PRODUCTION PLANNING
PROCESS IMPROVEMENT
IN HYDRAULIC CYLINDER
MANUFACTURING

AUTHOR: Anttoni Keinänen
Confidential information has been hidden.

The thesis was done in co-operation with Hydroline Oy. The aim of the thesis was to document and analyze development projects that the author has been working on in 2021 as well as present further development suggestions. The development projects and the further development suggestions were focused on production planning in tube and rod manufacturing as well as assembly of cylinders.

The current situation of the processes was visualized with process flowcharts. The development projects were divided into five tasks. The tasks include updating of resource data, updating of production models, changing the point of loading, splitting the work commandments and implementing a new production planning system. The development tasks were documented including reasons, goals and outcomes. The results were analyzed with a few factors which were work cycle time, batch size, throughput time and produced amounts. From the results it can be gathered that the updated data is more accurate than before and production planning has been more accurate after the changes have been implemented. The toolset of production planning is much more diverse than before.

Further development suggestions were given to help with the control of started production in tube and rod manufacturing, to be able to predict certain situations and problems already in production planning and to increase the observance of production plans by increasing the amount of information that the production workers have at their use.

Keywords
Production planning, production control, process improvement, development
## CONTENTS

1 INTRODUCTION ........................................................................................................... 7
   1.1 Topic ...................................................................................................................... 7
   1.2 Background ........................................................................................................... 7
   1.3 Client organization .............................................................................................. 8

2 SIX SIGMA DMAIC IN PROCESS IMPROVEMENT .................................................. 9
   2.1 Implementation ..................................................................................................... 9
   2.2 Definition .............................................................................................................. 9
   2.3 Define phase ......................................................................................................... 10
   2.4 Measure phase .................................................................................................... 10
   2.5 Analyze phase ..................................................................................................... 10
   2.6 Improve phase .................................................................................................... 10
   2.7 Control phase ..................................................................................................... 11

3 PRODUCTION PLANNING AND CONTROL ............................................................. 12
   3.1 Implementation ................................................................................................... 12
   3.2 Definition ............................................................................................................ 12
   3.3 Objectives of production planning ................................................................. 12
   3.4 Phases of production planning and control ................................................... 12
      3.4.1 Preplanning phase ......................................................................................... 13
      3.4.2 Planning phase ............................................................................................. 13
      3.4.3 Control phase ............................................................................................ 13
   3.5 Importance of production control ................................................................. 13
   3.6 Scheduling ........................................................................................................ 14
      3.6.1 Dynamic scheduling .............................................................................. 14
   3.7 Batch size .......................................................................................................... 15
   3.8 Throughput time ............................................................................................... 15
   3.9 Work cycle time ............................................................................................... 15

4 OVERVIEW OF THE ORDER TO DELIVERY PROCESS ........................................ 16

5 UPDATING DATA IN THE ERP SYSTEM ............................................................... 20
   5.1 Resource hierarchy .......................................................................................... 20
   5.2 Production models .......................................................................................... 24

6 CHANGING THE LOADING POINT AND SPLITTING WORK COMMANDMENTS ....... 25
7 IMPLEMENTING A NEW SYSTEM FOR PRODUCTION PLANNING ........................................... 28

8 RESULTS .......................................................................................................................... 32

  8.1 Work cycle time accuracy ......................................................................................... 32
  8.2 Timing differences of finished tubes and rods ......................................................... 33
  8.3 Produced tubes and rods ......................................................................................... 34
  8.4 Produced cylinders ................................................................................................. 36
  8.5 Throughput time accuracy ..................................................................................... 37

9 FURTHER IMPROVEMENT ......................................................................................... 38

10 CONCLUSION .............................................................................................................. 41

11 REFERENCES ............................................................................................................... 42

Figure 1. The DMAIC process (Shankar 2009.) .............................................................. 9
Figure 2. Order handling flowchart ............................................................................. 16
Figure 3. Production planning and scheduling flowchart ............................................... 17
Figure 4. Work queue creation flowchart .................................................................... 18
Figure 5. Production flowchart .................................................................................... 19
Figure 6. New assembly line layout ............................................................................ 20
Figure 7. Old resources of the tube and rod manufacturing lines ................................. 21
Figure 8. Updated resources of the tube manufacturing line ........................................ 22
Figure 9. Updated resources of the rod manufacturing line ......................................... 22
Figure 10. Old resources of the pre assembly and assembly lines ............................... 23
Figure 11. Updated resources of the pre assembly and assembly lines ....................... 23
Figure 12. Old version of a cylinder production model ............................................... 25
Figure 13. New version of a tube production model .................................................... 26
Figure 14. New version of a rod production model ...................................................... 26
Figure 15. New version of a cylinder production model .............................................. 26
Figure 16. Manufacturing requests of tubes, rods and cylinders .................................. 27
Figure 17. Planned work order for spare part assembly ................................................ 29
Figure 18. Objectives for the amount of tube production in two areas .......................... 30
Figure 19. Objectives for the assembled amount of a customer’s cylinders .................. 30
Figure 20. Real time data of the production of tubes .................................................. 31
Figure 21. Amount of finished tubes between January 2021 and November 2021 .......... 35
Figure 22. Amount of finished rods between January 2021 and November 2021 .......... 35
Figure 23. Amount of finished cylinders between January 2021 and November 2021.......................... 36
Figure 24. Tubes with a diameter of Ø115mm. ................................................................. 39
Figure 25. Tubes with a diameter of Ø75mm. ......................................................................... 39

Table 1. Categorization of factors that can cause production plan changes. ........................................... 13
Table 2. Categorization of problems that can occur in real time. .......................................................... 14
Table 3. Summary of finished development tasks.................................................................................. 32
Table 4. Results of work cycle time comparison. .................................................................................... 33
Table 5. Summary of proposed development tasks............................................................................... 40
ABBREVIATIONS

ERP enterprise resource planning
MES manufacturing execution system
DMAIC define, measure, analyze, improve and control
ANOVA analysis of variance
DOE design of experiments
BOM bill of materials
IT information technology
FCFS first come-first serve
SPT shortest processing time
LWKR least amount of work remaining
1 INTRODUCTION

1.1 Topic
The author has been working at Hydroline Oy’s Vuorela factory in the production planning team since the March of 2020. During this time there have been improvement projects that have focused on the accuracy of production planning. Also various changes have improved the process of production planning in general. The author has worked on some of these projects and development changes during 2021. Collaboration in these projects was done with multiple different sections of the organisation. In this report the development projects and the implemented changes are documented and presented, including the reasons which have lead to a need of change and the solutions that have been implemented. The development tasks haven’t been documented before and the documentation can help understand the ideology behind the changes better within the company. These developments were mostly focused on the production planning of the tube and rod manufacturing lines as well as the assembly line of Hydroline Oy’s Vuorela factory. In this report the results that have been achieved are discussed and suggestions for further improvements that could be implemented in the future are made.

