP) and Just in Time (JIT) are the key elements in modern and Lean production systems, they play important roles in the production planning to handle the release of the purchases for supplied components correctly. Release of the purchases needs to be done early enough to be successful but also as late as possible to reduce WIP and storage levels.

Figure 3 below visualizes the JIT process in a graphical form.

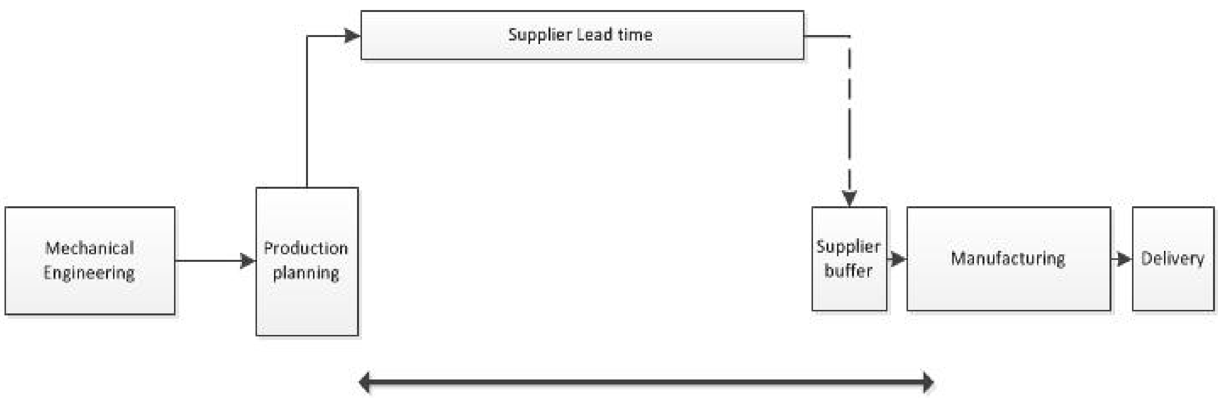

Figure 3. Just-in-Time planning and scheduling

Figure 3 shows a simplified process model where the black arrow points to the critical distance from the production planning to the beginning of the manufacturing. The box above is the lead time for suppliers, and this time begins when the production planning releases the purchase requisitions for purchasers. This critical distance cannot be modified to be shorter than what is the longest lead time component, but the flexibility can be used in to the other direction, thus giving more time for the deliveries. To reduce the amount of WIP and to be able to deliver the components just in time, the release should not take place too early.

However, this also means that the pre-defined lead time model for the whole office process including design engineering is also bound to the same lead time model regardless of the actually needed lead time for the engineering or other departments. Some cases this can be totally different than what is requested by the engineering.

The production planning should have an important role in the order-to-delivery process, since they are also responsible for the master data of the lead time models. The production planners have generally relatively good view and awareness of the current situation when looking at the whole process. This should be used more in the beginning of the process, since currently the role of the production planning is more supportive than decision-making in the process.

Next section describes the functionality of the * configurator tool used in the order booking.

3.2.3 Sales Configurator

Sales configurator* is a sales tool for the sales people. Tool is designed in way that the sales people can configure customer's specifications in a global environment and also so that the factory people can see what kind of machine they are about to order. All sales offices around the world globally use the tool.

Sales-configurator contains pre-defined accessories and properties of all possible combinations of machine types where customers can choose so that the machine corresponds to their needs. Configurable special components can also be added, where basically anything feasible is possible to spec by the customer.

Based on the accessories and roughly estimated special components, the sales-configurator defined basic degree of difficulty for each machine. This degree of difficulty is specified for each part by the estimation of needed delivery time or engineering work. Nevertheless, these estimations are quite general compromises and not updated regularly. All this means that the suggested degree of difficulty is often approximate and directional.

Figure 4 shows an approximate visualization of the lead time models of different difficulty classes used in the case company.

Figure 4. Difference of lead time models.

Degree of difficulty is divided to three possible classes in the sales-configurator. These are *-, *- and *-class. These letter represent also lead time model length, meaning that in an * –class difficulty the lead time is shortest and in the *-class longest. For example, simple * type motor with *-class degree of difficulty would mean * weeks of lead time and *-class * weeks. Both engineering complexity and lead time for purchased components are considered when determining the degree of difficulty, but as said in a previous section, this information is not updated regularly and it is always a compromise between either supplier lead time or engineering work load.

Next section presents the analysis of the mechanical engineering work phase and discusses the tasks conducted at that point of the order-to-delivery process.

3.2.4 Mechanical Engineering Job Description

Mechanical engineering in the case company is done case by case and it is mostly computer aided designing. Mechanical engineers design the machines according to customer specification. Simple and basic machines are done utilizing the existing structures and designs, but more complex demands by the customer usually require manual designing. Additionally, if the requested machine and its design is a repeat or replacement from previously ordered or delivered machine, the required engineering labour needed changes radically.

Mechanical engineering department is one of the biggest white-collar departments at the case company. This shows that the labour hours at the engineering department is also significant for the factory and the order-to-delivery process, since most of the employees at the department in question are all the time actively signed on one of the project.

Mechanical engineers create all the documentation and drawings needed in the manufacturing process. These documentations and drawings are created using assistant programs, but in many cases detailed manual work is also needed. More complex machines need more complex and tailored documentations, which mean more manual work intensive engineering process.

In the case company, the mechanical engineering is currently done in two phases. The pre-engineering stage consists of basic customer documentation generation and basic preliminary drawings for the machine. The second stage is the mechanical engineering, which is done separately and sometime by different designer. After this stage, the whole design of the machine is completed and the process can proceed to the next stage.

Some of the problem areas in the engineering is caused by the customer tailored products which creates situations where the engineering cannot be continued because of the communication between the open issues of the design. This would mean that the engineering work is on hold and it can continue only after the customer have given their answers to the open questions. These will lead to the situation where the actual lead time of the engineering process is much longer than the labour hours used at the same time in the process. Since the most demanding and difficult machines are often in this kind of situation, there must be always some extra buffer in the engineering lead time for more complex machine types.

Next sections provide detailed analysis of the engineering work phase to find out the key points from the relevant tasks that are done by the engineers.

3.3 Engineering Work Load Analysis

Engineering work load and lead times are the key elements of the whole order-to-delivery process. Engineering consists of electrical calculation, mechanical design and customer document creation. Altogether, these operations can take approximately * of overall lead time. When the current lead time models are fixed to certain types based on simple calculations, most of the cases the actual lead time of engineering is something else than planned.

Order backlog was analysed from year 2013 to find out the actual confirmed labour hours and to compare them with planned values. From these numbers the calculations showed that on average, only roughly * of the planned lead times was used in engineering. This average was calculated for a total of * projects, which gives good p-value of <0,005. When comparing confirmed labour hours to the planned labour hours from the same data, the difference was even bigger, just around * of the planned hours were used. Calculations for these statistics are presented in Appendices 2 and 3.

This analysis shows that there is a great need for a more detailed analysis of required engineering hours and also that there is a great opportunity to cut down the lead time from engineering. The engineering department is not organized in a way that the capacity is fully utilized, since even with these numbers the actual process is often delayed.

Figure 5 below shows the actual versus planned lead time of the engineering department from the year 2013.

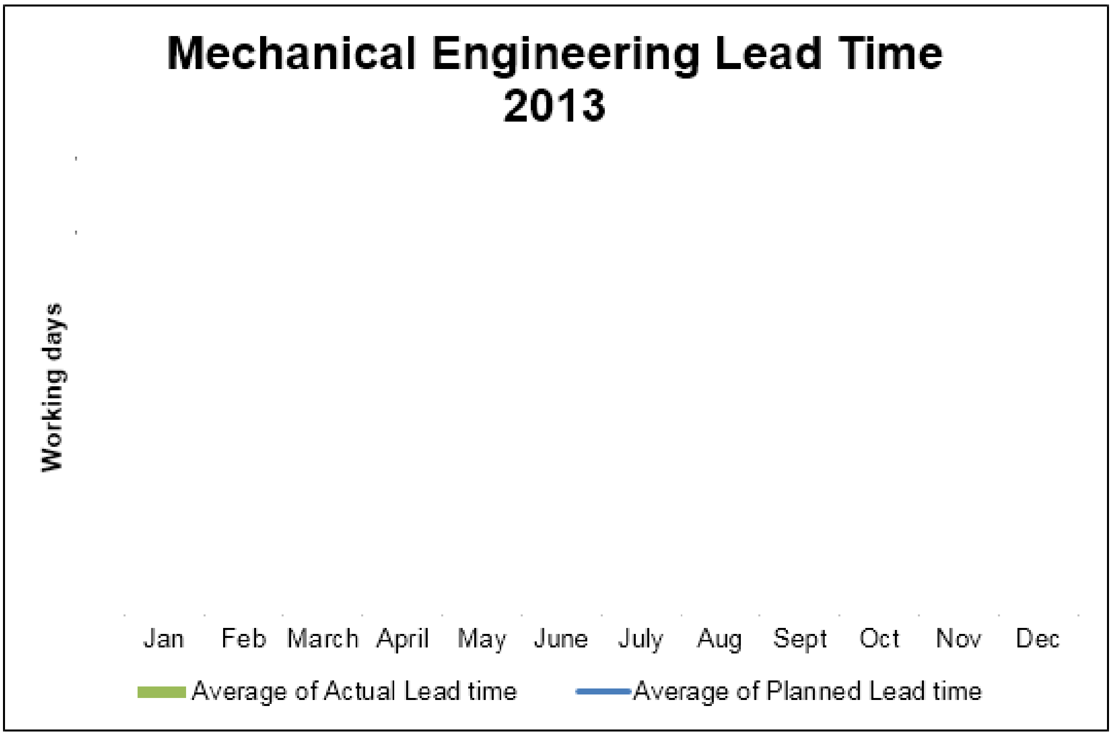

Figure 5. Mechanical engineering lead time.

