Reduction of inventory level in a production with capacity constraints

A study to analyse investments and production planning

Lisa Nordmark
Tuva Svensson

August 2015
Thesis for the degree of Master of Science
Division of Engineering Logistics
Department of Industrial Management and Logistics
Lund University, Sweden

Division of Engineering Logistics
Department of Industrial Management and Logistics
Lund University
P.O. Box 118
SE-221 00 Lund
Sweden

ISRN LUTMDN/TMTP-5797-SE

Printed in Sweden by E-huset Tryckeri
Lund 2015

to Benji and Gusten

Abstract

Equal capacity in the activities of a production line is of great importance when a good material flow is desired. This is one of the basic ideas of the Lean philosophy, a mindset every modern company strives to follow. In a production with unequal capacity, the company might have to build up inventory to be able to meet the costumer demand. Inventory is a recognized waste in a production and a cost in terms of inventory holding costs.

This study is conducted to the production at BorgWarner TorqTransfer System, a producing company of awd couplings for the automotive industry. The production process is controlled with a MRP system and consists of two main processes, the parts manufacturing and the assembly. Currently, the parts manufacturing has a capacity constraint and is forced to work seven days a week, the reason why a high inventory buffer needs to be built up during the weekend when the assembly is not producing.

The solution approach is based on four developed scenarios, all consisting of different solution approaches. The first scenario is an hypothetical implementation of a Kanban system, with required investments for equal capacity during the weekdays. In the second scenario, the theoretical rescheduling tool Rotation Cycle Policy is examined. The third scenario implies manual rescheduling of high rate products at the weekdays and low rate products at the weekends. In the last scenario, required investments for equal capacity during the weekdays with a maintained MRP-production is done. The study indicates that it is most profitable to eliminate the weekend production, which results in an elimination of unnecessary inventory. The most beneficial scenario is the last one, which implies a rescheduling of the weekly production planning in combination with required investments for a MRP controlled five-day production. With this scenario, a steady material flow is achieved. The savings of reduced inventory holding costs and reduced costs of salary for unsocial hours are compared against the cost for investments for a higher capacity in the parts manufacturing. With a annual depreciation of seven years, the investment proposal is viable after four years. A long term solution, based on forecasts four years foreward, assures the company of a sustainable production planning and predetermined investment proposals.

Preface

This thesis for the degree of Master of Science in Mechanical Engineering marks the end of our five year education at the Faculty of Engineering, Lund University. The work has been conducted from April 2015 to August 2015 at Borg Warner TorqTransfer Systems AB in Landskrona, Sweden.

First and foremost we would like to thank Johan Cederfeldt at BorgWarner for given us the opportunity to work within an interesting area where we have acquired valuable knowledge for the future. Thanks also to our supervisor Jan Olhager at the department of Industrial Management and Logistics, Lund University, for supporting us throughout this project. We would also like to thank our families and loved ones for all support.

Finally, to our close friends from Mechanical Engineering. Throughout out these five years, we have shared both tough times, happy moments and unforgettable events. A big thank you! We could not have done this without you by our side.

Lisa Nordmark & Tuva Svensson
Landskrona, 2015-08-09

Contents

List of Figures

List of Tables

1

Introduction

THE MANUFACTURING INDUSTRY HAS flourished over the past century, a result of a changing market where the demand has gone from being supply-driven to being demand-driven. The first big step was taken during the first part of the 20th century where the craft industry progressively became more standardized and more cost effective. The new industry concept was inspired by Henry Ford who introduced the high volume manufacturing in Detroit, 1910. It was, among other things, the modern manufacturing tools and the simplicity in the production that contributed to the development of a high speed production which made the assembly line process possible in 1910.[1]

When Toyota started with their domestic automobile production in Japan in 1930's, they had to develop the existing concept of mass production to suit their current country situation. The manufacturing needed to be more flexible and resource efficient since the local manpower was more expensive and a lack of plant facilities was a fact. At this time the Japanese people also started to request a greater variety of products than before[2]. The development of the industry took a big step forward in 1937 when the new way of manufacturing was defined as *Just In Time* by Kiichiro Toyoda. The philosophy of Just in Time was to produce the right amount of products at the right time, with the purpose to improve the ability to economically respond to changes[3]. Further on, more factories embraced the new concept with the goal to reach a production with high quality, low costs and short lead times. Years later, the different improvement strategies got its common name – *Lean Production*.

[1] Ståhl, *Industriella tillverkningssystem, Del II - Länken mellan teknik och ekonomi*, pp. 11-19.
[2] Ibid.
[3] Sandras, *Just-in-Time: Making It Happen: Unleashing the Power of Continuous Improvement*, p. 10.

The philosophy of Lean Production is still relevant in today's manufacturing due to the increased demand of greater varieties. The fast improvement of the production machines and techniques have established a larger competition among the companies, which makes continuous work of improvement crucial to maintain a profitable business.

Many of today's manufacturing companies adapt their offerings to customer demand. The demand-driven production requires a flexibility with purpose to keep a consistent material flow by equal cycle times in the activities. Low flexibility can cause undesired inventory along the production line, something that ties up capital and occupies space. To keep low inventory levels is something every producing company continuously strives for. The preconditions of this is to have a well designed material and capacity planning method and the required equipments.

1.1 Company description

BorgWarner Inc. is a global company located in 19 countries with around 22 000 employees. The company focus on developing the leading powertrain technologies that improves fuel economy, emissions and performance. Their products are key technologies for Engines, Transmissions and Driveline systems.[4]

When BorgWarner acquired the Traction Systems division of Haldex Group in 2010, the new BorgWarner TorqTransfer Systems AB (refers to as BorgWarner) was established in Landskrona. The company is expanding in its operating business area of All-Wheel Drive couplings for Front-Wheel Drive and Rare-Wheel Drive cars. The acquisition in 2010 increased BorgWarner's share to approximately 50 percentage of the AWD-coupling world market.[5]

The AWD business has grown over the last years, and is a continuously growing business. To maintain its position at the world market and to allow further growth, it is important for BorgWarner to work with continuous improvements of the production.[6]

1.2 Problem discussion

The production at BorgWarner consists of two primary processes, the parts manufacturing and the assembly, controlled partly by a Kanban-system and partly by a MRP-type planning. The parts manufacturing is divided into three main steps; the machining process, the washing process and the leakage test. The parts manufacturing and the assembly have different production rates which results in a unbalanced material flow along the production line. A capacity constraint together with limited flexibility at the parts manufacturing makes the process more time consuming than the assembly. To maintain an

[4] BorgWarner Inc, *The Company*.
[5] Ibid.
[6] Cederfeldt, *Inventory levels*.

ongoing assembly during the week, without any waiting times, the parts manufacturing is forced to produce to an inventory of semi-finished goods between the two processes during the weekend. The unbalanced material flow makes it difficult for BorgWarner to adapt a control method for a requested demand-driven production.

The unwanted inventory between the processes does not only prevent a balanced material flow at BorgWarner, but also ties up capital and takes up valuable space in the limited facility. BorgWarner's sales are increasing and expects a continuous increase in future years. To obtain the demand, investments in a larger machinery needs to be done but requires economical tenable.

1.3 Purpose

The project aims to improve the material flow at BorgWarner in order to reduce the inventory level of semi-finished goods.

1.4 Focus and delimitation

Boundaries that will be made includes all activities before and after the parts manufacturing process. The project will focus on improvements related to the material flow along the part manufacturing process and to reduce the inventory of semi-finished goods between the parts manufacturing and the assembly. The purpose will examine the possibilities of investments versus planning of the current resources. Analysis and optimization of production engineering data is excluded. Logical assumptions to make the study possible will be taken and be presented through out the report.

2

Methodology

CHOICE OF METHODOLOGY IS an essential part while doing a project. The methodology is made out from the objective and represents the characteristics of the project. The aim with the chapter is to give the reader an understanding of the study approach and the considerations made by the authors. Depending on the nature of the problem and the desired solution, the purpose of the study can vary. The four main purposes are presented below.[7]

Descriptive	A study where the main purpose is to identify and describe how an object works or how it is done.
Exploratory	A study where the main purpose is to get a more detailed knowledge in how an object works or how it is done.
Explanatory	A study that seeks for relations and explanations for the causes of how the object works and how it's done.
Problem solving	A study with a purpose to finding a solution to a identified problem.

By looking at the projects purpose it is clear that this is a problem solving project. BorgWarner has a distinct problem and asks for a well-defined solution based on analysis and calculations. The purpose will characterize the choice of methodology with regard to data collection and analysis.

2.1 Inductive and Deductive approach

Simplified, there are two ways of relating empirical data with theory, by inductive approach or deductive approach. The inductive approach is defined as having conclusions

[7] Höst *et al.*, *Att genomföra examensarbete*, p. 29.

based on given data that will generate a definitive theory. The arguments in the inductive approach are based on experience or observation. In contrast, the deductive approach is defined as having given theories generate hypotheses that should be tested against the collected data and eventually generate a conclusion. The deductive approach adopts arguments based on laws, rules or other widely accepted principles.[8]

In this project there are given theories that are going to be examined with data available from the company. Based on the purpose, some suitable theories and methods are going to be studied and compared against each other in respect to the current situation. The study will result in a practical solution proposal based on the conclusions on the analysis of the data. This make the a deductive approach relevant for the project.