1.2 Background
In the tube manufacturing line there are two machining phases and two welding phases. In the rod manufacturing line there is one machining phase, one welding phase, a friction welding machine and a robot welding machine. In these lines the production is done according to work commandments. These work commandments are based on manufacturing requests that come from the ERP system. They are unique for all items and they include information about all the phases that the item must go through, the work cycle time in which these phases should be completed and the location where the phase should be completed. The number and order of these phases can vary drastically between items. Some items go through one machining phase and others might require two machining phases and two welding phases. Some items have multiple phases that are done in the same stations and some items can also go back to the previous phases to be worked on.

The assembly line production can begin when all materials for a certain cylinder assembly are available including the tubes and rods. After the materials are available the work is set to a work queue, a work commandment is printed and the materials go to picking. After the materials have been picked, those materials are taken to the pre assembly station where the rods are prepared for assembly. After that the cylinders are assembled and tested for faults such as oil leakages. If the tests are ok the cylinders will go to painting and packing.

Six Sigma DMAIC is a theory that is specialized in process development. In this case it was chosen to be used because it gives a great point of comparison for these development projects, to see if the steps taken and the order of these steps in these development projects have been correct and if the level of research, analysis and results are sufficient. Generally, the DMAIC theory can be used to see if the development projects have been successful and if the processes have improved. The second theory that has been used is about production planning and control. The goal of the development projects have been to improve the production planning and controlling processes. The theory about
production planning and control gives good guidelines what to look for in the processes that are being developed, for example the dispatching of work orders which is in the control phase of the production planning process was dramatically altered in these development projects.

1.3 Client organization

Hydroline Oy is one of the leading hydraulic cylinder manufacturers internationally. The company started as a one man lathing shop in 1962 and it was called Metallisorvaamo H. Laakkonen. In 1984 the company built new facilities to Vuorela to match the growing demand. At the same time the name of the company was changed to Hydroline Oy. Nowadays Hydroline Oy has two factories and in total it employs more than 300 employees. Hydroline’s first factory is located in Vuorela, Finland and the second factory is located in Stargard, Poland. In Vuorela the production is more specialized and therefore the production is often lower in volume and higher in variation. In Stargard the production is less specialized and therefore the production is often higher in volume and lower in variation. Hydroline Oy has a long expertise from the field as the company has produced hydraulics for more than 50 years and the products have been manufactured in Vuorela since 1984. (Hydroline.fi 2021.)

Hydroline Oy has a wide international customer base. The customers of the Vuorela factory function in multiple different fields of business. Customers from the mining industry include companies such as Sandvik and Normet. From the harvesting industry there are customers such as John Deere and Kesla. Also crane manufacturers such as Cargotec and Bronto Skylift are customers of the Vuorela factory. (Hydroline.fi 2021.)
2 SIX SIGMA DMAIC IN PROCESS IMPROVEMENT

2.1 Implementation

The DMAIC theory was chosen in this work because the theory is heavily focused on the development of processes and what are the correct steps to take in the development projects. The development of production planning and control processes has been the goal of the development projects that have been completed. DMAIC theory can be utilized after the completion of a project to see if the development project has been successful and if the processes have developed. DMAIC was used to find and analyze the meaningful results.

2.2 Definition

According to Foster (2007) DMAIC was used in the 1990s by many companies in order to guide projects that involved the usage of Six Sigma. Also Foster stated that DMAIC is among the most common processes in implementing improvement tools. Lee-Mortimer (2006) described the DMAIC process to be the most commonly used tool for processes that don’t meet their specified requirements and for processes that are looking for improvement.

In Shankar’s (2009) *Process Improvement Using Six Sigma: A DMAIC Guide*, Shankar writes “The DMAIC methodology takes a problem that has been identified by the organization and utilizes a set of tools and techniques in a logical fashion to arrive at a sustainable solution(s).”

In a process inputs are turned into outputs by combining a collection of activities. The total input in a process consists of suppliers who provide the inputs and the inputs themselves which enter the process. The total output in a process consists of the outputs themselves which can be products or services and the customers who receive the products or services. The resources used in a process can include materials, environment, personnel and equipment. (Shankar 2009.)

Six Sigma DMAIC consists of five phases which are Define, Measure, Analyze, Improve and Control. The goal of DMAIC is to address the root cause in the end result of the improvement project. Input of the improvement process is the problem and the output is the solution (see Figure 1). (Shankar 2009.)

![Figure 1. The DMAIC process (Shankar 2009.)](image-url)
In Shankar's 2009 publication *Process Improvement Using Six Sigma: A DMAIC Guide*, Shankar compares the DMAIC process to a patient's visit to the hospital: "At first, the physician has the patient describe the problem they are experiencing by asking questions regarding their health (Define phase). Then they take the baseline readings with tests such as blood tests, urinalysis, electrocardiograph (ECG) tests, and so on (Measure phase). The physician then prescribes medication and asks the patient to try it out and return for ongoing visits (Analyze phase). During the return visits, tests are run to ensure/confirm that the medication is working and the diagnosis is correct (Improve phase). When the patient is improving, the physician reruns the blood tests, urinalysis, and ECG, to ensure that all vital signs are stable, and finally the patient is discharged (Control phase).”

2.3 Define phase

In the define phase it is ensured that the organization's priorities are followed and that the improvement project has the support of management in the organization. In the define phase the problem is identified and the project scope will be determined. In the define phase it is also ensured that the organization is ready to commit certain resources to the improvement project. However for the DMAIC methodology to be used in a project case there doesn't have to be a problem. DMAIC methodology can also be used in continuous improvement. (Shankar 2009.)