As seen in Figure 5, the green columns the average actual lead time used in engineering monthly, and in the blue line the average planned lead time. It is clear that there is significant gap between actual and planned hour's levels. The differences from monthly distribution is not practically significant in this case, the allocation of the data is done monthly to help visualize the averages.

Only small observation can be made from the summer holiday peaks, which shows a small difference from other periods. This is mainly because of the less qualified summer trainees working during these months. Generally the distribution of different machine type varies greatly during the year, there can be a bigger order for similar easy machines in one month and lots of difficult unique machines in one month. Consequently, this analysis is used in this Thesis only to present the difference between actual and planned lead time in the engineering in a visual form. The actual figures behind this data is analysed in more detail in Appendix 3.

Figure 6 below shows the actual confirmed labour hour versus planned labour hours for mechanical engineering from the year 2013.

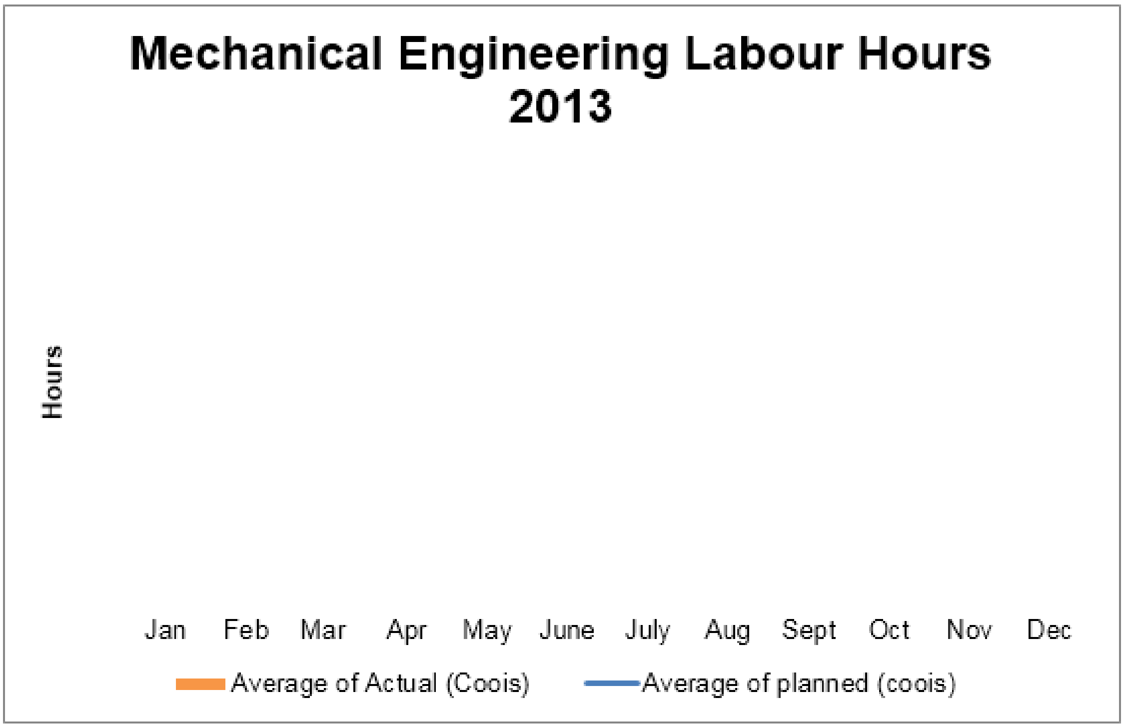

Figure 6. Mechanical engineering labour hours.

As seen in Figure 6, the orange columns for actual average compared to the blue line with planned average again leave a huge gap. These columns represent again a large amount of different machine types allocated monthly basis for visual reasons. The numbers are calculated in more detail in Appendix 2.

This analysis only shows the numbers and figures that have been put into the system. This means that it can be possible that there are, for example, mistakes in confirmations or hours deliberately left out that can distort the results. Engineers may generally type in manually the labour hours they have used for each case, so the possibility for wrong estimations can be significant. On the other hand, this would generally affect only on the amount of confirmed labour hours registered on each case, rather than the lead time of the engineering which is based on the start and end confirmations on to the information system.

Additionally, what comes to the On-Time-Delivery, OTD, of the engineering process, the analysis shows that the process is not working as it should. On-time-delivery is a generally used metrics to measure the preciseness of the process, most commonly against the delivery date. In this case the dates compared are the scheduled end date and the actual finishing date of the engineering process.

Figure 7 below shows the illustration of the OTD of the engineering process, using the same data as in the other calculations in this section.

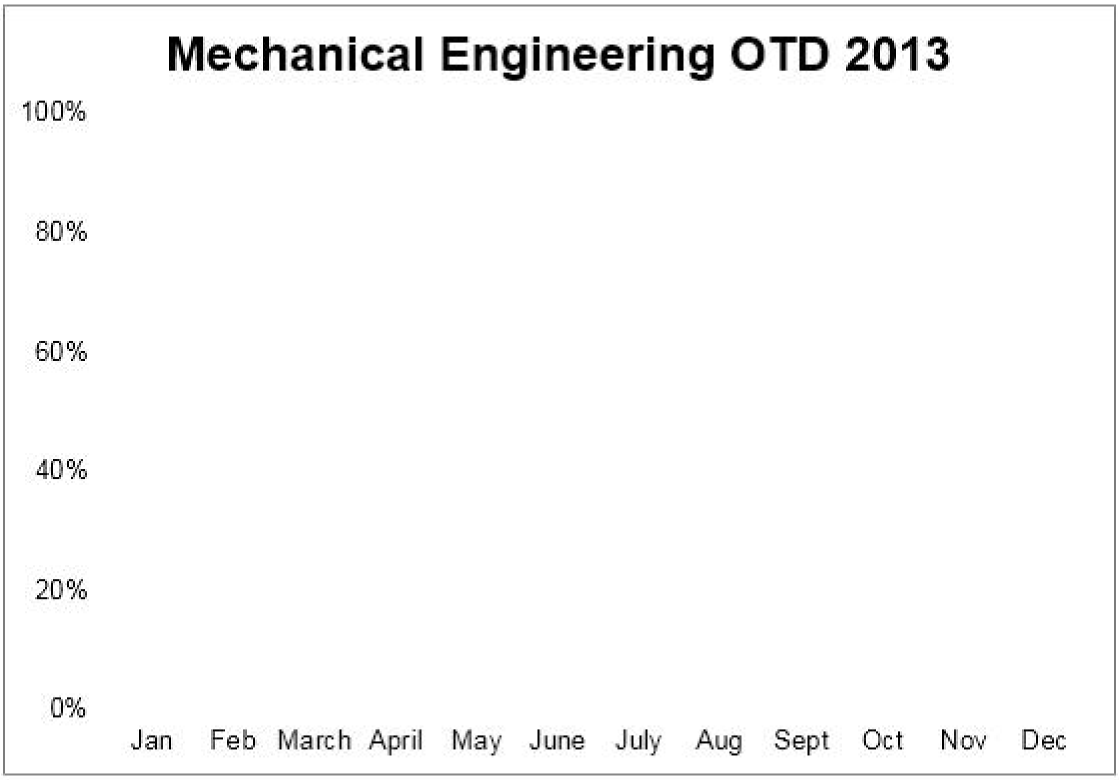

Figure 7. On time delivery of the mechanical engineering process (2013).

As seen in Figure 7, the average OTD is somewhere between *-* %, even with the results from the previous analysis shows that the time used in the process is significantly less than what has been given. This would suggest that the process is working inefficiently, merely focused doing wrong things at the wrong time. This could happen if the work-in-progress is causing overload situations even though the actual work is done considerably faster than scheduled.

The main issues at the engineering work from the process analysis perspective are clear. The work is done faster than planned, which means that the estimations for labour hours needed are incorrect. At the same time, the process is not in control due to the poor understanding of the work load. Process is delayed even with the faster work than planned, which would suggest that either there is not enough resources or the resources are allocated wrong.

Next section overviews the old project cases with the goal to find out the average labour hours needed for a basic machine without any complicated special items involved. This will help to understand the general work amount needed for designing an case company without disturbing factors. Later this information will be used when developing the new tools for engineering work load analysis.

3.3.1 Analysis of Order Backlog

Order backlog of the case company was analysed to find out the engineering work load and lead time for basic standard machine. This information can be used to recognize the more challenging properties from the engineering perspective. In the beginning, this analysis included all the delivered machines from year 2013. The main focus was to look for engineering actual confirmed working hours for each project. Information was exported from ERP system and analysed in an Excel file. Based on this analysis was found out that the engineering labour hours for a basic standard machine was relatively consistent between different machine types.

In this analysis the scope was to search and identify only the basic machines from the database. This was done by sorting out only the *-classified machines, with the assumption that *- and *-class machines would practically always include at least few components that require intensive manual labour. This remaining data was also cleaned from excessive customer documentation, meaning that any project that had more than just the basic documentation was also eliminated from this analysis.

The data was analysed by statistical methods using average, median and standard deviation to find out the optimal basic machine from each machine type category. This analysis was done with the statistical software Minitab, and the results are shown in the following figures.

The analysis of the actual engineering labour hours for the * machine type is shown in Figure 8 below.

Figure 8. Statistical analysis of * *-class actual labour hours.

Figure 8 shows that the average labour hours for basic * machine is * hours. Since the distribution is also relatively narrow, only just few higher hour exception relocates the distribution to the left side of the diagram.

The calculation shows that the mean labour hours needed for basic * machine is somewhere between * and * hours for 95% confidence level, which means that in a 95 % of the cases the labour hours sets in that interval. Since the average labour hours of the machines in question, was also in that interval, as being * hours, it can be estimated that the chosen basic hour amount of * hours is relatively safe choice.

Figure 8 shows that the number of population in this case was * pieces, which means that the statistical analysis is fairly reliable. This can also be confirmed from the calculated P-value, which is well below the usually accepted reliability level of 0.05. This means that the values are not random and they have statistical significance.

The analysis of the actual engineering labour hours for the * machine type is shown in Figure 9 below.