2.2 Data collection

Initially it is important to define and select what type of data that should be collected and evaluate how the choice of collection method affects the data. There are two main methods of collecting data and make analysis, either qualitative or quantitative. To differentiate them from each other it is said that the quantitative data consists of things that can be counted or classified as number, percentage and etc[9]. The data is preferably processed with statistical analysis and can so be linked to the deductive approach. The qualitative data instead is more detailed and mainly consists of words and descriptions. The data requires analysis based on sorting and categorization and can therefore be linked to the inductive approach.[10] Further on it is appropriate to divide the quantitative and the qualitative data into primary- and secondary data to take the credibility into consideration. Primary data consists of basic data gathered from the original source, while the secondary data consists of information previously collected or compiled.[11]

The execution of a quantitative research allows data to be collected from many different participants at many different research sites. The data is collected in numerical form by mathematically-statistically analysis, for example through structured observations. Performing a qualitative research collects data in a 'non-numerical form' by 'non-mathematical methods', then by a less structured observation.[12]

This project is primarily based on quantitative data since the purpose is clearly stated from the client. It is requested a solution based on numeric data which is consistent with the link between deductive approach and data collection, mentioned above. Primary data will mainly be used, e.g. data collected directly taken from the enterprise software. Secondary data, compiled data that is presented in a relevant form, will also be used. The qualitative data will be used as a complement to the qualitative data.[13]

[8] Soiferman, *Compare and Contrast Inductive and Deductive Research Approaches*.
[9] Höst *et al.*, *Att genomföra examensarbete*, p. 30.
[10] Ibid.
[11] Lekvall, *Information för marknadsföringsbeslut*.
[12] Soiferman, *Compare and Contrast Inductive and Deductive Research Approaches*.
[13] Ibid.

2.3 Focus of purpose

The purpose of the study narrows the hypothesis and the research questions down. The quantitative research has close-ended questions that examines variables determined from the hypothesis. Furthermore the hypothesis is tested to accept or reject the relationship stated in the theories. The qualitative research, on the other hand, has open-ended questions with a purpose that focus on one single aspect and gather as much information as possible about that.[14]

2.4 Theoretical review

The literature studies are an important part of a project and are an essential part in scientifically methodologies. A well-conducted literature study of what information there are within a specific area is an important contribution for the project.[15]

Performing a quantitative research requires a more detailed and comprehensive literature study than for the qualitative research. The literature review for the quantitative research can be used to identify the problem and to form the hypothesis. To do the qualitative research, the literature review is more concise than for the quantitative research. It can be used to provide evidence for the purpose of the study and to identify the underlying problem that will be dealt with.[16]

2.5 Analysis

It is important to take the method of data collection into consideration when choosing method of data analysis. One type of data collection requires one type of data analysis[17]. Broadly speaking there are two methods of analysing the data, the quantitative or the qualitative way. The quantitative way of analysing are done on quantitative data. Quantitative analysing techniques is often used in two different ways, either to explore the data to get more knowledge, or to show relationships and hypothesis that is made. The examination of the quantitative data can be done by histogram, tests of hypothesis etc.[18]

The qualitative way of analysing is done to qualitative data that is made out of words and descriptions, for example transcribed interviews. In this type of analysis, it is hard to make overall conclusions since the qualitative data collection often is made out of a small selection and depends of the choice of participants.[19]

[14] Ibid.
[15] Ibid.
[16] Ibid.
[17] **ghauri**.
[18] Höst *et al.*, *Att genomföra examensarbete.*
[19] Ibid.

The analysis of project will be of a quantitative type since this is the most correct way of analysing quantitative data and a quantitative analyse is what the company have requested.

2.6 Credibility

It is important to ensure that the results obtained has a good credibility, i.e. stands for an objective picture of the problem as possible. The credibility consists of reliability, validity and representability. The reliability is aimed at the trustworthiness of the data collection, the validity makes sure that the measurements required is determined, and the representability tells weather the conclusions are general or not. To increase the reliability of the data, it is good to keep documents of the decisions and methodology, as well as for the data collection and analysis. A way of creasing the validity is to triangulate, i.e. to examine one object by different methods, but with the same purpose. Triangulation can be done with both data collection and literature review.[20,21]

2.7 Our Approach

1. Study the production process
The first step of the methodology is to get an overview of the production process. This will be achieved through a thorough introduction of the material flow along the production line. To obtain a complete perception of the process, it will be studied both theoretically and physically. The theoretical study will be made by studying the company´s value stream map where every relevant activity is represented. The process, including the main storages, is mapped using icons that are connected with arrows. The physical study will be made through a review of the production process in real. This part of the study is important since it contributes with a complete understanding of how the machines is connected and where the storage of semi-finished goods occur.

2. Create a current status
The second step of the approach is to get a full picture of the situation by looking at empirical data that is relevant for the production. The empirical production data that will be compiled are both production engineering data and production planning data. Product manufacturing data is also relevant and will be compiled. The combination of the primary and secondary data will give a broad picture of the level of flexibility in the process.

3. Develop a future state
The third step of the approach is to formulate a target for the project to reach. This will be done by developing a future state consisting the desired characteristics. The characteristics will be determined based on the literature and on what the company has requested.

[20] Höst *et al.*, *Att genomföra examensarbete*.
[21] Soiferman, *Compare and Contrast Inductive and Deductive Research Approaches*.

4. Reach the future state
The fourth step of the process is to reach the future state, which will be done by developing different solution scenarios. The variation between the scenarios will be essentially different investment options versus planning options. The scenarios will be compared against each other in respect of cost and performance. To reach the future state, different scenarios can be combined in purpose to maximize the performance for a smaller charge.

5. Deliver a solution proposal
The last step is to provide a complete solution proposal with a well-designed approach for BorgWarner to follow. The solution will include investment proposals, costs and expected performance for a shorter and a longer term.

3

Theory

THIS CHAPTER AIMS TO GIVE the reader a clear picture of the theories and concept used in the study. The authors expect that the reader have knowledge of the content presented to fully understand the analysis and the conclusion. The topic of the project covers a wide area with many perspectives and the authors have chosen to describe the parts that they consider relevant.

3.1 Wastes in a production

All activities in a process that are not value adding to the product are seen as a waste. These kind of activities can occur in different ways in a production and can be divided into seven different categories, known as The seven wastes[22]:

1. Over-production
Makes large stocks in between the manufacturing activities.

2. Waiting times
When noting can be done, for example whilst waiting for a previous operation step or because of lack of material.

3. Transports
The transportation between production activities like different machines or factories.

4. Inventory
Ties up capital and take up space in the warehouse.

5. Motion
Motions of a man or a machine that are unnecessarily time consuming and can be reduced.

[22] Sandras, *Just-in-Time: Making It Happen: Unleashing the Power of Continuous Improvement*, p. 9.

6. Defects
When a product is defect because of quality errors. Causes paper work, waste material and lost customers.

7. Over-processing
Adding more value to the product than what the customer is paying for, like too tight tolerance, or using a too advance machine than what is necessary for the process.

3.2 Just-In-Time

One effective way to reduce the seven wastes in a production is to introduce a Just-In-Time based strategy. The concept is a production strategy with the purpose to minimize the load of work in progress in the production. The main point in the strategy is to produce the right amount of products, in the right time, not more or less. W.A. Sandras describes in his book ”Just-In-Time: Making it happen” that it is important to understand that JIT is a dynamic philosophy and a way of helping prioritize, not a guidebook of things to do. He clarifies that JIT is not a project, it is a process.[23,24]

In an ideal manufacturing environment there is zero waste, which is mentioned above, is a production with no non-value added activities. In reality, this is an impossible condition to reach. A value-added process may depend on one or several non-value added processes, which can be an issue for the continuous work of improvement. A descriptive example, quality inspectors might be a non-value added process but cannot be taken away before the quality defects have been eliminated. JIT is about progressively eliminate the dependence of non-value added activities and inventory.[25]

The problem with an unnecessarily large inventory is not just the fact that it ties up capital, it also hides problems and errors in the production. W.A. Sandras describes the JIT as a process to reduce inventory progressively, and continuously solves the problem that appears during the reduction. After one problem is solved it is possible to reduce the inventory furthermore, and then it appears new problems, and the work continues in this loop[26]. The result of the process is a production with low inventory between each activity that generates a good material flow and less quality errors. The scenario can be illustrated with the ”Japanese lake” Figure 3.1, where the water level represents the inventory level and the rocks represents the problems in the production. As long as the water level is high, the boat will not notice the rocks. If the water level is sinking, the boat will get stuck in the rocks and the boat trip will be disturbed. The principle can be equated with a production.[27]

---

[23] Yamashina *et al.*, *Japansk tillverkningsfilosofi och Kanban-systemet*.
[24] Sandras, *Just-in-Time: Making It Happen: Unleashing the Power of Continuous Improvement*, pp. 10-14.
[25] Ibid.
[26] Ibid., p. 26.
[27] Ibid., p. 20.