2.4 Measure phase

The gathering of information and data is done in the measure phase. At this point the improved process has been identified. With the collected information and data it can be used to better understand the expectations of the project, base construction of the process and what the problems are in the process. This data can include for example information such as how many products can be made in a set amount of time. The data will be needed to mirror and compare it with the outcome of the project to see if the improvement process was a success. In the measure phase it is important to develop an understanding of your process. This can be done with process maps for example flowcharts. (Shankar 2009.) For the continuation of the DMAIC improvement process into the analyze phase, action items will be identified at the end of measure phase. (Shankar 2009.)

2.5 Analyze phase

In the analyze phase, the cause-and-effect relationship in the process will be analyzed in depth. At this point it will be found out which of the inputs have the most effect on the output in the process. Basically the analyze phase is used to go through the multiple inputs in the process to find out the most significant ones concerning the output. In the analyze phase the action items that were identified in the measure phase will be implemented. (Shankar 2009.) In the analyze phase, statistical analysis can be executed with statistical tools such as Correlation and Regression, ANOVA and Hypothesis testing. (Quick 2019.)

2.6 Improve phase

In the improve phase you should be ready to take all of the previously collected information to model your process. At this point you should be able to tell which parts of the process you are trying to improve. The purpose is to model the process with the input gained from the previous phases
and to be able to control the behaviour of these inputs. (Shankar 2009.) Six Sigma tools and methodologies that can be used in the improve phase include Brainstorming and DoE (Quick 2019.)

2.7 Control phase

The last phase of the DMAIC methodology is the control phase. Before the control phase you have found out which are the significant input factors and in the control phase you will find a way how to control these input factors to influence the output of the process. (Shankar 2009.)
3 PRODUCTION PLANNING AND CONTROL

3.1 Implementation

The improvement of the production planning and control processes has been the goal of the development projects that are described in this work. Production planning and control theory is important for the development of the production planning and control processes because it describes the points which should be focused on and improved. The theory can be used to identify the key functions inside the processes and to get a better understanding of these functions for example how they should work in an ideal situation.

3.2 Definition

Production planning and control is the activity of ensuring that everything in the production process works as scheduled and at minimum possible costs. This includes ensuring the availability of materials and the correct time, place and quantity of produced goods. It is the responsibility of production planning to create plans that will ensure that customer requirements are met. This is coordinated with other parts of the organization such as procurement and manufacturing. (Kiran 2019.)

The volume of production often defines the type of production planning and control techniques that will be used. There is less need for complex planning and control in a high volume, low variety production and more need for complex planning and control in a low volume, high variety production. (Kiran 2019.)

In Aswathappa’s and Shridhara Bhat’s (2009) Production and Operations Management they define production planning as “The choice from several alternatives of the best means of utilising the resources available to achieve the desired objectives in the most efficient and economic manner” and production control as “The monitoring of performance through a feedback by comparing the results achieved with the planned targets so that performance can be improved through proper corrective action. This control mechanism is also responsible for subsequent adjusting, modifying and redefining plans and targets in order to ensure the attainment of goals.”

3.3 Objectives of production planning

The objectives of production planning include optimizing the production capacity with reducing the idle times of men and machines and by providing a work order for production that has long work cycle times and low setup times. Also the objectives of production planning include controlling the inventory levels and turnover. All of this should be done with minimal costs. (Kiran 2019.)

3.4 Phases of production planning and control

The functions of production planning and control can be grouped into a few phases. These phases are called preplanning, planning and control. All of these phases serve an important purpose in the complete picture of production planning and control. (Kiran 2019.)
3.4.1 Preplanning phase

The preplanning phase includes the preparation for production. In this phase the product design and specifications will be checked so that they are compatible for production. Also in this phase the surveys and forecasts will be analyzed and it will be made sure that production can handle the demand of the upcoming market. (Kiran 2019.)

3.4.2 Planning phase

In the planning phase the capacity and material reservations will be made. Through these plans it will be ensured that the company has the resources needed to supply the demand. At this point the tools in the production should be checked and planned. After these factors have been taken into account the scheduling and loading of the produced goods will be done. (Kiran 2019.)

Aggregate production planning takes place in the planning phase of production planning and control. Aggregate planning or in other words output planning is the process of determining the capacity a company needs to meet its demand over a set amount of time. It is basically the big picture version of a production plan. (Aswathappa and Shridhara Bhat 2009.)

3.4.3 Control phase

Finally in the control phase it should be ensured that the previous planning has been successful. It is important to follow-up with the situation of production and gather data and information about the process. With this data and information there should be a report of progress made so that possible replanning and modifications can be made with sufficient time. (Kiran 2019.)

The dispatching of work orders is done in the control phase. Dispatching is the activity that is done in between planning and actual production. In dispatching the paperwork and planning is turned into production by ensuring that everything needed for production is ready including materials and tools, and by issuing the work orders to the correct manufacturing stations in the correct schedule. All movement of materials should be done according to the production plans that are the framework of dispatching. Also dispatching includes supervision of work as in ensuring the movement of work from one operation to another according to the plan as well as ensuring the following of standard operating procedure. (Kiran 2019.)

3.5 Importance of production control

In any production there are certain factors that can change a production plan and require controlling after plans have already been made. This means that the production system should be made so that it allows the rapid changes of plans quite easily if there is need. (Kiran 2019.) Table 1 shows factors that can cause changes in production plans according to Kiran.

<table>
<thead>
<tr>
<th>Material-related</th>
<th>Facility-related</th>
<th>Resource-related</th>
<th>Prioritization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material shortage</td>
<td>Machine breakdown</td>
<td>Absence of workers</td>
<td>Change in demand</td>
</tr>
<tr>
<td>Material breakage</td>
<td>Machine maintenance</td>
<td>Knowledge of workers</td>
<td>Rush orders</td>
</tr>
</tbody>
</table>

Table 1. Categorization of factors that can cause production plan changes.
Because of the fact that the situation can change rapidly due to an uncontrollable factor it is important to have a control element in the production planning and control system. One of the key objectives of production control includes the detecting and preventing of any variation in the production system that can cause performance issues. With the data provided by production control the management of the company can take actions to improve the production system. (Kiran 2019.)