Figure 9. Statistical analysis of * *-class engineering labour hours.

The analysis shown in Figure 9 is similar to that in the previous picture, mean labour hours are in interval of * and * for 95 % of the projects. Additionally, the average labour work of * hours is in between this interval. Chosen * hour average for basic standard machine seems reasonable based on this analysis.

Figure 9 shows that the population is * and the p-value is well below acceptance level of 0.05. This means that the calculations are also trustworthy.

The analysis of the actual engineering labour hours for the * machine type is shown in Figure 10 below.

Figure 10. Statistical analysis of * *-class engineering labour hours.

Figure 10 shows that the mean 95 % confidence interval for this machine type is between * and *. In this case the average of the labour hours is around *. For this machine type the basic hourly rate was chosen to be * hours. It could be slightly higher, but the chosen value seems appropriate. The variance in this case is much higher than other machine types, which leads to fairly wide range of confidence interval.

In this case, the number of population is a lot smaller than previous ones, just * pieces. This also affects to the p-value estimation, which is in this case higher. Nevertheless, the p-value is also well below the acceptable level and this analysis can therefore be justified as reliable.

Since the engineering work is currently divided in to two separate work phases, pre-engineering and mechanical engineering, similar calculations were done also for the pre-engineering.

Figure 11 below shows the average pre-engineering labour hour analysis for * machine type.

Figure 11. Statistical analysis of * *-class pre-engineering labour hours.

Based on Figure 11, it can be confirmed that the average labour hours for pre-engineering for * type machine are around * hours with the confidence level of 95 %. Therefore the estimate figure of * hours can be regarded as reliable.

Equivalent graphs were made also for other machine types from the pre-engineering work phase, but since these work phases consists mainly of basic tasks to create necessary long term component purchase requisitions and basic customer documentation, big differences were not found between different machine types. Based on this analysis was decided that the basic hour amount for all machine types is going to be * hours.

This order backlog analysis showed that the chosen basic labour hours for each machine type was in the right direction and those could be used in the development of the new configuration tool for analysing engineering hours.

Next section will discuss about the lead times of the engineering process.

3.3.2 Lead Time Calculations

A second significant contributing factor to the order-to-delivery process is the lead time. Therefore an overall lead time calculation for the whole order-to-delivery process was also conducted. This was done to find out the actual impact of the engineering labour hours to the whole process and its lead time. Engineering is just a small fraction of the order-to-delivery process, but it has a significant role in defining the overall lead time for each individual project. Table 2 below includes a lead time analysis for most common lead time models used in the case company.

Table 2. Lead time calculations for the order-to-delivery process models.

Type	Lead time model	Lead time (wk)	Lead time (d)	Pre-eng plan lead time	Pre-eng avg lead time	Meng plan lead time (d)	Meng lead time (d)	Sum plan	Sum act	%	-%	Diff	Lead time with avg eng	% diff	% -diff
*															
*															
*															
*															
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Table 2 shows that the can be seen that the actual lead times differ significantly from planned lead time when looking at planned and actual lead times in engineering and comparing them to the actual and planned lead time of the overall lead time for the whole order-to-delivery process. This can be seen both the lead time inside the engineering process as also analysed in Section 3.3, but also when comparing the time difference in relation to overall process.

Figure 12 shows a graphical analysis of this same result.

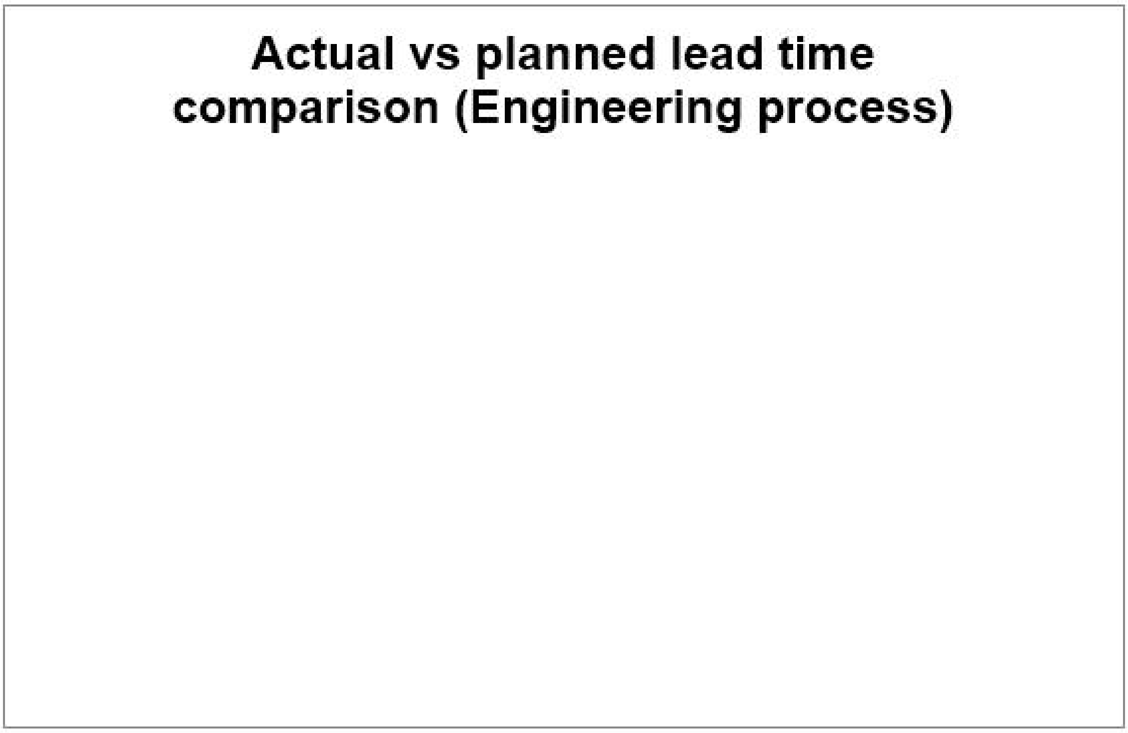

Figure 12. Actual lead time compared to planned lead time.

Figure 12 shows on the horizontal axel the current lead time models used in the case company and on the vertical axel the potential of the lead time cut in percentages. Figure shows that the average lead time cut could be around * up to over * in engineering by using more realistic lead times in the engineering. Different product types have more capability to cut down the lead time, and in the figure can be seen that the most effective lead time cut could be achieved on the longest lead time models such as *- and *- class machine types. Furthermore, the * –class machines which are a certain permanent magnet type machines, are almost never completed with the planned lead time but rather significantly faster schedule.

Figure 13 below shows the same comparison to the overall order-to-delivery process, when engineering lead time is optimized with average lead times. This figure shows how the overall process could be improved if the engineering lead time would be shortened to the minimum.

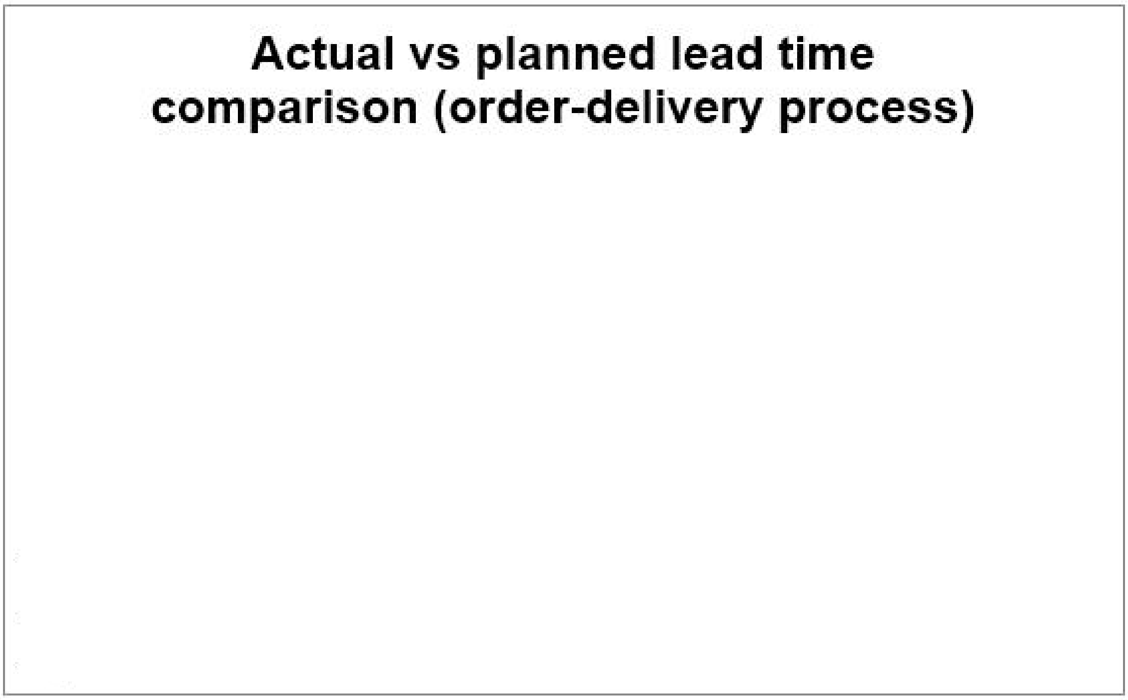

Figure 13. Planned lead time compare to actual lead time in the order-to-delivery process.

The diagram in Figure 13 shows that if the engineering lead times could be optimized to the average lead time actually used, the overall lead time for the order-to-delivery process could be cut down from * up to over * from current lead times. In this figure it is also notable that the biggest lead time cut could be possible on the longest lead time models, and not as much on the shortest one. This would mean that most likely the longest lead time models are almost always possible to complete much faster than what the original lead time model give them for the planned lead time.

Analysis suggests that the more detailed and accurate analysis would be most beneficial on *- and *-class machines, and not so much in the easier machine types. The effect on the whole lead time of the order-to-delivery process in these easier cases is still relatively small. However, if the engineering labour hours are better known, the mistakes in the estimations and false promises given to the customers could be avoided also on the easier machines.