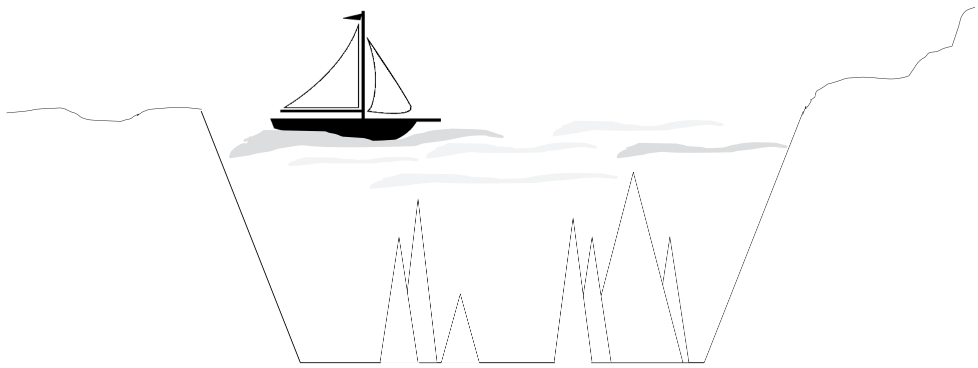


Figure 3.1 Japanese Lake

3.3 Inventory

A producing company needs different kinds of inventories and it is of great importance that the inventory control system is working. Generally, there are three main forms om inventories; Storage, Work in progress and Finished goods inventory. A Storage contains raw material and components that are waiting to be processed or assembled. One type of storage is *safety stock*, a stock that hold inventory and keep up a high service level even when there are big fluctuations and unexpected events.

Work in progress represents products that are in the actual manufacturing process, often in front of a machine waiting to be processed. If the process is not steam lined it might be appropriate to use a inventory for semi-finished goods. The finished goods inventories contains finished products that are waiting to be delivered to the customer.[28]

The inventory in a production can be described schematically according to Figure 3.2, a graph that describes how the inventory level changes over time. Q represents the incoming delivery that refills the inventory in periodic intervals, D represents the demand and SS represents the safety stock. In this case the incoming delivery occur at one time per period.[29]

[28] Olhager, *Produktionsekonomi: Principer och metoder för utformning, styrning och utveckling av industriell produktion*, p. 281.
[29] Ibid., p. 286.

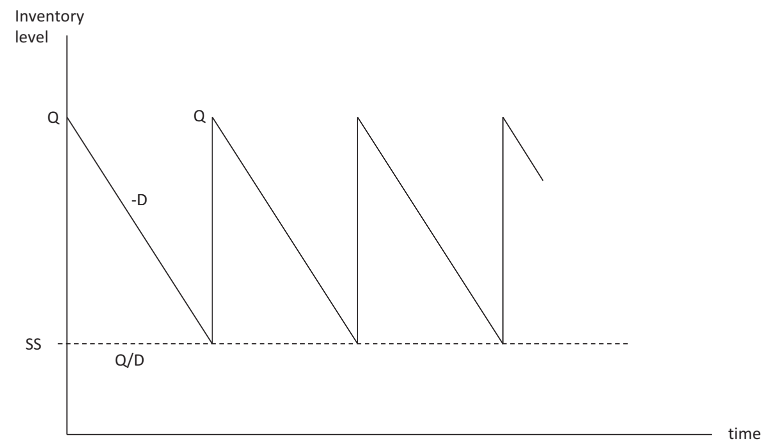


Figure 3.2 Change of Inventory level with a periodic review.

If the incoming delivery takes place in the same time as the manufacturing, the graph will look different, see Figure 3.3. The slope of the incoming delivery in this case will not be vertical like the previous example, but will grow over time. The angel of the slope describes how fast the inventory is growing. P represents the refill rate, SS represents the safety stock, D represents the demand and $P - D$ represents the rate which the inventory is changing. If $P > D$ an increase in the inventory will happen, and if $P < D$ a decrease in inventory will appear. During one period, the total incoming delivery over time is equal to Q, as shown in Figure 3.3.[30]

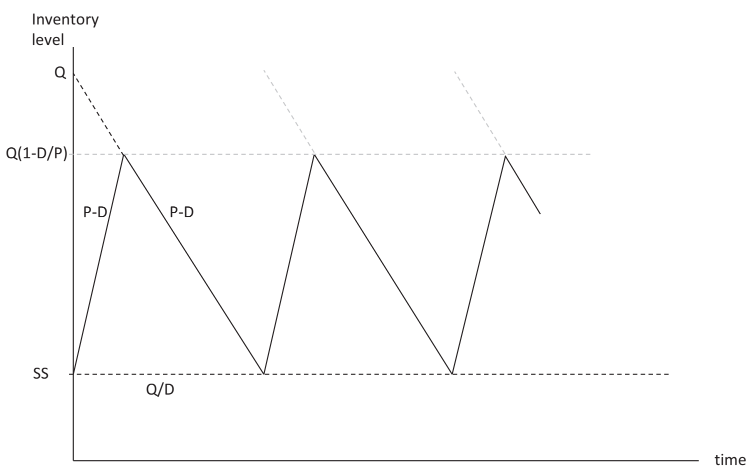


Figure 3.3 Inventory level with a demand during the incoming delivery.

[30] Olhager, *Produktionsekonomi: Principer och metoder för utformning, styrning och utveckling av industriell produktion*, p. 290.

3.4 Production related variables

The following section explains the production-related costs that are mentioned in the report, in order to provide the reader a clearer view of the subject.

3.4.1 Production lead time

Production lead time represents the time it takes for the product to go through all the processing steps in a production. Lead time does not only include the processing time but also the setup time, waiting time, transport time and time in storage as semi-finished goods.[31]

3.4.2 Cycle time and production rate

Cycle time is described as the time from when one product is finished in a specific activity until the next product is finished in the same activity. This means the time between two units are completed. Cycle time is frequently used when talking about production activities and when a flow production is desired.

Production rate is the inverse of the cycle time and describes how many products the activity completes during one specific time unit, often referred to as units per hour.

3.4.3 Set up time

Set up time is defined as the time is takes to change the production equipment in a setup between two articles. The time is calculated from the last correct product of the first type to the first correct product of the second type.[32]

3.4.4 Set up cost

Set up cost does not only represents the cost of the downtime during setup, it can also include costs that might occur due to the setup such as consumables. The cost of downtime is a sum of costs for staff, depreciation of the machine, electricity etc.[33]

3.4.5 Salary cost

Salary cost includes both the salary to the employee and cost supplements, such as tax and social security contributions. The direct labor that is connected to the machining process varies depending on whether it is weekday och weekend.

[31] Ibid., p.29.
[32] Ibid., p.135.
[33] Ibid., p.284.

3.4.6 Inventory rate and Inventory holding cost

Inventory rate is a rate that covers the costs of material handling, warehouse hiring, rejects et.c. The inventory holding cost is defined as the inventory rate of the product value and is calculated on an annual basis as follows.[34]

$$H = r \cdot V \tag{3.1}$$

H = Inventory cost of one product
r = Inventory rate
V = The value of one product

As seen in Equation 3.1, the size of the inventory is of great importance. A too small inventory might have negative consequences in terms of supply reliability, but a too high inventory ties up unnecessarily big amount of capital. This is a conflict that requires continuous development.

3.4.7 Overall Equipment Effectiveness

OEE is a key performance indicator and describes the efficiency of a machine. The OEE is often used as an indicator when measuring the actual performance of an equipment and is calculated as follows.[35]

$$OEE = Availability \cdot Performance\,Rate \cdot Quality\,Rate \tag{3.2}$$

Availability	A relationship between the scheduled time for a machine and the time the machine actually is producing.
Performance rate	A relationship between the real production volume and the volume that actually is produced.
Quality rate	A percentage of products that fit specifications after the processing.

3.5 Push-type and Pull-type production

It is known that there are disagreements on the definitions of pull and push production systems. In the article “Linking systems to strategy”, W. L. Berry and T. Hill have chosen to replace the expressions with ”Push-type” and ”Pull-type”.

In a ”Push-type” control approach the processes along the line are operation as long as there is material available. The raw material is purchased, based on a forecast of customer demand, i.e. not of the actual customer demand. One drawback of the strategy is the devoid of a maximum level in the inventory of semi-finished goods. The approach is suitable for companies that manufacturers a wide range of special-type products, each with a low production volume.

[34] Olhager, *Produktionsekonomi: Principer och metoder för utformning, styrning och utveckling av industriell produktion*, p.284.
[35] Zammori *et al.*, “Stochastic overall equipment effectiveness”.

The basic principle of a "Pull-type" control approach is based on the Just-In-Time strategy. The approach is suitable for companies that manufacturers a low range of standard type products, each with a high production volume. A "Pull-type" approach is a process where only the last operation needs to have a daily schedule, based on either a actual customer demand or a planned demand forecast. The manufacturing in the other stages are done automatically in pace with the downstream material demand. This strategy contributes to reduce the seven wastes. The material flow in a "Pull-type" is described in Figure 3.4.