3.6 Scheduling

The management of the order and the timing of activities or tasks is referred as scheduling. The order of tasks is often depicted by setup times, work cycle times and due dates. Different scheduling rules can be divided to local rules and global rules. Local rules only consider the situation of a single machine or a station and global rules consider the big picture for example a factory. Local rules include SPT, global rules include LWKR and some rules like FCFS can be used in both settings. The manner of scheduling decides which types of rules should be used. Local rules are more difficult to handle but seem to be deemed more effective. Generally in situations where information such as due dates are scarce and the maximum throughput is considered important, SPT is found most effective and when due dates are taken into consideration the choice is much more difficult. (Kutz 2015.)

3.6.1 Dynamic scheduling

A dynamic scheduling system is a system that utilizes real time data and information in situations where they are available to be used. The effects of modifying a schedule should be considered throughout the whole manufacturing system. Inside such a system there should be a possibility to react to any changes that happen in real time with an acceptable response time. (Cowling and Johansson 2002.)

According to Ouelhadj and Petrovic (2009) problems that occur in real time can be divided into two categories. (See Table 2).

Table 2. Categorization of problems that can occur in real time.

<table>
<thead>
<tr>
<th>Resource-related</th>
<th>Job-related</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absence of operators</td>
<td>Rush jobs</td>
</tr>
<tr>
<td>Machine breakdowns</td>
<td>Cancellation of jobs</td>
</tr>
<tr>
<td>Unavailability of tools</td>
<td>Changes in priority of jobs</td>
</tr>
<tr>
<td>Failure of tools</td>
<td>Changes in processing time of jobs</td>
</tr>
<tr>
<td>Shortage of materials</td>
<td>Changes in due times of orders</td>
</tr>
<tr>
<td>Defective materials</td>
<td></td>
</tr>
</tbody>
</table>

These possible problems and situations should be acknowledged in a dynamic scheduling system and the system should have the readiness to react to these changes. (Ouelhadj and Petrovic 2009.)
3.7 Batch size

Batch size is the quantity of the items which have to be produced at the same time. The batch size can be determined for example by a customer order. Batch size can be an important factor for production planning. In dispatching of work orders the order can be set so that bigger batch sizes are used and therefore the setup times are minimal in production. According to Johnson (2003) setup times and material handling constraints often cause the batch sizes to be unrealistic.

3.8 Throughput time

Throughput time is defined as the amount of time it takes to manufacture a product from the start to the finish which can be storing or shipping to a customer. The reduction of throughput time can hold multiple benefits in both resource management and quality aspects. (Johnson 2003.)

3.9 Work cycle time

The work cycle time or manufacturing cycle time is the duration of business and production activities which are completed to process certain quantity of a product. Batch sizes, material calculations, production preparation and scheduling are important activities when investigating work cycle times. (Jovanovic, Milanovic and Djukic 2014.)
4 OVERVIEW OF THE ORDER TO DELIVERY PROCESS

The order to delivery process includes the chain of processes that start from receiving an order from a customer and end in delivering and invoicing this order to the customer. At the Hydroline Oy’s Vuorela factory these processes include order handling where the customer orders are registered into the system, production planning and scheduling where the orders are loaded, work queue creation where the production plan is made and the production process where the ordered items are produced.

Process flowcharts are charts that describe the principles of the process and the flow of tasks within the process. The chart follows the logical flow of information inside a process. Process flowcharts are a great way of visualizing a process. This can be done for example to find the significant inputs and outputs inside a process or to find out if the process is working as intended. With process flowcharts you can indicate bottlenecks inside a process or find the steps where to apply process improvement. There were existing process flowcharts that were found but they were quite old as most of them were last updated in 2018 or 2019 so the order to delivery process flowcharts were updated to match the current situation and flow of processes.
The order handling flowchart begins with an order as an input which is supplied by the customer. The order is then processed and registered into the ERP system by a production assistant. If any ordered item codes are missing, the production assistant forwards the order to a design engineer. The design engineer creates any missing item codes and then forwards the order back to the production assistant. The production assistant checks if there are any missing prices from the ordered items and if there are, the order is forwarded to a key account manager who then adds any missing prices into the system. After all the data on the order is found from the system the production assistant together with the production planner confirms the delivery time of the ordered items. After this an order confirmation is created and then sent to the customer. (See Figure 2).

The production planning and scheduling flowchart begins with an input of a manufacturing request which is supplied by order handling, ERP system’s storage fulfillment or as an internal request. The manufacturing request is handled by a production planner. The production planner searches for open manufacturing requests which need to be loaded. After that the open requests are loaded. In order to confirm the correct schedule for the production, the production planner must check the customer capacity, total capacity of the factory and the tentative availability of materials. After the correct time of production has been found, the manufacturing request is confirmed in the ERP system. If there are any faults found in this process e.g. missing price or item code, they are informed to the person who handled the order. (See Figure 3).
The work queue creation process starts with the input of a loaded manufacturing request which is supplied by a production planner into the ERP system. The production planner searches for all loaded manufacturing requests and checks the availability of materials. If the materials are not found the material availability of the manufacturing request will be checked again at a later time. If the materials are found, the production planner moves the manufacturing request into a work queue. Then the production planner goes through all the manufacturing requests in the work queue and decides the order in which they will be produced during the day. The order of the manufacturing requests in the work queue is determined by a few factors such as the urgency to the customer, the size of the produced items and the quantity of the produced items. Sizes and quantities are used to optimize the flow of production for example similar sized items can be machined with the same tools and the number of items can be optimized to fit them better on the carts. (See Figure 4).
The production process includes information flow with the suppliers and the customers. This information flow includes orders and forecasts. The process itself starts from a customer order. Manufacturing requests are created from these orders and a work queue is created from the manufacturing requests as depicted in previous flowcharts. After that the pickers will print out the picking list as well as the work commandment. The materials will be picked and taken to washing. After that there are different phases completed in the tube and rod manufacturing lines. These phases include machining and welding. After the tubes and rods are completed the tubes and rods are washed, the assembly components are picked and the pre assembly can begin where the rods are prepared for assembly. From the pre assembly the parts are taken to the assembly after which the functioning of the cylinders will be tested. If the tests are fine the cylinders are taken to painting. After painting is done the cylinders are left to dry and when they are dry they are packed and shipped to the customer. (See Figure 5).
5 UPDATING DATA IN THE ERP SYSTEM

5.1 Resource hierarchy

For the ability to plan and control production accurately in the ERP system, the information related to production in the system must be up to date. In the ERP system there are resources for all machines and stations that are found at the factory. These resources are then further used to set a place where a phase of production should be completed. The resource hierarchies of the tube and rod lines as well as the assembly line were updated within the ERP system to match the current state of machines and stations in the factory. At some point in the past years the layout of the tube and rod manufacturing had been changed from a cell layout which had three cells to a line layout which has two lines but the resources in the system weren't updated within the project. There were also outdated resources, for example machines that weren't at the factory at all anymore. In the assembly line the layout had been changed previously and the resources hadn't been updated. As a result of this the assembly line resources had old assembly stations and benches in them.