3.4 Key Findings of the Current State Analysis

The current state analysis started from the analysis of the current order-to-delivery process in the case company. There were two major focal points found from the case company. First, the order booking and the lead time planning at the beginning of the order-to-delivery process lacks clear procedures. Secondly, the engineering process does not seem to be under control in the means of ability to forecast the ongoing and future work load.

Table 3 below shows the key findings of the current state analysis.

Table 3. Key findings of the current state analysis.

What	Why
Rigid lead time models	Fixed length lead times instead of case by case flexibility
Lead time planning procedures	Protocol not followed
Engineering process unknown	Labour hours not analysed case by case
Engineering process overestimated	Planned labour hours and lead times based on old averages
Lack of accurate engineering labour hours	Manual confirmation by user

The current state analysis showed significant weaknesses in the planning and managing of the lead time models in the order-to-delivery process. The process does not seem to be under control from the lead time planning perspective. The lead times are based on old average figures, and they are used in the organization apparently rather randomly and with wide safety margins. Nevertheless, the process is lacking behind even the planned lead times or labour hours are not used for actual work.

Another observation from the current state analysis is that the order booking process is not currently handled as it should be. Order booking is a crucial point in the order-to-delivery process to ensure the optimal lead time for each case. However, the feedback from the office reveals that many of the cases don’t follow the defined steps in the procedure. The role of the production planning is small in this stage, although the visibility for the overall process could be best utilized by this department.

This analysis shows that there are significant room for improvement in the lead time of the engineering. Calculations show that the average cut of the lead time could be somewhere *% in engineering. This would mean major cut of the lead time of the overall process. Basic problem of the case company is that the engineering work load is not known, making the accurate forecasting of the lead times almost impossible. Forecasts are currently based on just few parameters and are most of the time way of the actual work load as this analysis shows.

Based on this analysis, the focus point in this research is going to be to find a new way to analyse the engineering work load. Additionally, the important role of production planning needs to be redesigned to better serve the need of the customer. This would mean that instead of planning the manufacturing process, the focus should be in the whole order-to-delivery process. New planning model is needed to assign the tasks to handle the overall process planning. This model will be based on the findings in the literature and to be able to test this new model, new tools needs to be developed aside. These new tools are needed to analyse the engineering work load.

Summing up, the current state analysis conducted in this section shows that the engineering process is one of the key processes in this case organization from overall lead time perspective. This process should be analysed with much more accurate methods to be able to serve the customers at best possible way and to be able to forecast the delivery times realistically.

4 LEAN LEAD TIME PLANNING

As the objective of this study is to develop the best possible process, it is important to check the current practice for process development. Therefore, this section includes best practice for lead time planning based on books and articles on lean lead time planning. From. Some of the focus points are the lead time planning and lean principles. This is done to absorb the best practice for developing a new process model. Using this knowledge, the new process model can be designed in a way that it is optimal for specific usage, combining the common knowledge in the organization to the best practice from the literature.

Lean management and principles are one of the key concepts in this section, since the optimization of processes, minimization of waste and smoothness of process flow are the main goals in the lean management.

4.1 Lead Time Planning

In Manufactured To Order (MTO) or Engineer To Order (ETO), the lead time planning is usually done based on either backward scheduling or forward scheduling or combination of both. Yeh (2000), describes this as a customer focused planning approach, where Bill Of Materials (BOM) is combined with routings and finite capacity scheduling using both forward and backward scheduling in a way that the cumulative lead time is optimized and the Work In Progress (WIP) is also as minimal as possible. (Yeh 2000)

Lean management principles commonly use Little's law to define Work-in-progress in one mathematical formula. Little' law is defined as following:

Lead Time = Inventory (WIP)/Throughput

This formula suggests straightforward that the lead time could be shortened by reducing WIP, if the throughput remains the same. Generally this means that the WIP is always related to the lead time and it should be considered when the aim is to cut down the lead time. Relationships between these parameters create the basis of measuring the effects of the process improvements. (Krajewski et al. 2010: 272)

Finite scheduling in this process is combined with materials requirements with a MRP, material resource planning. MRP is a common tool in most current ERP systems; such as SAP, which is in use at the case company also. The current lead time planning principle resembles closely Yeh's (2000) system, which is illustrated in Figure 14 below.

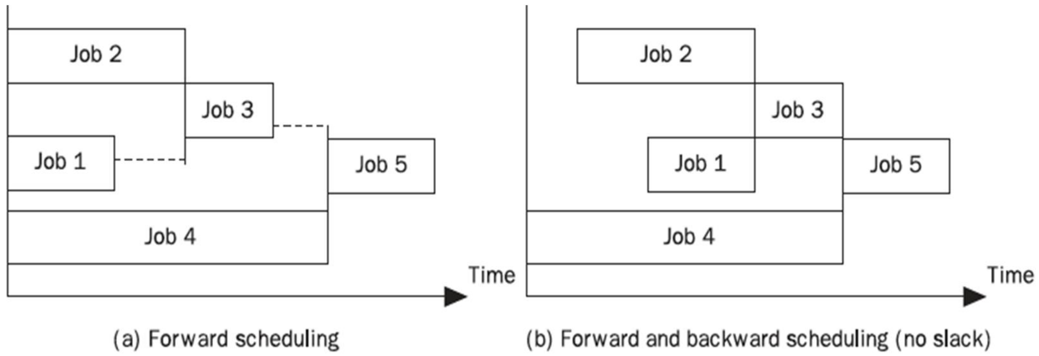

Figure 14. Scheduling basics (Yeh 2000: 185).

Combination of backward scheduling and forward scheduling removes extra gaps from production schedule and is in that way also reducing WIP. However, when all jobs are planned the most optimum way, the overall lead time remains the same.

Next section applies lean manufacturing principles to the office processes.

4.2 Lean Manufacturing and Office Process

One of the big challenges in the modern manufacturing industry is to create organization leaner, lighter and focused to serve customers better (Martin and Cheun 2000)

Lean manufacturing has been a rising trend in manufacturing since 1980. One of the key elements that are often linked to lean manufacturing is WIP. Less WIP can be seen as a powerful way to improve manufacturing productivity. Scientists and experts all over the world repeat the same thoughts, high level of WIP results long lead times (Lee-Mortimer 2006) and higher quality (Henry et al. 2010).

Lean principles are commonly targeted to achieve certain improvements in the process flow. Some of these improvements consist of such things as workforce flexibility, multi-talented workforce and removing of bottlenecks by relocating workforce. Generally, these aspects are usually equally problem areas in many organizations since the flexibly and talent is not acquired among personnel. Therefore, implementation of these aspects could relieve the bottlenecks and improve the profitability and effectiveness of the processes. (Krajewski et al. 2010: 322)

When the main goal in process development is the Overall Equipment Effectiveness (OEE), high quality or on-time delivery rate, the good result is often gained by increasing buffers and WIP. As Lee-Mortimer is describing, most companies have adopted some parts of the Lean manufacturing ideology, such as 5S, Value Stream Mapping or TPM, but the whole concept of creating a lean manufacturing process is still somewhat missing.

When looking at the whole order-to-delivery process, the lean manufacturing ideology can be used also other than just the production side of the process. The same principles occur there also, such as reducing WIP and buffers to reduce lead time.

Just-in-time (JIT) is another regularly used term considering manufacturing processes. When production process is optimized with JIT, benefits are easily noticeable such as low level of stock, but it also means that the manufacturing must be started as late as possible and without backlog (Houghton and Portougal 2001). When this way of thinking is used, it often also means that the work load is rocketing up and down and it has negative affect on capacity cost. The article by Houghton and Portougal also suggests that the JIT planning used by most commonly used ERP systems such as MRP, materials resource planning, is blindly relocating customer orders based on minimizing stock levels. This leads to the misusing of capacity and creates need for excess use of overtime and other costly ways to handle the bouncing work load. (Houghton and Portougal 2001). In addition, it is suggested that optimized lead time and improved quality can lead to improved performance without need to increase resources (Hendry et al. 2010).

Looking at the engineering and other office processes of the case company, the aim at minimized WIP using optimized JIT procedures are causing heavily alternating workloads and also causing extra overtime costs.

Next section analyses the possibilities to bring flexibility to production and capacity planning.

4.3 Flexible Production and Capacity Planning

Capacity planning is one of the most important tasks at the production planning. Wang and Shih have defined their planning model as an advanced overlapping production planning model. Their model is based on flexible and overlapping production jobs and also on fact that the jobs themselves should be able to be sliced down in to smaller units. This would mean easier handling of the overall capacity and workload between different workstations. Based on the calculations, splitting jobs in to smaller pieces and using enough margins, can the capacity utilization be optimized a lot better than any other traditional capacity and workload calculation (Wang and Shih 2010).

In many cases the traditional MRP scheduling, Materials Resource Planning, generates situations where jobs are planned to be done at the latest possible time but with flexible buffers to level the capacity, which often leads to greater stock levels and longer lead times (Ashayeri and Selen 2013). Additionally, the usage of extra buffers still leads to uncertainty in error situations, since the buffers might have been used to level the work-load minimizing the buffer needed to fix the errors. General understanding is that the usage of MRP leads to in many cases to higher WIP, Work In Progress, which leads to aforementioned problems (Ashayeri and Selen 2013).

Figure 15 below shows an example of the advanced overlapping planning model.