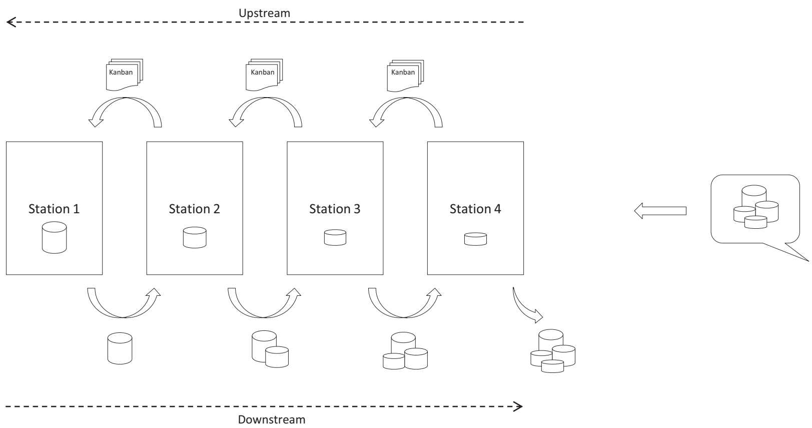


Figure 3.4 A Pull type production system

3.6 Time-phased vs. rate-based material planning

W. L. Berry And T. Hill also describes the difference between a Time-phased and a Rate-based material planning approach, in terms of markets and manufacturing variables. According to J. Olhager and Berry and Hill, a list can be compiled with the strategic variables with respect to the two various material planning approaches, see Table 3.1.

Table 3.1 Comparison of Time-phased and Rate-based material planning

Strategic variables	**Material planning approach**	
	Time-phased	Rate-based
Market and Product characteristics		
Product type	Special	Standard
Product range	Wide	Narrow
Individual product volume per period	Low	High
Planning and control level		
Production activity control	MRP-type	JIT-type

3.6.1 Requirements for a rate-based production

With regard to Table 3.1, following list describes requirements for a rate-based production.

1. Continuous and relatively stable product demand
The customer demand must be somewhat possible to predict and the consumption must be steady, both internally and externally.

2. Uniform production plans and schedules
Large variations and seasonal patterns that can be anticipated must be levelled to minimize the impact on the flow of the whole production line.

3. Short setup times
The set up times is not allowed to take up too much time from the value-added production time.

4. Limited product variety
It is hard to maintain a good flow and level the production line if there are too many different products to adapt to the production.

5. Continuous production flow
It is important to minimize interruptions on the ground of errors from equipment, quality and setup. This requires continuous improvement of these factors.

6. Synchronized and balanced process
Every operations must have roughly the same capacity to be able to produce in the same rate as the final stage of the process.

This strategy requires a greater responsibility by the working groups in form of more planning and control, as well as a good team work and a great leadership. It is also of high importance that the workers just produce enough to meet the customer demand, not more because they are idle or there is material available, it is to avoid over-production.[36]

3.7 Material and Capacity Planning

Many companies often seek to have a manufacturing process that can achieve smooth production with high utilization and low inventories. This is a well-known and difficult problem to solve. A production with an uneven material flow can create bottlenecks throughout the production line that ties up capital and take up valuable space.

The advantage of a good material and capacity plan is to ensure that the products can be delivered to the customers at pronounced time and to reduce non value added activities in the processes, like inventory and waiting times.

[36] Nicholas, *Competitive Manufacturing Management: Continuous Improvement*, p.269.

3.7.1 Material Requirements planning

Material Requirements planning, also called MRP, is a well-known and widely used time-phased production planning method for productions with many manufacturing stations. The method is computer based and is a good alternative for companies that produces to customer order, where the orders are relatively unique in comparison to each other. In these cases it is difficult to produce to stock since it can be hard to predict the upcoming orders.[37] The main objectives that is feasible with a MRP system are.[38]

- Ensure that the materials, components and products that are needed always is available in the right time and at the right place to be able to deliver to the customer on appointment.
- Constantly working on keeping inventory levels down.
- Make a plan for each manufacturing step in the production process, schedule delivery plans, and operate the purchasing activities.

The master production schedule in a MRP system is based on the customer orders that the sales department has received and can be degraded into detailed material requirements. Each finished product that a customer can order consists of several subassemblies, which in turn consists of other subassemblies. The lead time is determined as the sum of all the subassemblies lead times. For example, if a customer requires product A, a demand of that specific product will occur in the MRP system. As seen in Figure 3.5, product A consists if the subassemblies A1 and A2 which in turn will trigger a demand for those products. Further on, product A2 consist of A21, A22 and A23 which results in a demand for those subassemblies as well, see Figure 3.5 on the following page. The net requirement of the materials for a product are developed based on availability, outlying orders, lead times and lot sizing rules. All that information is available in the system and represents the basis of what to purchase and how long the delivery time will be for the customer.[39]

[37] Olhager, *Produktionsekonomi: Principer och metoder för utformning, styrning och utveckling av industriell produktion*, p. 314.

[38] **gallego**.

[39] Olhager, *Produktionsekonomi: Principer och metoder för utformning, styrning och utveckling av industriell produktion*, p.314.

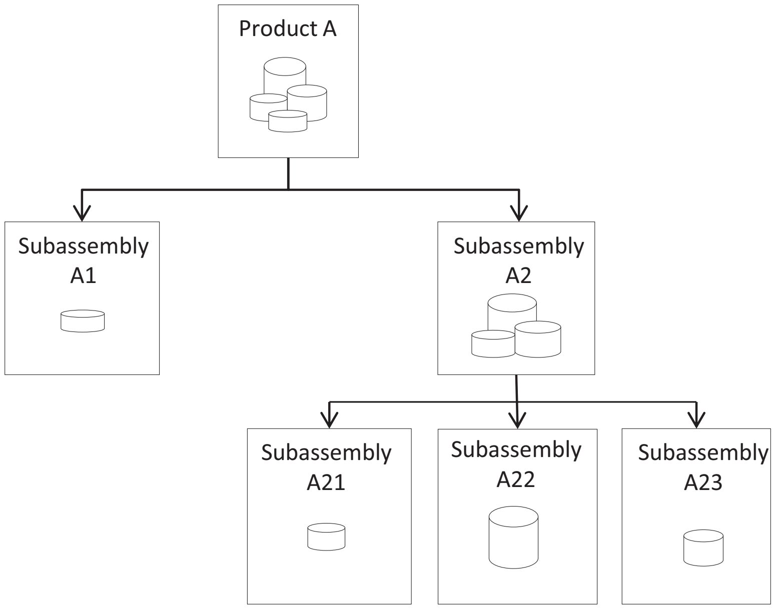


Figure 3.5 Illustration of the concept of Material Requirements planning.

When orders are received in a MRP system, the materials are scheduled and submitted to the production, which results in a production with no specific limits on work in progress inventory. A. Manikas, M. Gupta & L. Boyd describes in their article, how manual games for simulating production runs in different production systems with the purpose to give an insight into the mechanics of how different production planning control techniques was created and tested. MRP was one of the systems that was examined and the test clarified that a MRP system maximises the throughput but results in high inventory, which causing high lead times. This is one of the characteristics of the system that indicates that MRP is a classic push production system.[40]

3.7.2 Rotation cycle policy

When the production capacity is limited and the demand for different products is stable and fixed over a long period of time, rotation cycle policy can be a suitable material and capacity planning method.[41]

A rotation cycle policy is a combined material and capacity requirement method where the products are produced in a repetitive cycle. The time basis of a rotation cycle policy can be different, depending on the situation for the production, but is always constant. The mix and the quantity of each product in the cycle is determined on the basis of how frequent the product is. Assume that the time of the cycle is one week, then the production sequence repeat itself every seventh day, see Figure 3.6.

[40] Manikas *et al.*, “Experiential exercises with four production planning and control systems”, p.314.
[41] Axsäter, *Inventory control*.

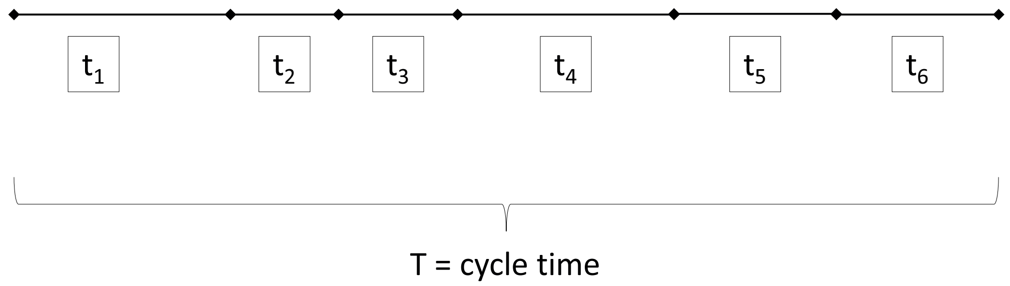


Figure 3.6 Illustration of a Rotation Cycle Policy

A prerequisite for this strategy is that the customer demand is stable and the mix of products is fixed over a long period of time. The purpose is to maximize the utilization of the equipment and create a continuous material flow and by that reduce the ques in the production, since that constitutes the largest part of the lead time. This results in reduced tied capital and less work in progress.