Figure 6. (Figure removed) New assembly line layout.
The new assembly line layout can be seen in Figure 6.

In the ERP system, the resources are used on the manufacturing requests of items. On these requests, the resources indicate the place where the production phase should be completed. In order to direct manufacturing requests and the items related to them to the correct machines or stations, the resources should be accurate. Also, correct resources can be critical information for data collection for example when there is a need to check how much the load of a single machine is in a manufacturing line. Without the correct resources no one would be able to tell where the load of the work phase is going to happen. For these reasons the resources needed to be updated and now they will also serve their use in future projects to come.

Figure 7. (Figure removed) Old resources of the tube and rod manufacturing lines.

Figure 7 shows the old resource hierarchy of the tube and rod manufacturing lines. The layout of the resource hierarchy was done to match the three cells that were used in the past. The texts are difficult to read and it is hard to get a clear picture of the production layout from this information.
As seen in Figures 8 and 9, now the first level in the resource hierarchy is the level of the tube and rod manufacturing lines. Under the resources of the lines there are all the cells that include the phases that are done in that line. Finally under the cells there are all the machines that are found in those cells.
Accurate information in the system was needed to be able to track and control the produced items, where they are in the production and where they were going. However before this was achievable the production models of all produced items had to be updated.
5.2 Production models

The production models include the information which will be shown on the manufacturing requests and the printed work commandments. This includes all phases done to those items, work cycle times for those phases and the resources where the phases should be completed. To find out the amount of items that needed updating, data was collected about all the items that had been produced between the years 2018 and 2021.

Also a method of continuous improvement was taken into use as there is now a way for the workers to inform wrong phasing, work cycle times or resources to the production planning team who will then update this information according to the comments of these workers. The method is to send an internal claim and this method was already being used in other departments of the company for example when broken items are noticed in the production, there will be an internal claim sent to the department that is responsible for this item. Therefore there was already a ready solution that just wasn't being used. The system was taken into use and the personnel working at the factory were informed about this. With these changes it was ensured that the production models of items stay up to date and the massive work of updating all the information won't be useless after a few years go by and new projects are implemented.
Previously the point of loading was the tube and rod manufacturing. Whenever new orders were loaded they were loaded into the capacity of the tube and rod manufacturing lines. However it was identified by management that the bottleneck of the factory was the assembly line. Therefore it was decided that the point of loading should be the assembly line instead of the tube and rod manufacturing lines. The production control system was changed from a push from tube and rod manufacturing approach to a pull from assembly approach. New capacity calculations were made and the new capacities were set for the pre assembly and assembly stations. It was instructed to the production planners and production assistants who handle and load the manufacturing requests that they would be using the assembly line capacity instead of the tube and rod line capacities to load customer orders. This change also brought along the splitting of work commandments. Previously production in the factory had been done with a single work commandment throughout the whole factory. It was printed in the picking phase of the tube and rod manufacturing lines and it followed the products all the way to the packing department. That work commandment would include all phases that were completed inside the factory. It also included information about every single material that would be used throughout the manufacturing of the product in the factory.

Figure 12. (Figure removed) Old version of a cylinder production model.

As seen in Figure 12, previously the production models featured every phase that was completed in the factory starting from tube and rod picking and manufacturing. After that came the assembly picking, pre assembly and assembly phases and after those the painting and packing phases.

With the change in the production control system, the work commandments were split into three where the tubes and rods would have their own work commandments that were completely separated from the assembly of the cylinders. Basically this meant that the tube and rod manufacturing
lines became “suppliers” for the assembly line. This change started from the item data and the BOMs of all the items that would be updated. The item data and the BOMs were updated so that the ERP system would split the tube and rod manufacturing requests from the cylinder manufacturing request. In this way there were now manufacturing requests for the tubes and rods that could be printed into their own work commandments. After this the production models were also split into three where all the tube and rod item codes were given their own production models. Also there was an update supplied by the supplier of the ERP system which would allow the automatic creation and loading of these tube and rod manufacturing requests when you load the cylinder manufacturing request. In this way there was no need to manually load the tube and rod manufacturing requests after loading the cylinder manufacturing requests.

Figure 13. (Figure removed) New version of a tube production model.

As seen in Figure 13, in the new tube production models only the tube manufacturing phases are shown.

Figure 14. (Figure removed) New version of a rod production model.

As seen in Figure 14, like in the new tube production models, only the rod manufacturing phases are shown in the new rod production models.

Figure 15. (Figure removed) New version of a cylinder production model.
As seen in Figure 15 only pre assembly, assembly, painting and packing phases are shown in the new cylinder production models.

Figure 16. (Figure removed) Manufacturing requests of tubes, rods and cylinders.

Because the tubes and rods have been split from the cylinder manufacturing request they have their own manufacturing requests, their status is not related to the status of the cylinders and therefore they can be produced independently (see Figure 16).

With these changes it was allowed to manufacture and store tubes and rods in bigger batch sizes as they weren't anymore connected to the quantity of cylinders to be assembled. It is now possible to combine multiple similar tube work commandments and rod work commandments already in the ERP system so that in the production the setup times would be minimal and the work cycle times would be as long as possible for a single batch of items. It is also possible to produce tubes and rods that go to high volume cylinders in larger batches and if needed, to maintain a buffer of those tubes and rods. In this way it could be ensured that the bottleneck of the factory, the assembly line would have production ongoing at all times. One of the key ideas was also the optimization of material availability. With the work commandments split the material need dates were also split. Previously all materials including the materials for the assembly were needed one day before the start date of production. Since all phases were done on the same work commandment that meant that the start date was the date when tube and rod production was started. With this protocol the assembly materials arrived too early and were stored while the tube and rod manufacturing was happening. Now with the work commandments split the material need date for assembly materials is in most cases the day before the planned start of assembly.