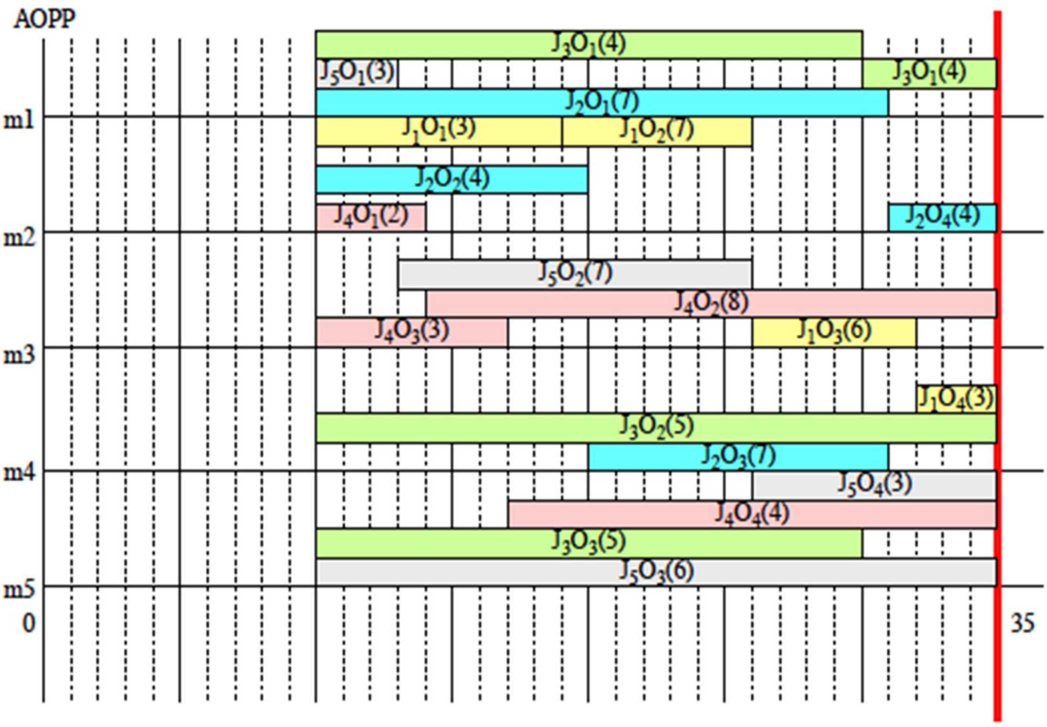

Figure 15. Advanced overlapping production planning (Wang and Shih 2010: 885).

Figure 15 contains an example of the advanced overlapping planning model, where overcapacity is handled by splitting one job in to two jobs, filling an empty slot and relieving excessive workload so that the situation can be handled.

However, handling this sort of production planning, by splitting jobs, can only be used in a situation where breaking the work chain is plausible. In some cases this kind of planning cannot be done, since certain stages in production or process require the previous phase to be completed before the next one can begin. This would mean that the overlapping in cases like these could not be used or at least significant changes to the process would need to be done.

When the goal is to have as flexible process as possible, Du et al. (2003) suggest that the both BOM, Bill-Of-Materials, and the routing master data of the product, should be combined as early as possible in the process. By this they mean that the process that creates the BOM for each individual product, should also create the manufacturing routing structure, which in the most cases is currently handled separately. As a result, this should improve the information and material flow in the organization and production (Du et al. 2003).

Since the SAP ERP system is the factory standard in most large manufacturing organizations, it is meaningful to look for alternative case examples from literature about SAP optimizing and planning. APO, Advanced Planner and Optimizer, is a SAP tool and integrated additional module developed by the SAP Company themselves. APO is a flexible optimizer for supply-chain, process and production planning and scheduling. In a research by Chen and Li (2012), it was found as a key mechanism to handle multiple factories capacity simultaneously using APOs more intelligent algorithms than basic MRP can offer. APO also offers possibilities to track and analyse forecasts more accurately than basic SAP components (Chen and Li 2012). Another key point from the research was also the observation that the information being transparent and real-time is most important fact to survive in a multiple manufacturing site organization (Chen and Li 2012).

Next section analyses the critical chain associated features of the lead time planning situations.

4.4 Critical Chain Project Management

Critical chain is a project management theory that is based on the rule of the identifying the shortest route from start to finish. The Critical chain project management theory was originally introduced along with the Theory of Constraints (TOC) by Goldratt in 1997 (Goldratt 1997; Krajewski et al. 2010: 285-287).The critical chain theory differs from critical path ideology by introducing buffers and using the slack between the non-critical-path-tasks to level the workload. This also effects on the priority of the tasks, since the critical chain theory does not try to find the optimum solution but rather a decent solution that can be accepted. Critical chain method is based on the requirement that the non-critical path task should be finished as late as possible.

Buffers for critical chain project management include the project buffer, feeding buffer and resources buffers. With these buffers the ideology defines the maximum critical chain length, and rather than focusing on following individual tasks completion compared to the planned schedule, the focus is on following the consumption of the project buffers. This also creates the opportunity to handle the risk management in the project.

Ming and Wuliang (2009) are presenting their idea of an action plan critical chain method, which differs from Goldratt’s theory by the requirement of as late as possible finishing for non-critical task turned around to the possibility of such task to be started as early as possible. Although, the reasons why this is on the other way in the TOC theory is the key concept of minimizing the Work-In-Progress (WIP), which inevitably increases if the non-critical tasks are scheduled to be finished as soon as possible. (Ming and Wuliang 2009; Krajewski et al 2010). Instead this action plan theory might generate situation where time seems to be not an issue and making possible for resources to multitask or re-schedule task in a way that the overall schedule could be compromised.

Figure 16 below shows an example of such active plan based critical chain method.

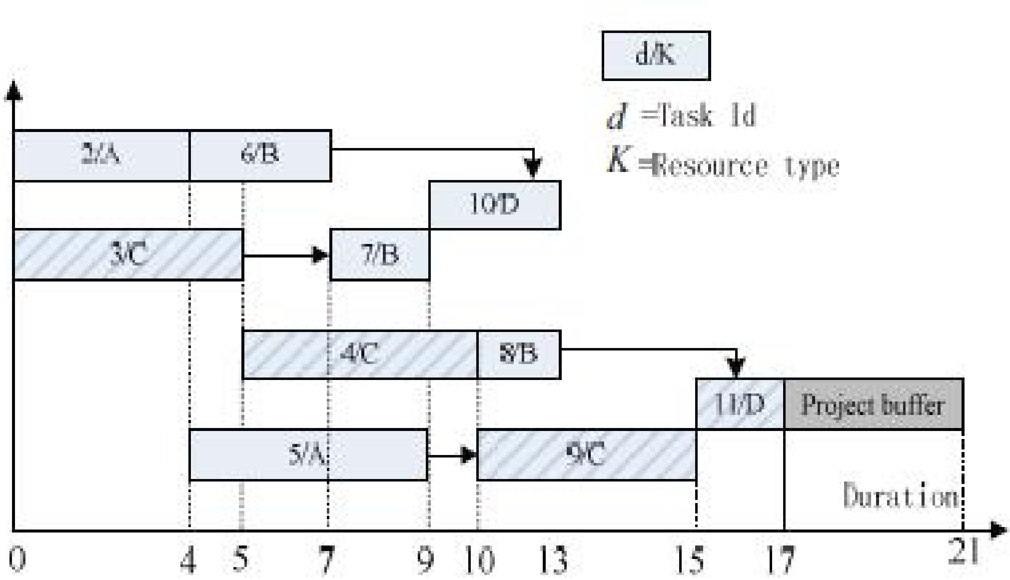

Figure 16. Active plan based critical chain method (Ming and Wuliang 2009: 2768).

Figure 16 shows an example of an active plan based critical chain method, with critical chain marked with cross-sectional lines in the boxes and the project buffer marked at the end.

4.5 Best Practice and Conceptual Framework

The previous sections consists the key elements and development areas that are connected to this study. This section presents a summary of these aspects and concepts. This is done by combining all the knowledge and best practice that has been shown here, and the result is the conceptual framework built around the main aspects that should be focused on. The conceptual framework presented in Figure 17 below is a visualization for this study to help bring the development areas under one topic and summarization.

The conceptual framework of this study is presented in Figure 17 below.

Figure 17. Conceptual framework of this study.

Figure 17 shows how the topic of this Thesis, the planning models for the order-to-delivery process, will be approached to find a solution for the case company.

Figure 17 shows that the new planning model should be built around few basic concepts. First, there is a general idea of Lean management and lean principles adaptation to planning. This means that in order to cut the slack from the process, lean principles are a good starting point. This includes cutting down the Work-in-progress and focusing on doing the right things in each work phases in the process. These right things should be something that clearly adds value to the customer and all other actions should be eliminated where possible. This would mean that the office process should be examined so that the process is as lean as possible without additional caps between different work phases.

Secondly, the scheduling rules should be defined so that in any capacity situation correct actions can be done to achieve optimal lead time for each customer case. These rules should be defined in a co-operation with engineering department in a way that the capacity is under control and utilized optimum way. The optimization of the engineering work load should be done in a way that the resources are fully utilized, but also in a way that at the same time the overcapacity situations are avoided.

Thirdly, overlapping work phases should be taken in to consideration where possible. This would mean that everything that is traditionally done in chain in the case company should be re-analyzed about their inputs and outputs and ultimately made possible to do at the same time. This would mean significant benefits in overall lead time, but in the other hand it would mean that more resources should be pointed to each case simultaneously. Traditionally this is something new to the current way of working, which is based on the thought that one engineer should be responsible for each project alone from start to finish.

Fourthly, lead time analysis should be done with more accuracy than currently is done at the case company. This means that the new analysis tool needs to be developed to be able to forecast needed engineering work load for each project. To be able to plan the process at the most flexible and optimal way, the different work phase’s structures and lead times must be known. This would also be linked to another work phases than engineering, such as the time window needed for supplied components.

Fifthly, critical chain analysis and principles should be taken in to use in the case company. When all the important phases in the process are analysed and the lead time of each phase is known, the critical chain defines the overall lead time for each project. The critical chain also brings forward the tasks that are the most critical for the order-to-delivery process and should be dealt carefully and on time.

Finally, this becomes more important and complicated when the work phases are separated and sliced down in to smaller parts. Most of the times the optimal situation for an individual department and its work load, requires using other than standard as late as possible scheduling. Consequently, to be able to balance the capacity, separated parts could be scheduled differently to achieve optimal situation. These scattered pieces are then in the centre of defining the critical chain and overall lead time.

Based on the principles demonstrated in this conceptual framework and the findings from the current state analysis, the new planning process model is defined in the next section.