The period is structured in a way that the limited recourse always has full utilization and never runs out of material, which is a important factor in a production with an uneven capacity among the line. The products are scheduled in a pattern where the high frequent products are produced in a higher frequency than the lower frequent products. Some products can occur one time every cycle and some products can occur multiple times of a cycle. For example, if a cycle is one week, one product might be produced every second week and but another product is manufactured two times during the same week.[42]

In the book Produktionsekonomi, J. Olhager explains how to design a competitive cycle production, in purpose to minimize the cycle time and the costs in regard to the capacity restriction. In a case where all the products have a common cycle time, which means that all the products are produced one time in each cycle, there is an equation for the cost of change overs and inventory.

Minimize

$$C = \sum_{i=1}^{n} K_i \frac{1}{T} + H_i \frac{D_i T}{2}(1 - t_i D_i) \tag{3.3}$$

T = The cycle time
K_i = Change over cost for product i
H_i = Inventory cost for product i
D_i = Demand per time unit for product i
t_i = Operation time for product i

[42] Hej, *Teknisk Tidskrift*.

It should be noted that the operation time for each product is individual, depending on the frequency. By deriving Equation 3.3 with respect to the cycle time, an equation of the minimum cost is obtained. Through this equation, the minimum cycle time can be expressed.

$$T^* = \sqrt{\frac{2\sum K_i}{\sum H_i D_i (1 - t_i D_i)}} \tag{3.4}$$

The equation above does not take the limited recourse in consideration, but as mentioned above, a rotation cycle policy is organized on the basis of the bottleneck. To get a complete basis for taking a decision of how long the cycle time should be, the cost minimized cycle time must be combined with a cycle time with respect to the capacity limitation. The equation below takes the set up times and the actual processing time into consideration.

$$\sum_{i=1}^{n} (s_i + t_i D_i T) \leq T \tag{3.5}$$

$$T \geq \frac{\sum s_i}{1 - \sum t_i D_i} \tag{3.6}$$

$$T_{min} = \frac{\sum s_i}{1 - \sum t_i D_i} \tag{3.7}$$

The cost minimized cycle time must be larger than the cycle time above, and of that reason it is referred to as T_{min}. T^* and T_{min} both represent the minimum time allowed in their different aspects, and of that reason the optimum cycle time is the largest one of T^* and T_{min}.[43]

$$T_{opt} = max\{T^*, T_{min}\} \tag{3.8}$$

3.7.3 Kanban

Kanban is the Japanese word for ”card” or ”sign” and is the name of a material planning system that visualises the inventory using cards as signals for replenishment. Kanban is a JIT-type production system that plans the required material by the available capacity of the inventories along the line. To be able to introduce a kanban system, the production must fulfil the requirements of a rate-based production.

[43] Olhager, *Produktionsekonomi: Principer och metoder för utformning, styrning och utveckling av industriell produktion*, pp. 332-336.

The orders in a kanban system moves upstream, from sales to purchase, while the products moves downstream, from purchase to sales. In practice, the signal cards can symbolize either work or transportation orders of a specific product, to replace just the quantity that have been withdrawn by the downstream process. The main purpose of the system is that it should make it possible to determine the size of the buffers and to avoid an over-production, which is the most critical of the seven wastes explained in the beginning of this chapter. Another advantage of the system is that it is a good visualization tool since it is easy for the workers to gain an understanding of the material flow and if they match the current duration.

Different types of kanban

There are different types of kanban systems for a production to embrace, addictive on what is required.

Conveyance kanban — Also called C-kanban. A signal for transportation of an outbound buffer to move to an inbound buffer. The outbound buffer is the one right after the workstation and the inbound buffer is the one right before the next workstation in the process. This kanban card system identifies the part, the quantity, where the parts comes from and where they are going.[44] This kind of system can be useful in a production with long distances.[45]

Production kanban — Also called P-kanban. A signal for production of parts or assemblies. The P-kanban is the kanban system that most people think of when they talk about kanban since the card contains information about operational data and lot size.

According to Olhager four rules exists for a production with a kanban system that must be followed.

- Processing is not allowed without authorization from a kanban card. This means that the processing may stop if there is no signal from a kanban card even if there is capacity to produce.
- No transportation is allowed between the stations without authorization from a kanban card.
- Only standardized load carriers is allowed to transport units,
- Defective parts is not allowed to go from one station to the next without any workarounds, both of the specific detail and the error source.[46]

[44] The Productivity Press Development Team, *Kanban for the shopfloor*, p. 21.
[45] Nicholas, *Competitive Manufacturing Management: Continuous Improvement*, p. 274.
[46] Olhager, *Produktionsekonomi: Principer och metoder för utformning, styrning och utveckling av industriell produktion*, p. 48.

How kanban works in practice

The most common system is the two-card kanban where the production uses both C-kanban and P-kanban. When work station 2 needs details to process it sends a C-kanban to the outbound buffer of the station before, work station 1, with information of the detail and quantity. The requested details are transported from the buffer to work station 2, together with the C-kanban, and is now ready to be processed. The details that was taken from the outbound buffer of work station 1 needs to be replaced. Every detail in the buffer have a corresponding P-kanban which now is placed in a que right before workstation 1, waiting to be produced. When there is capacity available, a card is taken from the que and the details starts to be produced, according to the instructions on the card. The new details are placed in the outbound buffer of work station 1, and replaces the details that earlier was transported to work station 2. When work station 2 needs more ready details, the whole process is repeated.[47] The procedure is shown in Figure 3.7.

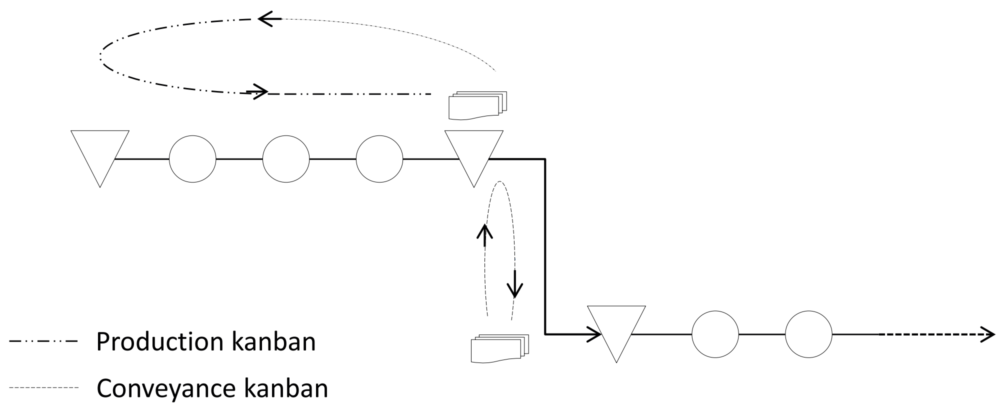


Figure 3.7 Illustration of two different Kanban systems

If the production tries to adapt a kanban system without achieving the essential conditions for a kanban environment, the system can turn out to be useless and in some cases even destroy. The introduction of the system is often poorly considered and the lack of knowledge are usually large. J. Olhager summarizes some classic misunderstandings or pitfalls about kanban. One of them is when the build-priority system needs to be supplemented with external priority. The foundation of the kanban system is that the order of the cards represents the actual demand since it has occurred from real demand of material in the production process. If the organization needs to prioritize manually among the cards, that reveals the organizations lack of potential or lack of knowledge about how the kanban system works.

[47] Yamashina *et al.*, *Japansk tillverkningsfilosofi och Kanban-systemet*, p. 25.

3.8 Frame of references

A well-established material and capacity planning helps a production keeping a high service level, but it also represent a good tool for inventory control. One way of obtaining these requests is to implement a Kanban system. As mentioned earlier in the theory chapter, a rate-based production must be fully implemented before Kanban can be introduced. The first step of implementing a Kanban system is to investigate if the production can fulfill the list of *requirements for a rate-based production.*

1. Continuous and relatively stable product demand
2. Uniform production plans and schedule
3. Short setup times
4. Limited product variety
5. Continuous production flow
6. Synchronized and balanced process

The process of implementing a Kanban system must start with a preparatory work of fulfilling the requirements above. This preparatory work can often be extensive and require significant investments, which in some cases might be a bigger project than implementing the actual Kanban. If some of the requirements above are not achievable, Kanban may not be a suitable system for the production.

To investigate the inventory level in a production, a rotation cycle policy is a suitable tools for this. The objective with the introduction of a rotation cycle policy is to minimize the equation for the cost of inventory and set ups. The longest time of the cost minimized cycle time, and the cycle time with respect to the limited recourse, is chosen. The result of this method can be used to evaluate the optimal inventory level for the current production with the existing resources.

$$T^* = \sqrt{\frac{2\sum K_i}{\sum H_i D_i (1 - t_i D_i)}} \tag{3.9}$$

$$T_{min} = \frac{\sum s_i}{1 - \sum t_i D_i} \tag{3.10}$$

4

Current status

BorgWarner TorqTransfer Systems produces AWD couplings for the automotive industry. Today, they are offering ten different couplings for the industry for many know customers, such as Volkswagen, Volvo, Land Rover Lamborghini etc. The ready coupling is either delivered to a customer that connects the coupling to the rear axis and then sends it to the final customer, or directly to the final customer that assemblies the coupling to the rear axis themselves. A brief introduction of the products and the product shares is shown in Figure 4.1 below.