Almost always there are some negative consequences that follow as a result of changes. In this case the fact that the cylinder work commandment is handled completely separately from the tube and rod work commandments causes extra work for production planning as well as the personnel in production. Production planning has to do another material availability check before assembly to ensure that all assembly materials are on hand. In cases where the assembly materials aren't available it will cause extra work for the personnel in the assembly picking section. When it’s known that the assembly materials will not be arriving shortly, the tubes and rods have to be moved from the carts to pallets when its possible to ensure that the flow of carts remains. Sometimes the tubes and rods will just have to wait on the carts. Depending on materials in this way can be detrimental to the performance of the tube and rod manufacturing lines especially when the material shortages are mostly caused by other factors than the tube and rod manufacturing lines themselves.
IMPLEMENTING A NEW SYSTEM FOR PRODUCTION PLANNING

Shortly after the point of loading had been changed and the work commandments had been split it was noticed that there was a need for a system where to plan and control these work commandments. The amount of control the ERP system offered wasn’t enough as there wasn’t a scheduling tool being used inside the ERP system. There was a built in scheduling tool available inside the ERP system but it didn’t yet serve the purpose and would have required other changes to be implemented. That meant that creating a planned work order wasn’t possible without extra tools. Also, previously the items had moved in the production mostly on their own as the single work commandment would move with the produced items through the factory. Now there was a need to do a second material availability check and a second printing of work commandments before production on the assembly line.

Previously all controlling of the order of work commandments in the production was done manually. A work queue was given to the foremen of the tube and rod manufacturing lines by the production planners and after that the foremen were responsible for creating an order of work for the personnel in production. The order was then controlled and ensured in the production lines with different boards which had work orders listed in order.

The management wanted to reduce manual work as much as possible and to take information into the electrical systems where the information and data would be easier to reach and find. At this point almost all spreadsheets used in production planning were forgotten and brainstorming started for a system that had an integrated scheduling tool and could have all the needed information in it. Management, the production planning team and the foremen of production were closely involved in the brainstorming sessions. For this system it was also important that dynamic scheduling could be done. This meant that the system had to have a readiness to react to changes or certain situations in real time. There already were existing tools in the ERP system to prioritize manufacturing requests according to customer due dates so these tools would also be implemented in the new production planning system.

After a while of planning and testing there was a highly customised MES system for production planning. It was first tested in use with the tube and rod manufacturing lines. Originally the system had two different sections. One where production planning was able to create an order of work commandments and one where the work orders were visualised to the production as a work queue. At first the production planning tool was just a simple visualised board which had different sections for tubes and rods. These sections would show the next five days and you were able to drop in the work commandments inside these days with a drag and drop function. You could also change the order of work commandments with the drag and drop function. These visualised work commandments had information such as the item codes, unique work id and the quantity in them. As time went by and new ideas surfaced there were several new functions implemented inside this same system. Also some of the older functions were updated and improved.

Nowadays in the system you can do scheduling for the tube and rod manufacturing lines, four different assembly areas, six different parts manufacturing cells, painting, packing, friction welding,
welding robot and VS1, which is a fully automated machining and welding line. Also, there are now multiple different visualised status for these work commandments that help the production planning, for example it can be seen which tubes already have their rod counterpart ready or in production and vice versa. You can also do prioritization for these work commandments by marking them as urgent or critical. Those work commandments will be taken through the factory as fast as possible. Also, the amount of data that was usable by production planning was increased. Now you can see the items codes, unique work id, size of the items, original planned start date from the ERP system, the estimated duration of work and the amount of load that has been planned for the day in minutes and in quantity of items (see Figure 17). Also, there are other functions where the status or the location of materials can be checked, the status of the work can be changed and general information about the work commandment is available.

![Figure 17. (Figure removed) Planned work order for spare part assembly.](image)

Afterwards, a list of started works was also added to the MES system where you could check the status and see information about the work for example when it has been started or when the work commandment has been printed. With this information it is easier to track certain work commandments and to minimize the number of idle works. Multiple reports have also been created within the MES system. These reports can be used to get information such as which items haven’t moved in the production for a set amount of time, which work commandments are ready for assembly and which work commandments are missing tubes or rods. These reports help in the daily work of production planning and the production foremen.
Figure 18. (Figure removed) Objectives for the amount of tube production in two areas.

Figure 19. (Figure removed) Objectives for the assembled amount of a customer’s cylinders.

As seen in Figures 18 and 19 there is also a built in tool which shows the objectives for production. The data can be sorted by produced items for example tubes or rods or the objective for a single area of production can be checked. Management can set the objectives for different areas of production for a week and these objectives are visualised in real time at the factory in these areas. In this way the personnel working in those areas have goals to pursue. The graphs also show the real time progress that is made during the day and during the week. Production planning can check the objectives of an area and sort the data according to the machines or even customers. In this way it is possible to plan the production in a way which serves these objectives as closely as possible.
As seen in Figure 20 there is also a tool where you can see real time data of the quantity of items that are currently in production. It shows the quantity that is being produced in a certain area of the factory for example in Figure 20 there is visualised data of the amount of tubes that are in the tube manufacturing line. The yellow line shows the quantity of tubes that are ready for picking, the purple line shows the quantity of tubes that are being picked, the cyan line shows the quantity of tubes that are picked and startable, the green line shows the quantity of tubes that are started and being produced, the red line shows the quantity of tubes that are interrupted for a reason for example a material shortage and finally the brown line shows the quantity of tubes that haven’t moved in more than three days for an unknown reason. There is a report of these unexplainably stopped items that is sent to the emails of certain people every day. These people are then responsible for finding out the reasons of the stoppages and for trying and keeping the quantity of those items as low as possible. The development of this tool is still in progress. New features that have been thought of include sorting by customers to see how many items for a certain customer are being produced/will be produced and a possibility to switch to a view of the current situation in a simpler graph.