5 BUILDING A MODEL FOR FLEXIBLE LEAD TIME PLANNING

This section describes the development process of the new flexible lead time planning model. First, there is a description of the new process model. Secondly, there is an analysis of the new configuration tool that was developed. Finally, there is short description of the new order-to-delivery process with flexible planning model and analysis of the tests of these new processes.

5.1 Flexible Planning Model Framework

Production planning holds the most important place in the order-to-delivery process when the overall lead time is defined. The flexibility comes from the different and exact lead times for each case and the decision of which lead time can be used at certain case must be at the hands of one stakeholder group. When all different needs are summed up, it will be necessary to have a certain referee group between different demands.

At the current process model, the production planning is basically involved only after the crucial steps have already taken, and the most responsibility for the team is handling and levelling of the manufacturing and capacity.

In the new suggested process model, the production planning is responsible for order review and lead time calculations right in the beginning of the order-to-delivery process. Additionally, the current role of levelling the manufacturing at the midpoint of process remains as currently. New role must be defined also to the checking point right before the manufacturing begins. This role is needed so that the manufacturing can be released and handled over to the manufacturing supervisors. At this stage the production planning must go through and confirm the manufacturability of the product, meaning that the purchases are valid, bill of materials, routings and structures are correct.

Figure 18 below shows the new flexible planning model suggested in this study.

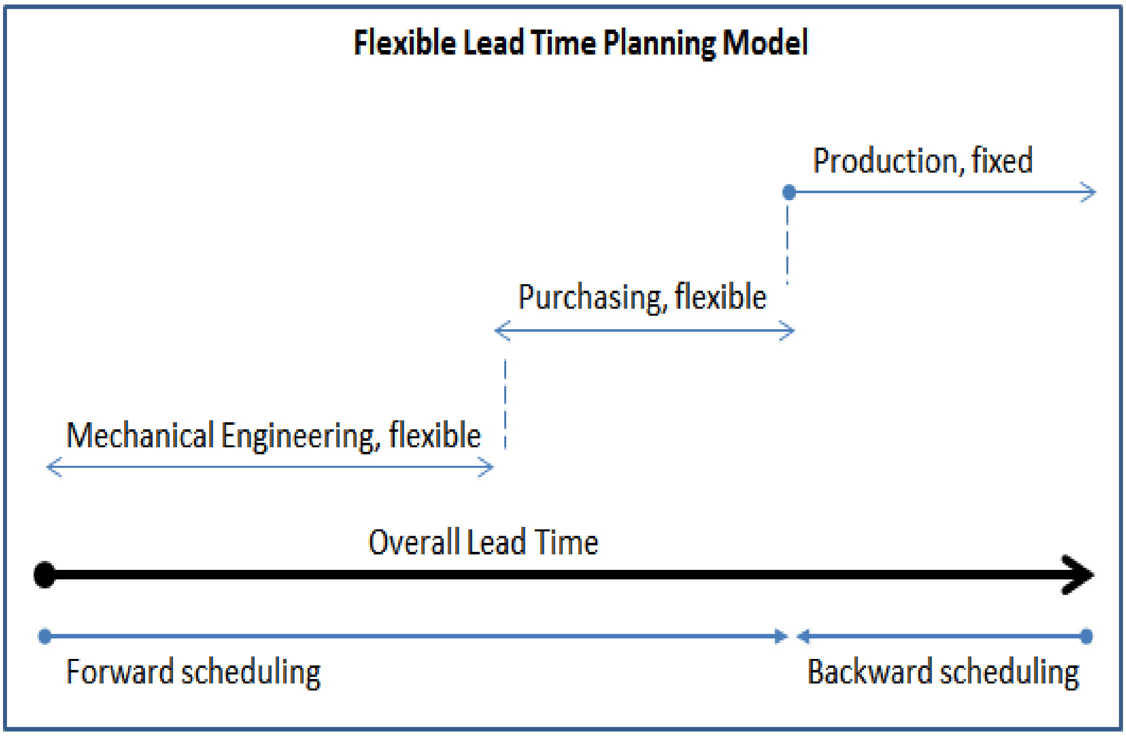

Figure 18. Flexible planning model.

Figure 18 shows that the new planning model consists of flexible work phases. This is different from previous model where all the lead times for each work phases were fixed, as the models were only few to choose from.

5.2 Configuration Tool for Lead Time Analysis

Based on current state analysis and the common understanding among key stakeholders, one of the main focus points of this Thesis was to look for better ways to handle engineering lead time and work load. A new tool was developed to create accurate analysis of engineering work load based on the customer specification.

This tool is a relatively simple excel-file that consists of data connection to * database and pre-determined estimations of engineering hours needed for each main component or accessory. Additionally, the special components were put in to analysis and most commonly used and repetitive parts were given estimations.

The tool compares these planned work estimations to components that have been selected by the customer resulting a summary, which is the total estimated engineering work needed in hours.

As a part of this project is also required to assign resources for using the configuration tool and also maintain the database for estimated engineering hours. Additionally, some rethinking is needed for metrics of engineering work load. This means that based on these new calculations, it is possible to measure the future load in engineering department more detail than what is currently done. Likewise, new metrics is needed to compare actual confirmed labour hours to planned hours of new calculations. Based on this analysis, the estimated hours for each stage can be adjusted if needed

5.2.1 Configuration Tool

The tool searches data from the databases and combines the available information to pre-analysed list of accessories. In the analysis part of this Thesis, basic machine engineering labour hours was calculated based on monthly averages. These hours are used as a starting point in the tool, and any extra estimated hour found because of selected accessories are then added to the sum of labour hours.

The project team analysed more than hundred different accessories and special component and their effect on the engineering work. Based on this analysis, estimations were given to each component or specification, so that the most important different combinations are taken in to consideration. When these components or properties are spotted from the customer specification, the estimated labour hour amount is added to the calculation.

The basic model for configuration tool is presented in Figure 19 below.

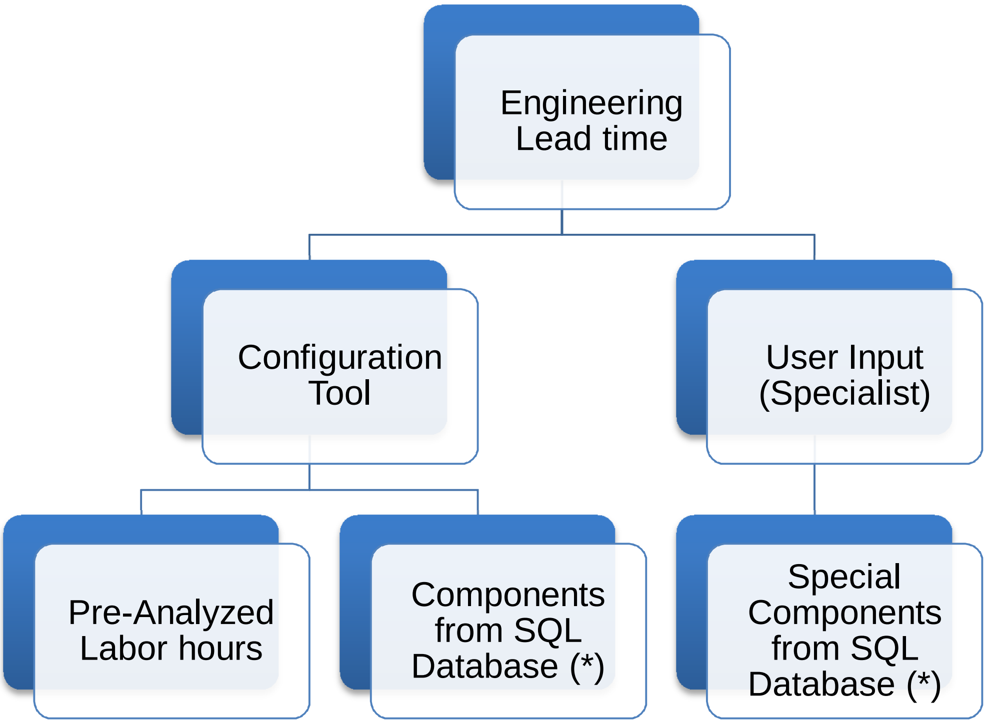

Figure 19. Configuration Tool Diagram

Figure 19 shows how the data is exported from the databases. Data from databases is combined with the user input or the labour hours of pre-analysed component list, and after this the result is a total labour hour needed for engineering, which is also transformed in to a lead time with certain adjustable multiplier for safety margin.

There are specific cases where there is also need to divide the amount of workload in to several identical parts. This situation was also handled in the configuration tool. The user can divide hours by changing appropriate parameters in the configurator in a way that they are levelled between different positions. If the result after the calculations seems to be incorrect compared to the estimations of an experienced designer or team leader, there is also a parameter in the configuration tool where the user can add any number of hours to the calculation. This is a backup for the cases where the calculations have not succeed to analyse critical properties correctly or the calculation for some other reason can be figured to be too low.

This tool is developed in such way that it is easily updated and modified if needed. This is important in the stage where this project is proceeding, since the changes and modifications must be done at the same time they are spotted to ensure the validity of the configuration data. Since the real cases for this configuration tool have yet been relatively small number, the modifications are supposed to be done further when the project continues with pilot testing.

A snapshot of the new configurator tool is available in Appendix 1. In this study, the configurator tool is a basic excel-spreadsheet, but as suggested later in Section 6.3, the development of the sales tool integration will be the next step in this project after the configuration tool can be confirmed to output realistic data. Accordingly, since the sales tool integration is following, the data for the properties has been kept in the same format as in the sales tool, so that the upcoming integration should be possible without large changes to the databases.

5.2.2 User Group for the Configuration Tool

The configuration tool is planned to be as simple as possible as for the user interface, so that the person who books the new order for a new motor can at the same time calculate the engineering labour hours needed for each case. After this calculation is done, can be defined what kind of estimated delivery time can be offered to the customer. Nevertheless, at this stage the estimation should be circulated through other departments and stakeholders, before the estimation can be confirmed to be exact. Mainly this refers to the production planning and engineering departments, if the sales person does the engineering calculations. This checking point would prevent totally inaccurate calculations to proceed in the system.