The latest edition of BorgWarner's couplings is the Generation V (GenV) coupling that was introduced in 2012, 14 years after the first one, Generation I, was introduced by Haldex Traction in 1998.

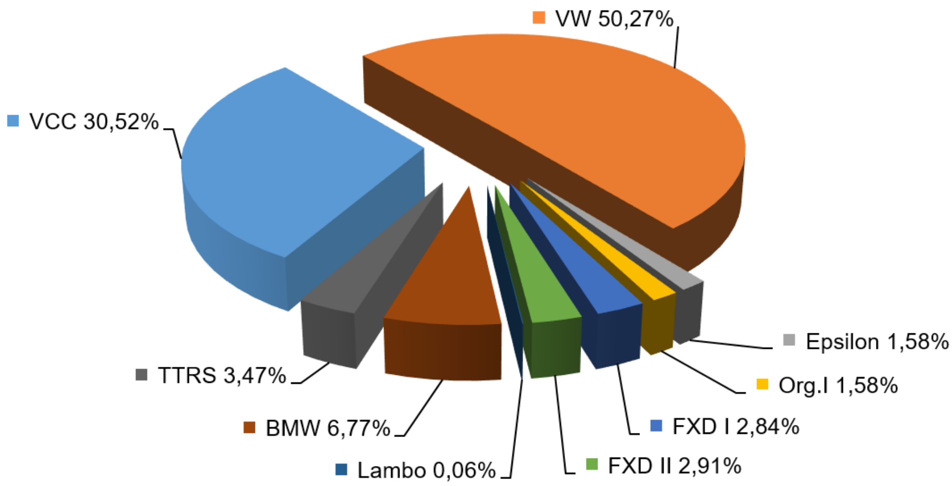


Figure 4.1 Product distribution.

As seen in Figure 4.1 VW is the largest customer in terms of the number of ordered coupling housing, a volume that represents 50.27 percent. VCC and BMW, also have big volumes represented, 30.52 and 6.77 percent respectively. The three products are together representing over 80 percent of the processed coupling housing, and are expecting to continue increasing in the near future.

As mentioned in the problem discussion, BorgWarner needs to create an inventory after the parts manufacturing to be able to obtain a smooth flow in the assembly. A detailed view of the pace difference between the two main parts is shown in Table 4.1.

Table 4.1 Production rates for parts manufacturing and assemly.

Produkt	Bearbetning ∑[st/h]max	Montering ∑[st/h]max
Epsilon	10	0
VCC	87	227
TTRS	27	0
VW	135	285
FXD I	14,5	11,4
FXD II	14,5	11,4
Org. I.	6,5	19,5
Lambo	1,65	0
BMW	15	68

4.1 Production planning

The production planning process starts when a sales forecast is made out of the orders that the customers makes, one and a half years ahead. Depending on the agreement between the customer and BorgWarner, the customer has the right to change its orders up to a few weeks before the final delivery. Based on this information, a master planning schedule for a longer term can be done and transferred into the SAP system. Further on, the production planners at the logistic department makes a definite production plan some weeks ahead and sends it out to the supplier, the machine processing and the assembly. The production planning is based on a weekly schedule where the production volume on each machine is determined.

Currently, the production process at the parts manufacturing is running seven days a week, totally $125, 8 hours$. The weekly production volume is made out of the available hours of the week after repairs, maintenance et.c. is taken into consideration. The weekly volume might differ from the demand, but should in the end reach the customer demand over time.

4.2 Logistic flow

The logistic flow describes the product progress, from the sales forecast via production and until it leaves the plant for the customer. The progress is roughly described in this section and visualized in the value stream map below, see Figure 4.2.

When the production planning is done as mentioned above, the logistics team can plan the raw material required for production. The suppliers are delivering raw material to the plant three times per week, based on the orders mentioned above. A cluster-sampling inspection of the goods is made in the receiving point to ensure that the quality meets the quality specifications. The approved goods are then put into an inventory of raw material, shown as the shape of a triangle in the value stream map in Figure 4.2.

The production process at BorgWarner can roughly be separated into two main parts, the parts manufacturing and the assembly. The parts manufacturing consists of three processes; machine processing, washing and leakage test where the machine processing gets a weekly production plan to follow. When the products pass the leakage test, they are moved to an inventory between the processes where they will be stored until being picked up for the assembly process. The assembly process do also get a weekly schedule from the production planning of what to produce.

When the product leaves the assembly line, it comes out as a ready product and is moved for strapping. When the batch is ready strapped it is moved to the finished goods inventory where it will stay until being picked up by the shipping section for further delivery to the customer.

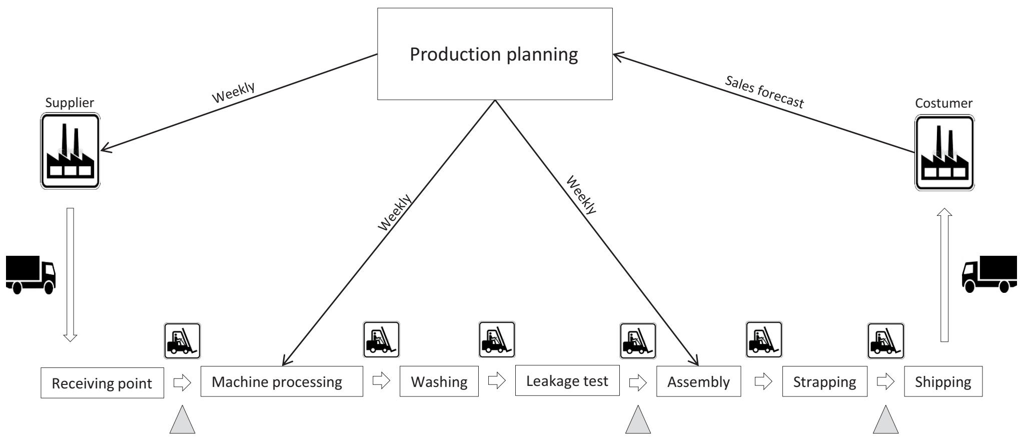


Figure 4.2 Value Stream Map of the production at BorgWarner.

4.3 Project focus

The section below gives a detailed overview of the delimitated parts of the production. A visualization of the focusing area is shown in Figure 4.3.

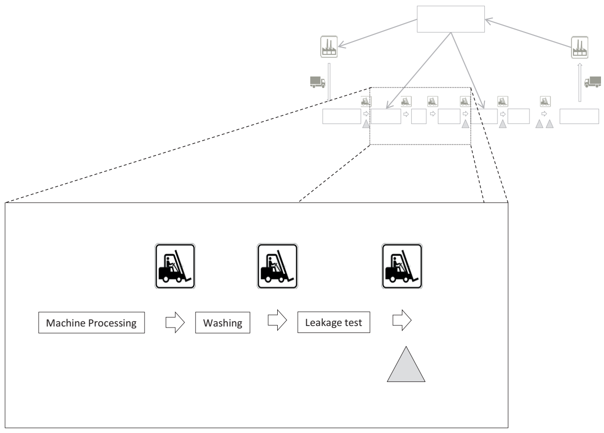


Figure 4.3 Limitation of manufacturing process.

4.3.1 Inventory

BorgWarner collects their goods in three different inventories; *Storage*, *Semi-finished goods inventory* and *Finished goods inventory*. The storage contains coupling housing which should be processed through the part manufacturing and end up in the inventory for semi-finished goods. The storage also contains the purchased goods such as control modules, clutch plates, pressure relief valves and actuators that should be connected to the coupling housing in the assembly lines. Since the assembly lines works with a higher phase than the part manufacturing lines, BorgWarner places their processed goods in a inventory for semi-finished goods. When the products has passed through the assembling process they are put in the finished goods inventory until they are picked up for delivery.

Inventory of semi-finished goods

As mentioned above, the inventory of semi-finished goods collects the coupling housing that has been processed in the parts manufacturing. As seen in Figure 4.4 to the right, the level of the inventory has increased over the last year, and is expecting to continue increasing in the near future.

Figure 4.5 shows the average inventory level in the storage of semi-finished goods, based on the planned production volume for 14 weeks in 2015, week 38 to week 51. The production volume for these weeks can be considered reliable and representative of the current status. The distribution between the different products is the same as Figure 4.1.