The implementation of the production planning system in the MES environment has developed the toolset of production planning to a completely new level that could never have been reached with the previous tools. However the usage and upkeep of this system requires much more effort from the production planners which can be seen as both good and bad. In this case the fact that production planners place more effort on this mostly means that production planning is done more carefully than before but the amount of work placed into this system has also reduced the time that production planners have for other tasks.
8 RESULTS

The projects that have been done can be divided into five development tasks to make the measurement and analysis of these projects more straightforward. In this way the shown results can be directed to certain parts of these projects.

Table 1 shows a summary of the development tasks that have been completed. The summary shows the initial state, the change that was made and the effect that the completion of the task has had.

Table 3. Summary of finished development tasks.

<table>
<thead>
<tr>
<th>Task</th>
<th>Initial state</th>
<th>Change</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Updating resources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Updating production models</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Changing the point of loading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Splitting work commandments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Implementing a production planning system</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.1 Work cycle time accuracy

The work cycle times are related to the development tasks 1 and 2. The work cycle times have been measured and the results have been analyzed to see if the updated information is more accurate than before.

Production models of the tube and rod manufacturing as well as the assembly line were updated in a large scale update and they are being continuously updated. Those production models include the work cycle times of items. The work cycle times are an important part of many calculations that include for example capacity planning. The planned load of a certain work comes from an equation of planned work cycle time multiplied by the amount of pieces in the batch. For the calculations to
be accurate the planned work cycle times should also be as accurate as possible. However with such a variable production it is almost impossible to reach a perfect comparison between planned and real work cycle times. The real work cycle times can differ between the machines where the products are made and how the workers report the work cycle times. From the comparison calculations the most extreme differences were excluded since there were quite many inputs that were obviously falsely reported by the workers. The calculations were made by comparing the planned work cycle time which comes from the production models and the reported real work cycle time which is reported after the phase is completed. Data was gathered where the planned work cycle times from the production models were compared to the reported work cycle times and the average timing differences were calculated from those values. The smaller the average timing difference is the better, since that directly measures how accurate the planned work cycle times are.

Table 4. Results of work cycle time comparison.

<table>
<thead>
<tr>
<th>Production resource</th>
<th>Avg timing difference 2020 (min/piece)</th>
<th>Avg timing difference 2021 (min/piece)</th>
<th>Difference (min/piece)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre assembly and assembly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tube manufacturing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rod manufacturing</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From Table 2 it can be seen that the only increase in the timing difference has happened in the manufacturing of rods and it is an increase on average of 4 minutes per piece. In cylinder pre assembly and assembly there has been a reduction on average of 3 minutes per piece. In tube manufacturing the reduction was on average 7 minutes per piece.

For the most part it seems that the updating of data has been successful and the constant upkeep of data is clearly a positive thing. There has been a negative development in the accuracy of rod manufacturing work cycle times but the difference in this case is so small that the positives heavily outweigh the negatives.

8.2 Timing differences of finished tubes and rods

The timing differences of finished tubes and rods are related to development task 5. The timing differences have been measured and the results have been analyzed to see if production planning has been more accurate with a highly customised production planning system than with a manual production planning system.

In 2020 production was controlled manually at the factory and in 2021 there has been a custom production planning system in use. One of the most critical measurable data for the tube and rod production lines is the difference between the finishing time of the tubes and rods. The amount of work in the assembly line and therefore the performance of the assembly line are heavily dependant on the similar finishing times of tubes and rods. The finishing time differences were measured from three different unique cylinders that have been produced during the years 2020 and 2021. In total 71 manufacturing requests were analyzed between these three items. These three items were
selected because the phasing of the items is very different and they have been produced in high volumes in both years.

The first measured item is an item where both tube and rod have two phases which are welding and machining. In this case the timing should be easily controlled both manually and in the system because the number of phases is similar. For this item in 2020 the standard deviation value was [ ] and the variance value was [ ]. In 2021 the standard deviation value was [ ] and the variance value was [ ]. Therefore we can conclude for this item that production planning has been more accurate in 2021 than in 2020.

The second measured item is an item where there is a small difference in the number of phases between the tubes and rods. The tube has three phases which are machining 1, machining 2 and welding. The rod only has one machining phase. In this case the difficulty of controlling the timing should be in the mid range because of the small difference in the amount of phases. For this item it was clear that production controlling was more effective in 2020. In 2020 the standard deviation value was [ ] and the variance value was [ ]. In 2021 the standard deviation value was [ ] and the variance value was [ ].

The third item is an item where the number of phases is very different. The tube has a total of six phases which are machining 1, welding 1, machining 2, welding 2, machining 3 and welding 3. The rod only has two phases which are machining and welding. The timings for this item should be the hardest to control out of all the items. This was quite clearly shown in the results from 2020 but the results from 2021 are surprisingly good. In 2020 the standard deviation value was [ ] and the variance value was [ ]. In 2021 the standard deviation value was [ ] and the variance value was [ ]. Production planning for this item was much more efficient in 2021.

From these results it can be concluded that when it comes to the edges of the array as in easy to control items and hard to control items, a production planning/controlling system is more reliable and accurate than manual controlling at the factory. In the medium difficulty items I believe that manual controlling proves to be more efficient because in manual control there is always a human factor involved in the amount of effort put into the controlling. With easy to control items the effort put into controlling those items can be minimal and in hard to control items the effort might not be even placed. Therefore most effort goes into the medium range items.

8.3 Produced tubes and rods

The quantity of produced tubes and rods has been used to find and analyze the results gained from development tasks 4 and 5.

From 2020 to 2021 there has been an increase in the batch size in tube machining from an average of [ ] pieces to an average of [ ] pieces. The reported average work cycle time in tube machining in 2020 was [ ] minutes per item and in 2021 it was [ ] minutes per item. For rod machining, from 2020 to 2021 we managed to increase the average batch size from [ ] pieces to an average of [ ] pieces. The reported average work cycle time in rod machining in 2020 was [ ] minutes per item and in 2021 it was [ ] minutes per item.
Figure 21. (Figure removed) Amount of finished tubes between January 2021 and November 2021.

As seen in Figure 21, the year 2021 as a whole has been uptrending for tube production. In the quantity of finished tubes there has been an average increase of \%%. If the summer holiday months June, July and August are excluded, the average increase is as high as \%%. As the values suggest, there has been quite an impressive improvement in the quantity of finished tubes in 2021.

Figure 22. (Figure removed) Amount of finished rods between January 2021 and November 2021.