In the order-to-delivery process, the main scheduling and capacity responsibility is production planning. Therefore, the input from configuration tool should be available also to production planning so that the optimal lead time for the order-to-delivery process can be created. In any case, an experienced designer must check the calculations for the engineering labour hours as stated in Section 5.2.1, but as the result should be converted in the format of an order-to-delivery lead time model, the production planning must do the actual data input and planning in the business information system.

Other stakeholders must also be taken in to consideration when overall lead time is defined. The configuration tool only calculates engineering hours needed, but also the delivery time for the components that have the longest lead time must be defined. When this information is gathered, the actual lead time from order to delivery is confirmed. As this could mean that the overall lead time can be confirmed only at this stage for more certainty, this analysis should be done in as early stage as possible in the process.

Next section begins the build-up for the new order-to-delivery process based on these analyses and findings from the literature.

5.3 New Order-to-Delivery Process Model

The new order-to-delivery process includes new steps for a more specific analysis of the lead time and more detailed labour hour estimation for engineering.

This proposal for a new model is based on the principle that more than one work phase can be made in the same time. To achieve this, for example, mechanical engineering should be segmented in to several smaller parts. When these work phases can be made simultaneously, significant saving in overall lead time can be achieved. The initial model for a new process model is described in Figure 20 below.

Figure 20. New order-to-delivery process model.

As seen from Figure 20, the new tasks are planned to be done right after order booking phase. In this stage, the production planning or order booking personnel are analysing the needed lead time using the configuration tool and other inputs from example purchasing department. The same tool is in use with the engineering supervisors so that they can confirm that the calculations are done correctly and they can add their own estimations for such cases that don’t have calculations done, such as special components not listed previously.

This order-to-delivery process is much more complicated than the previous model used in the case company. This model requires the engineering personnel to divide their work load with colleagues, and it also means that the engineering capacity needs to be measured and balanced. In the previous model the production planning was done after the mechanical engineering, which included mainly manufacturing finite scheduling and order monitoring. This role is redesigned in the new model and it mostly consists of manufacturability checkpoint, basically go - no go decision to be made by the production planner.

New model requires the production planning to be available right in the beginning of the order booking. This is the moment where the overall lead time is decided, and the actual lead time planning in the ERP system is done by the production planner after the decision has been made. This decision is based on the engineering lead time analysis done by the engineering foremen and production planner, purchased components lead time provided by the purchaser, and the capacity situation at the most critical work phases. These critical work phases are defined with the critical chain principle, and most commonly consists of engineering and production situation.

Capacity planning should be done for each project case by case. Currently, the capacity planning is done only for the manufacturing process, but in this new model the engineering process is as crucial as well. The engineering process is very time consuming in some of the cases and it should not be made in the wrong time if the work phase is not on the critical chain in the overall process. This would enable the possibilities to adjust the work load in such way that the capacity is not the issue and work is done at the most optimal time. This also reduces the work-in-progress in the engineering department.

As Section 4.1 suggests, the WIP is one of the critical phenomenon behind overcapacity and poor utilization of the capacity as well. This critical chain planning should be done in a way that the scheduling is closer to the original critical chain management theory, meaning that the buffers should be visible at the end to confirm the risk management, but also in a way that the non-critical tasks are scheduled to finish as late as possible to minimize the amount of WIP in the process.

Next section handles the testing phase of this new order-to-delivery process.

5.4 Testing of the New Model

Testing of the new model and especially the new configuration tool is important phase in this research. After the new configurator tool was developed, numerous amounts of calculations were made to ensure the reliability of the calculations. Calculations were compared to the actual labour hours confirmed to actual cases. Some of the cases were broke in to pieces and smaller details were considered and estimated from engineering point of view. From these analyses, small adjustments were made to the calculation factors and estimations of the engineering hours.

Test results were showing that the calculated hours from previously completed projects were much closer to the actual confirmed hours than what was in the beginning when comparing the average planned hours.

Figure 21 below shows an example of comparison with approximately * projects from the year 2013. Test projects were chosen randomly, and the configuration tool was run for each of them to find out the estimated labour hours with the new tool.

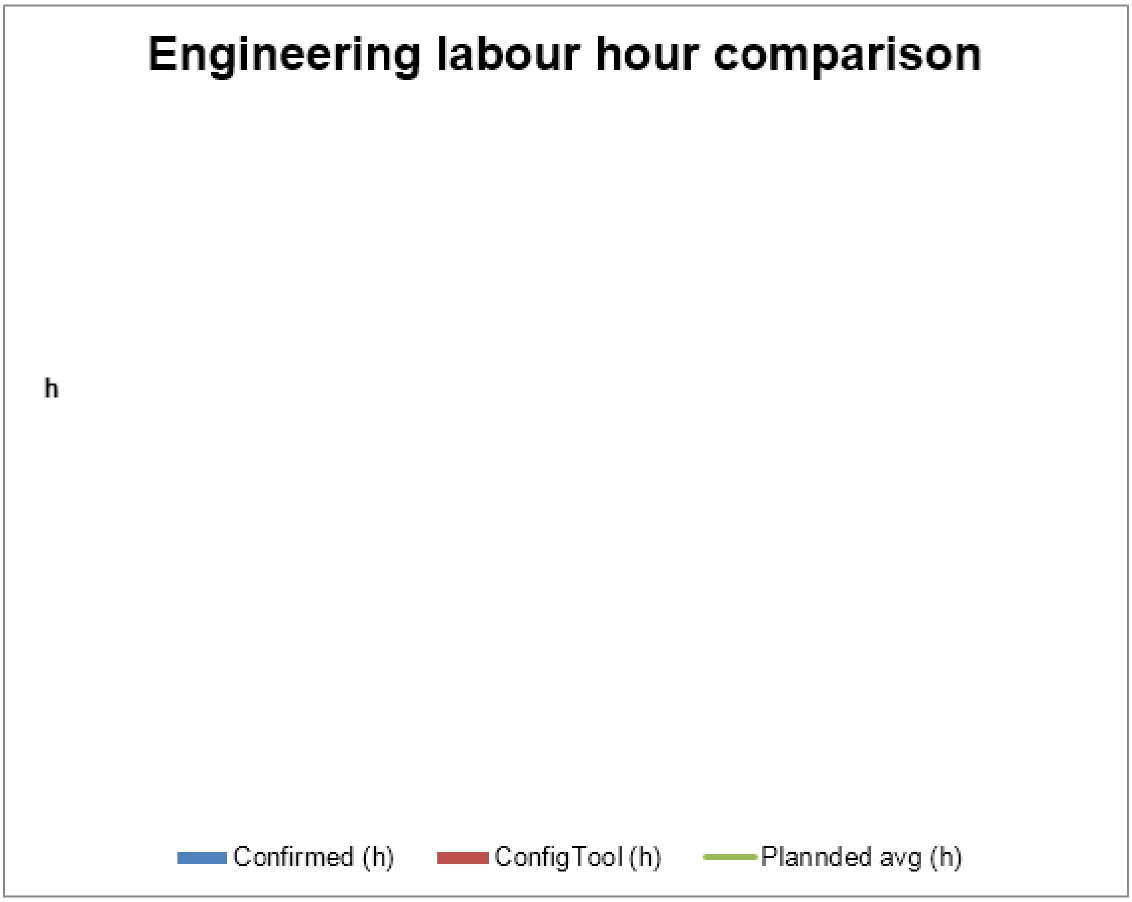

Figure 21. Engineering labour hour comparison by product type.

Figure 21 shows the difference of original planned labour hours from confirmed labour hours and hours calculated with new configuration tool. It is clearly visible that the new calculations correlate much closer with actual confirmed hours than previous average based hours. However, since the number of the units in this analysis is around *, it means that there are only few participants from rarely existing difficulty classes, mostly the *-class machines.

Most of the machines in this analysis belong to the *- or *-class, since those are most commonly sold machine difficulty classes. Nevertheless, the total number of analysed projects is significant and therefore reading the results can be justified to be at least reasonably reliable. Using this analysis, some of the parameters were adjusted, since the trend could be seen going in the same direction with similar cases.

Based on this analysis, the project team decided to arrange a pilot test group to start utilizing the new tool in practise. Specific sales region group was selected as pilot test group, in this case the marine region. Group was selected because the customers and classification organization usually have strict and systematic specifications. In marine cases the classification organizations generally define exact rules and properties each manufactured machine must fulfil.

Testing phase with actual cases started from the first new order booked for marine sales group after the initial test was finished. Before the first test started, it was decided to use original average based model as a lead time model, since the actual process was no allowed to be in danger. Simultaneously, the lead time model was analysed by the methods this research project defines, starting from analysing the engineering labour hours needed, estimating the time needed for supplied components and combining these as a total lead time model.

After test phase, the proposal lead time for the new order-to-delivery process is presented in the next section.

5.5 Proposal Lead Time Model for the Order-to-Delivery Process

Since the testing of the new lead time model with new engineering labour hour configuration tool was conducted with several actual projects and considered to work as planned, the proposal model will be similar to the initial model with only minor adjustments. These adjustments are referring to the engineering configuration tool, which was updated during the testing period.

New process model for order booking is tested with pilot cases and the estimations for the order-to-delivery process were considered relatively realistic. The timescale of this Thesis does not however make possible to analyse the results from these test cases after the whole process is completed, since the lead times for these test cases were more than * weeks from the booking.

The proposal model for the new order-to-delivery process model is similar than in the previous section the initial model. Figure 22 below presents the final proposal model.

Figure 22. Final proposal for the order-to-delivery process model.

Figure 22 shows the changes from the initial model are the Order-to-delivery planning task position, which changed from being after the Order booking to previous or simultaneous task. This would ensure that the order booking is already done based on accurate data instead of fixing the figures afterwards as in initial model would have suggested. In the order-to-delivery process phase, the input to be able to define the process model must come from the purchasing department. There are always from * independent sales order specific components ordered for each case. The lead time for these components must be received to the production planner so that the overall lead time can be defined.