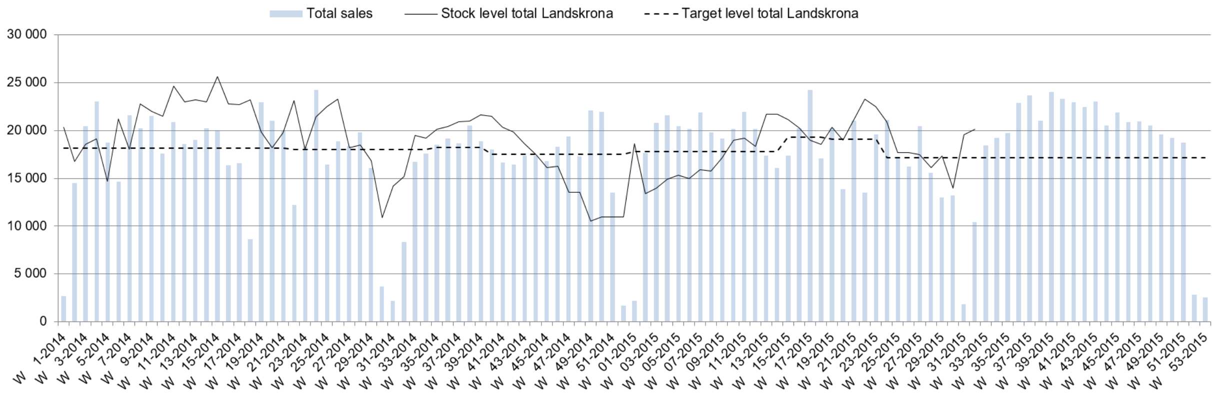


Figure 4.4 Chart of inventory level history.

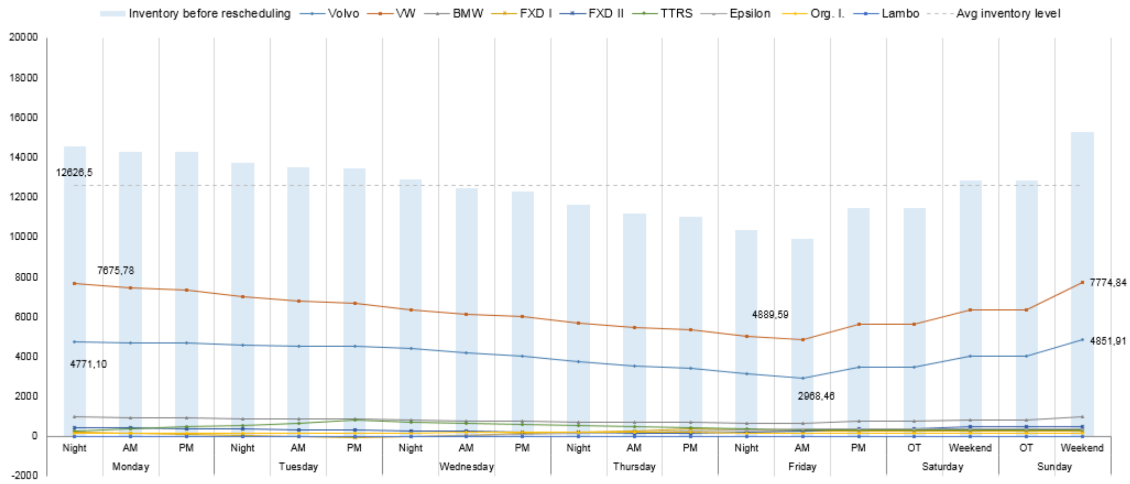


Figure 4.5 Chart of average inventory level of each product.

Figure 4.5 can be compared with Figure 3.3, where P represents the throughput rate from the parts manufacturing and D represents the throughput of the assembling. Q represents the total amount of coupling housing that is produced during the whole week. With Figure 3.3 in mind the negative slope between Monday and Friday occurs because the assembly rate is greater than the parts manufacturing rate ($D > P$), in example $P - D$ results in a negative value. Since the assembly line is closed during weekend, the middle storage is filled up with the parts manufacturing rate ($P > D$) which is shown in the graph, between Friday and Sunday. In example $P - D$ results in a positive value which has the consequence of a positive slope.

4.3.2 Parts manufacturing

In the current situation, BorgWarner has ten processing machines, and hopes to have one more running at the end of the year. This means that in one year, BorgWarner has expanded their machinery from eight to eleven processing machines. The expansion is a result of the company introducing its latest edition, GEN V. The biggest difference, production wise, is that the raw material that BorgWarner receives is not fully processed, i.e. BorgWarner drills, threads and mills the products as a first step today, something they did not do earlier. This process is referred to as the machine processing.

Different coupling housing runs by different programs in the machine processing. When the products, all parts except two, has reached its final shape and dimensions, the coupling housing continues for washing. The washing process removes the chips which has arisen in the previous process. The products that does not directly continue for washing, takes another path for a process to get rid of burrs, to then proceed for washing by the same procedure as mentioned above.

The product continues on to the leakage test where it is exposed to a first performance test. The products that fulfils the requirements at this stage is put in a bin and transported to the middle storage where it will be kept until it is taken for assembly.

The parts manufacturing is currently working in four shifts, seven days a week. This, so they can build up the an inventory of semi-finished goods during the weekends to be able to run a smooth assembly line during the weekdays. Weekly passes through the parts manufacturing are approximately 18,000 products, of which VW, BMW and Volvo are constituted around 80 %, see Figure 4.1 for more detailed view over the distribution of the products in the parts manufacturing.

Products and machines

The nine different products, shown in Figure 4.6, are processed at different machines at the parts manufacturing. Each machine are prepared to process different combination of products which is shown in Figure 4.6. The percentage distribution is based on how many products of each model that are produced, compared to the total amount of products that the machine is producing.

In Figure 4.7 the time distribution of each product at the different machines are presented. The difference between Figure 4.6 and 4.7 is that the last picture takes the aspect of the production rate into consideration. In example, according to Figure 4.6, Epsilon constitute 18% of the products produced by machine 3, which corresponds to 40% of the time available at machine 3, according to Figure 4.7.

Figure 4.8 shows the machine distribution of each product. The figure represents how big part of the total amount of each product that each machine is processing. Products with high volume are produced in many machines and the products with lower volume are represented in less machines.

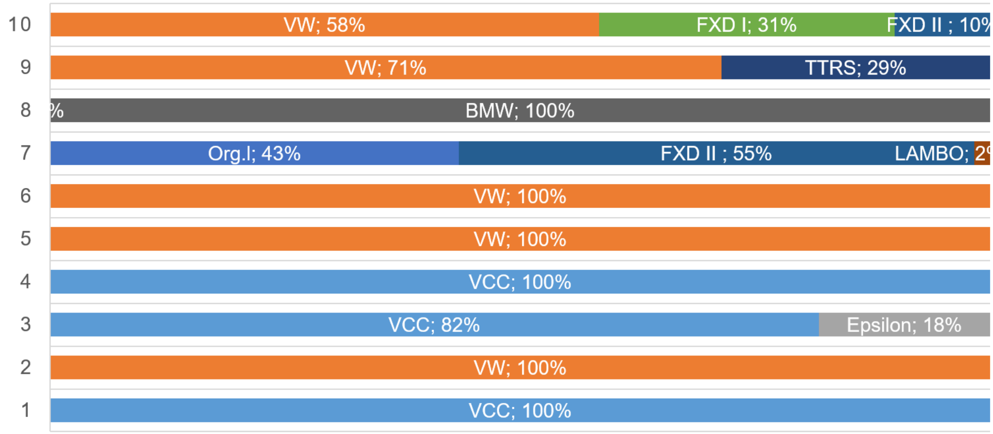


Figure 4.6 Product distribution at machines, based on number of products

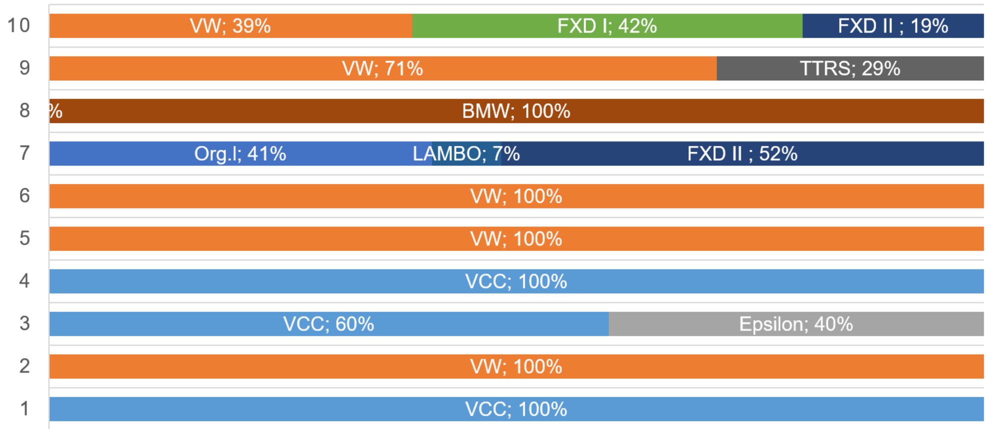


Figure 4.7 Product distribution at machines, based on time spent.