As seen in Figure 22, the year 2021 has been uptrending also for rod production. In the amount of finished rods there has been an average increase of \%%. If the summer holiday months June, July
and August are excluded, the average increase is %%. There has also been quite a big improvement in the quantity of finished rods in 2021.

### 8.4 Produced cylinders

The quantity of produced cylinders have been used to find more results that have been gained from development tasks 4 and 5.

As a direct relation from the increased batch sizes in tube and rod production also the average batch size in cylinder assembly was increased from pieces to pieces from 2020 to 2021. The average reported work cycle time was reduced from minutes to minutes.

![Figure 23](image)

Figure 23. (Figure removed) Amount of finished cylinders between January 2021 and November 2021.

As seen in Figure 23, the year 2021 has been uptrending also for cylinder production. Cylinder production is quite heavily influenced by the results of tube and rod production so that was expected after the increases in the amounts of finished tubes and rods. For the amounts of finished cylinders there was an average increase of %. If the summer holiday months June, July and August are excluded, the increase was %. This is a meaningful increase to the output of a bottleneck resource for a year.

With the tube and rod manufacturing work commandments split from the assembly work commandments there is an ability to optimize the batch sizes and to reduce the setup times in machining. The effect of separate production planning can be seen quite clearly from the average batch sizes. There might be multiple reasons behind the reduced average work cycle times. One of the reasons could be that there are differences in product catalogs that have been produced. There is a group of certain items that have long work cycle times that have been produced less during the year 2021 than 2020. One of the reasons could also be that the effort put into the accuracy of work cycle times has increased the amount of correct reporting. Generally the splitting of work commandments has given
potential that couldn't have been used in the past. However it is still quite a fresh change and the ability to utilize this potential hasn't been fully unlocked yet.

8.5 Throughput time accuracy

Throughput times have been measured and analyzed to find out if production planning has been more accurate after all the development tasks have been completed. One aspect for production planning and control to be successful is the difference between the planned throughput time and the reported throughput time, which should be minimal. In this case it wasn't possible to measure the difference throughout the whole production line because of the different structures of manufacturing requests between the years 2020 and 2021. However it was possible to utilize the phase numbering inside the production models to reliably measure the difference starting from the collection of assembly parts. Therefore in this case the differences were measured starting from the collection of assembly parts and ending in the completion of the last phase number which is when the cylinders are marked as ready. It has been measured if the planned throughput times are accurate compared to the actual reported throughput times. It was found that the average difference between the planned throughput time and the reported throughput time in 2020 was \( x \) hours. The same difference in 2021 was only \( x \) hours. This means that in cylinder manufacturing the planned throughput time has been much more accurate in 2021 than in 2020.
9  FURTHER IMPROVEMENT

There has already been significant improvement in the toolset that can be used by management, production planning and the foremen of production. With these developments the overall visibility and transparency of the whole production process has been improved tremendously and the effort that can be placed to production planning and control can be much larger. However, there is always room for improvement and addition. After all of these developments and changes there are still some problems that persist. One of these problems is the fact that there is minimal control for items that are started from the work queue and being produced in the tube and rod manufacturing lines. For production planning, the traceability of these produced items is lost after they are picked and started. As previously commented, the amount of phases between items can be very different. These differences in the amount of phases and the lack of control lead to imbalance between the tube and rod manufacturing lines.

The fact that tubes and rods are being finished at different times leads to the finished item having to wait on the carts for their counterpart to be finished. This leads to the fact that the carts aren't freed back to the picking and they can't collect new items for production as fast as they should.

After the tool would be used in production planning, the information about the production plan should be transferred to the production lines. It could be done with screens that are placed to the vicinity of all the machines/stations where they are needed. These screens would have a visualised work queue that the workers could follow. These work queues should also have enough information
for the workers to recognise the products that should be worked on next. This information should include the size which is often a very clear tell for the workers about the products that are on the carts. For example the difference of a tube with a diameter of Ø115mm and a tube with a diameter of Ø75mm is very clearly visible to the eye (see Figures 24 and 25). Also a difference in length between items can be seen very easily as there can be rods with a length of 40cm and rods with a length of 450cm in the production.

Figure 24. Tubes with a diameter of Ø115mm.

Figure 25. Tubes with a diameter of Ø75mm.

On top of the sizes, the amount of items that should be on the cart can also be a good way to tell which cart is the one you are looking for. More information that the workers would need would be
the item codes and the unique work id so that they can look at the work commandments that are in
the carts to identify the exact work and to make sure that they have the right cart.

Table 3 shows a summary of development tasks that have been planned for the future. The sum-
mary shows the initial state, the proposed change and the objectives of the development tasks.

Table 5. Summary of proposed development tasks.
CONCLUSION

It can be said that the changes made in the production planning system have brought the production planning and control processes of Hydroline Oy to a more modern state. There is no need for as much manual work anymore and there are only a few places where to handle information and data. Generally, the amount of confusion and ignorance related to production planning and control has decreased as the amount and the accuracy of data and information at use has been improved tremendously. The data has been used to create reports and visualisations that can measure performances, create objectives and show helpful information for production. Overall the toolset that production planning has in their use is now much more diverse. There is now an ability to place much more effort to production planning and therefore the ability to make it more accurate and optimized. However there is still work to do in the future in regards of the development of production planning and control processes.

The results of production planning development seem positive comparing the data between the years 2020 and 2021. There are clear signs that certain aspects have improved, however so much has also happened outside of production planning in this time that the results have to be looked at quite carefully. There was plenty of data to compare and analyze but finding the significant data that can be directly connected to the development tasks was difficult. Keeping this in mind I still believe that in general these steps have been taken into the right direction. Some problems and confusion could have been avoided with more careful preparation and with more time.

In development projects and changes there are always positive and negative sides. Keeping that in mind can help the decision making related to these changes. To make the decision making more easier it is also important to back up your findings with all the necessary information. What I have learned from these projects is that it is important to listen to the people who are in the middle of these processes and mostly affected by the changes. Also, going through difficulties with a positive mindset can change the general situation from dwelling in the problems to trying to achieve solutions and results. Overall being a part of these development projects has been both challenging and rewarding as well as eye-opening and I can say that personally I’ve learned a great deal during this time.
11 REFERENCES