The electrical engineering task has been divided in to two separate tasks, which are done in the same work phase. These tasks are electric calculations and mechanical basic engineering, which in general consists of simple basic structure generation that is run automatically by the inputs from the electric engineer. This stage is important to complete as soon as possible, compared to the other engineering stages that can be scheduled as late as possible. This is due to the reason that most customers request preliminary documentation fairly soon after the order has been booked. Additionally, the basic structure allows the purchasing begin simultaneously the quotations for the components that have longest lead time.

The dark arrows under the figure shows the direction of scheduling for each work phases. This means that the first phases are always done as soon as possible, and the rest of the phases are scheduled backwards from the delivery date and they should be done as late as possible.

The dashed vertical line in Figure 22 represents the flexibility point in the order-to-delivery model. If the customer request for the delivery date is later than the calculated model suggests, the most work engaging phases can be adjusted to more preferable location, meaning that the engineering work load can be levelled.

Finally, the arrows in the model are now connected to the actual workflow better than in the initial model. Furthermore, this model consists of parallel work phases that are done simultaneously, such as purchasing and mechanical engineering. The critical chain determines the overall length of the order-to-delivery process, which includes also the project buffer in the end of the model.

6 DISCUSSIONS AND CONCLUSIONS

This section includes the discussion and conclusions of this study. It begins with the summary of this study. Secondly, it gives some practical recommendations and suggestions for the organization and the proposal for next steps in the project. Finally, it contains the evaluation of this study and the overview of the reliability and validity plan analysed in the end of the section.

6.1 Summary

This Thesis focused on generating a new process model for the order-to-delivery process of the case company. The objective of the Thesis was to develop a new flexible planning model for the order-to-delivery process in order to gain more agility to deal with the present day demands from the case company customers. Today, when the competition for customers is fierce and any advance to separate from competitors is crucial, the lead time becomes one of the most important figures besides the cost for the product or service. Therefore, such a solution can give a competitive advantage to the case company in a way that it can react faster and more agile than the competition.

This study suggests a new process model to handle the order-to-delivery process with more flexibility features. In the new process model, the focus is placed on the beginning of the process, where the overall lead time for each case is determined. Additionally, aside of the development of the new process model, this Thesis concentrated on improving the visibility and agility of the engineering phase of the order-to-delivery process. Engineering department has been working with relatively basic and roughly estimated labour hour lead time models, which has led to poor utilization of the engineering capacity. This was demonstrated by the results of the current state analysis in this Thesis, where the utilization of the planned models has been as low as * % of the lead time and labour hours. This results in extra gaps between the different work phases in the overall order-to-delivery process, and in the end, in longer lead time that would have been necessary. On the other hand, when the estimated work load is poorly known, it also leads to the cases where the given labour hour estimation or lead time is not adequate, meaning that the overall lead time for such a case is too short.

The current state analysis confirmed that the biggest agility and flexibility potential for the order-to-delivery process is in the engineering work phase. Therefore, in this study, the main focus was to build new tools for analysing the engineering work load. This was done by calculating the average labour hours for basic machines and then analysing the extra work needed component by component from the catalogue that the customer can utilize when creating the specification for their order. This analysis led to the development of the configuration tool for the order booking personnel to be used when new orders are received. With this tool, the overall lead time for each case can be analysed more carefully from the very beginning, and more exact estimations of lead time can be given to the customer. Additionally, when the lead time for the purchased supplied components are known, the lead time model from the order-to-delivery can be build case by case in contrast with the current model of relying on fixed models.

The new process model also defines the new roles for the beginning of the process, meaning that the current role of the production planning should be extended to the lead time planning of the overall order-to-delivery process, rather than just focusing on balancing the production capacity and the work load.

Based on the results, this study recommends that the lead time model for the order-to-delivery process should be analysed as early as possible in the process, presumably right after the order booking or even before. This should make it possible to estimate the lead time more accurately and with more forecasting possibilities. The new roles also would mean that the production planning should take more responsibility of the engineering work load levelling and scheduling, since as this study suggests, the engineering work phase has a significant effect on the whole order-to-delivery process lead time.

With the new roles and flexible planning models, the overall lead time of a typical ordered machine in the case organization should be possible to cut down by about * % from the previous situation. Better understanding and visibility of the engineering process, as well as better estimation of the lead times, obtained through applying the proposed new planning model, should make the case company significantly more agile and flexible when competing for new customers, thus matching the original objective set for this Thesis.

6.2 Next Steps

This study pointed to several problems in the current lead time planning models and the existing order-to-delivery process. The new planning model used together with the new analysing and configuration tool should help the whole organization to better understand the order-to-delivery process.

Next steps should be the implementation of the new processes and establishment of a pilot group. The pilot group can be selected from the project management regional sales groups that are currently divided into 7 different regions geographically. As the testing of the model was started in the Marine region, it could be logical to continue the pilot testing with the same group. As soon as possible, this pilot group should be expanded to the other regions. Accordingly, responsible people must be assigned to handle the testing and implementation of the new models and tools.

The implementation of the new process model is discussed in Section 6.3 with other managerial implications. Next step for this project is also to spec the configuration tool further in a way that it could be integrated to the existing sales tool *. This would make the excel calculations unnecessary, and also ease the work load from the managers and production planning when booking new orders. This integration should also be done in a way that the data used in the calculations is still available for engineering personnel. This is necessary for the administration purpose, so that the data can be updated regularly and without typical bureaucracy in the system development organization.

6.3 Managerial Implications

There are several managerial implications from this study for the case organization. To implement the new process model, new work phases needs to be instructed and capacity needs to be assigned to perform the new assignments. Additionally, to implement the new planning model, the configuration tool needs to be introduced to concerned personnel and trained to use accordingly.

Currently in the case organization, the order review principles are defined and these meetings should be held before each new order has been booked to the system. Unfortunately, these meeting are mostly not arranged but instead the bookings are made based on the sales people's assumptions and personal estimations. This leads to a situation where in many cases the other functions opinions are not taken in to consideration. Usually this has not developed into catastrophic situations since the sales people have relatively good knowledge based on their background and long work experience, but in a process orientation organization it should not be bypassed.

Aspects to consider by the management when implementing the new process model:

1. Define and assign new production planning roles for the order-to-delivery planning
2. Review the order booking principles according to the order review process
3. Define engineering team leader roles to support engineering work load analysis
4. Assign responsible people to improve and develop the confirmation process of the engineering labour hour registration
5. Define and establish metrics and weekly follow-up of the work load analyses
6. Assign responsible people to further develop the configuration tool and its properties
7. Launch the development project to further integrate the configuration tool to the sales tool *
8. Establish principles to follow-up the implementation from overall perspective.

By following the suggested steps, the flexibility of the order-to-delivery process could be achieved as proposed in this study. The project team should continue as before and start implementing the pilot group. When the pilot group can be confirmed to work as planned, the implementation can continue to the other region groups. Additionally, in the same time the development project for * integration should be started as soon as the new principles can be confirmed to work as planned.

6.4 Evaluation of the Study

This Thesis introduced the new process model for lead time planning in the case organization. The new planning model included new process phases and tasks and configuration tool for more accurate analysis of the engineering work load. The engineering work load was identified as one of the most important work phases in the case organization, which led to the development of the analysis tool. The combination of a better analysis of work load and better handling and understanding of a new customer order should provide significant benefit to the case company, and in the end, also give more value to the customer with better customer service through more exact forecasts and shorter lead times.

The scope of this Thesis was limited to answering the research question of how the lead time model planning could be developed for the order-to-delivery process to become more agile and flexible. This was succeeded in this Thesis, since the accurate analysis of engineering work load only gives * % more flexibility in lead time planning. This can be used to shorten the lead time, or in cases where the lead time is not essential, the extra slack can be used to level out the work load in engineering.

What was left outside this Thesis was the actual deployment of the process model and the proposed configuration tool. This was done intentionally due to the short framework of this study. However, with the pilot testing in a few selected actual customer projects, the process model and configuration tool received good feedback and the estimated lead times for the order-to-delivery process and engineering work load were evaluated as realistic. When the accurate engineering work load and lead time can be combined with the other time consuming work phases, such as the lead time needed for purchased components, the flexibility of the order-to-delivery process can be achieved more fully which was set as the goal for this Thesis.

6.5 Validity and Reliability

Section 2.4 presented the validity and reliability plan for this study. First, it was stressed that the research should be well planned and designed. This study followed relatively close the initially planned research design, completed with conducting the current state analyses, data collections and theoretical research. Based on the results, the initial model was developed following the first analysis round, and after testing the model the final adjustments were made.

Secondly, the research validity proposal recommended using as much samples as possible and as wide a time scale as it can be achieved to arrive at reliable results. To ensure that the collected data was statistically reliable, Minitab statistical software analysis tool was used to estimate data. This tool confirmed that the calculations were statistically accurate and the sample size was adequate to make conclusions.

Some of the sample sizes of this study were smaller than others, which was dependent on the typical distribution of certain types of machines. To achieve a larger sample size, the time horizon should have been increased significantly and this would have implied other problems since the operational environment and methods have developed during the years. Furthermore, the Minitab statistical software suggested that even the smallest sample size analysed for this Thesis had enough variety and consistency, so that the data was statistically acceptable.

Another requirement for reliable research defined was that the results should be replicable if the study was conducted by another researcher. Since most of the data collection and analysis was quantitative and exported from the corporate ERP-system, the repeated research would most likely bring up similar results and conclusions. The principles used in the data analysis were also standard statistical calculations. Therefore the results for a repeated research would also likely to be similar.

Finally, validity of the research requires the measurements to respond to the research question, and the measurements to measure the facts correctly. Since this Thesis was about developing a new process model, done from the point of view of lead time and effectiveness of the process, the selected measuring units could also be considered relevant and applicable.

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Engineering labour hour and lead time configurator tool

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Labour hours average calculations with planned and actual hours

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Lead time average calculations with planned and actual hours

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