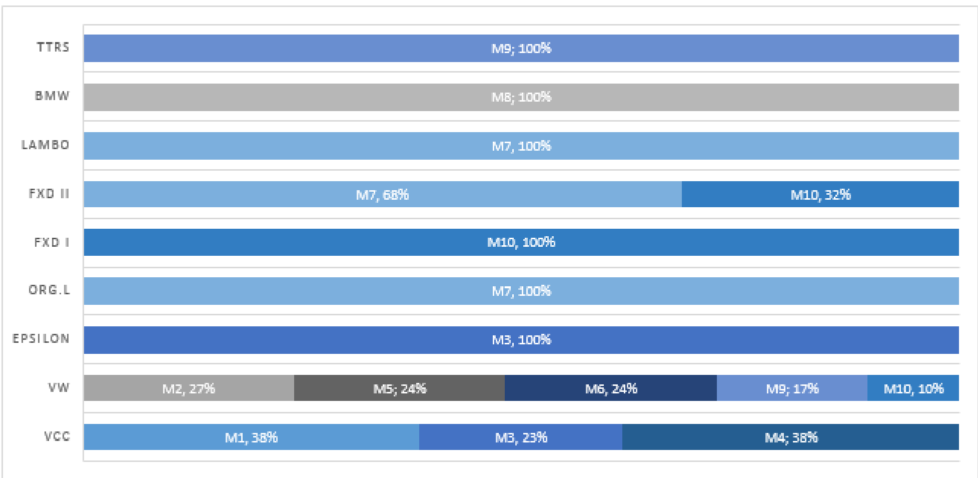


Figure 4.8 Machine distribution of products.

4.3.3 Assembling

The factory has four assembly lines that assembles components in a flow production, as shown in Figure 4.9 below. The coupling housing is taken from the storage of semi-finished goods and works as a frame which the purchased components are connected to, in order to constitute the final coupling. Different from the parts manufacturing, the assembly lines are scheduled to work in three shifts, five days a week, under normal conditions. The total throughput from the assembly lines, in five days, is the same amount as the total throughput from the parts manufacturing lines in seven days. The four lines have the equipments to assemble the products according to the Table **??**.

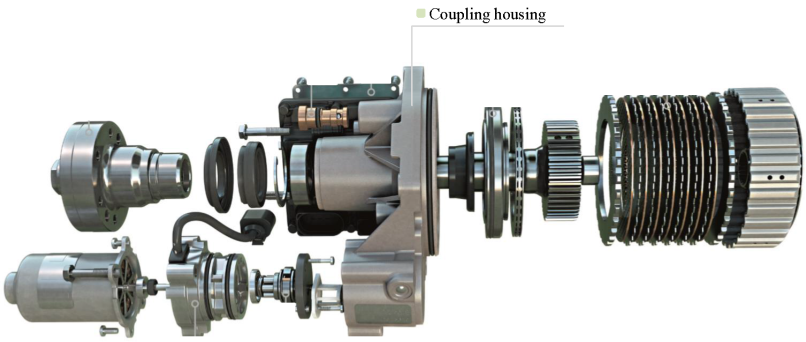


Figure 4.9 Assembly of coupling housing.

Table 4.2 Product distribution on assembly lines.

Line 7	VW/TTRS, VCC
Line 9	VW/TTRS, VCC
Line 10	VW/TTRS, BMW
Line 8	FXD, ORG.L, LAMBO

4.3.4 Kanban at BorgWarner

The current kanban system works as followed. The machine processing has a magnetic board, board 1, where all the pallets in the production are represented by a magnet. Different product variants are represented by different types of magnets. When a pallet is finished from the machine processing, a magnet from board 1 is taken away and put in a collecting tray. There is a similar magnetic board by the leakage test, board 2, where all the pallets are represented by magnets, just like on board 1. Different from the machine processing, the leakage test do also have a kanban-box, box 1, with kanban-cards that represents different pallets. When a pallet is finished from the leakage test, a magnet is taken away from board 2 and a kanban-card is taken from box 1. The kanban-card is then attached to the finished pallet that is placed in the middle storage. When the assembly line takes a pallet from the middle storage, the kanban-card is placed in another box, box 2, that is placed in connection to the middle storage. The number of kanban-cards in box 2 represents the number of pallets taken from the parts manufacturing process to the assembly line. Once per shift, the kanban-cards in box 2 are moved to box 1 and at the same time, board 2 is updated with the same number of magnets that the number of kanban-card that was moved from box 2. The number of kanban-cards from box 2 subtracted with the number of pallets in the parts manufacturing process, represents the number of magnets that should be moved from the collecting tray on to board 1. The described Kanban flow is visualised in Figure 4.10

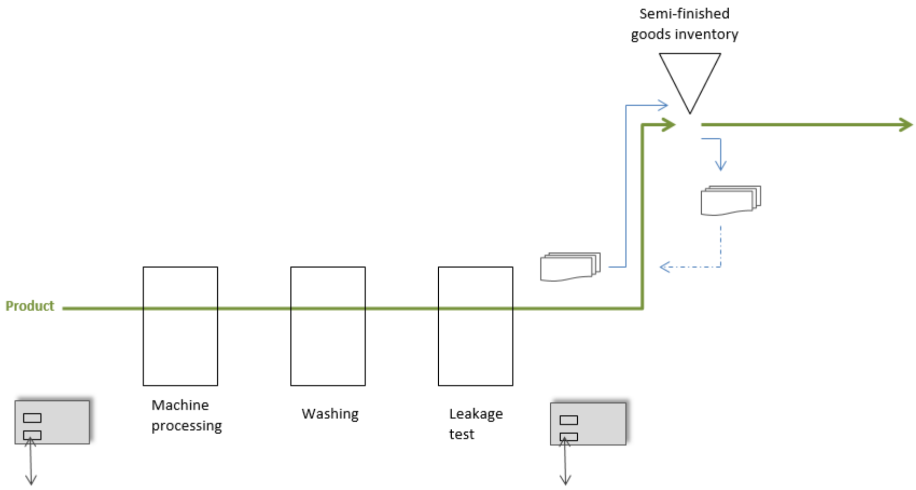


Figure 4.10 Visualisation of the Kanban flow at BorgWarner.

5

Analysis

LACK OF CAPACITY IS the main cause that prevents the possibility of having a steady material flow, and this results in today's high inventory level of the semi-finished goods. According to the purpose, the project aims to give BorgWarner the possibilities of a better material flow and a reduced inventory level. The characteristics of the desired future state is summarised below.

The future state: The desired future state is to reach a flow production with no inventory of semi-finished goods, which is a pure JIT-type production. The costs of the change are desired to be minimal, preferable zero. If a JIT-type production with a Kanban system is not possible, motivated investments that are profitable and reduces the inventory level and the cost of salary can be done.

5.1 Calculations of production related variables

The following section describes calculations of the variables used to determine profitability in different scenarios.

5.1.1 Machine cost

Investing in new machines entails not just the cost of the actual machine, but also time for installation which is counted for as 80 man hours per machine. The installation time is just counted for in terms of hourly salary of an operator, since the machining processing time wont be reduced because of the installation. In other words, no production needs to be re-scheduled because of the installation of a new machine. A detailed overview can be seen in Table A.1, A.

5.1.2 Fixture cost

It may be necessary to invest in new fixtures for the existing machines to increase the flexibility or similar. Depending on what fixture is to be bought, the product requires either one or two fixtures in the machine. The time difference between installing one or two fixtures is so small that installation time is assumed to be the same.

In the case where new fixtures are bought for new machines, the setup time is not counted for since no production needs to be re-scheduled because of the installation of a new fixture onto a new machine. In the other case where the fixture is installed onto an existing machine, the current machine processing needs to be re-scheduled to weekends since the installation time of a new fixture often takes 10 weekdays. For every new fixture or pair of fixtures that is bought, one set of tools needs to be bought as well.

A detailed view of the cost calculation is described in Table 5.1 where the tool and fixture cost are set different for each product. The number of new fixtures is determined to cover the demand which varies depending on scenario. The setup time is represented by the downtime and is counted for as 80 man hours per fixture or pair of fixtures. The hourly setup cost is described in detail in a subsection below.

Table 5.1 Installation times and costs for different fixtures.

Product	Installation time [weekdays]	Fixture Cost [kr/st]	Tool Cost [kr/st]
BMW	10	457 650	260 620
VCC	10	409 500	307 033
VW	10	370 800	322 553
FXD I	10	353 250	241 129
FXD II	10	388 800	339 388
Lambo	20	412 155	376 419
TTRS	10	370 800	322 553
Org.I.	10	310 500	348 775
Eps	10	370 800	322 553

5.1.3 Setup cost

Setup cost is calculated by adding the costs for the hourly depreciation with the hourly salary costs and multiply this with the downtime due to the setup. An assumption regarding no lost sales is done since BorgWarner re-schedules the production to weekends to able to maintain the requested weekly volumes.

The depreciation cost is calculated by dividing the machine cost by the depreciation time which is stated in the company policies as seven years. The annual cost is divided by 48 weeks and 125,8 hours per week to get a hourly depreciation cost.

The salary cost includes costs for both operators and maintenance technicians. The staffing is assumed to be on person per machine during one hour, based on the clients data. Currently it is almost twice as expensive to staff during weekends rather that during weekdays. To get a realistic number of the cost for moving weekday production to weekends, the setup cost is multiplied with a factor of 2.5. See Appendix B.

5.1.4 Inventory level and Inventory cost

To get a realistic value of the inventory level during the last quarter, week 47 has been used to show the distribution of the products during each shift during a fully utilized week. By using the processing forecast for the last quarter represent a reference week, it is ensured that the capacity will be enough even when the production pressure is at its maximum. The risk of taking a mean value of weeks with many scheduled stops will generate an average week with unrealistic low production volume.

By applying the product distribution from week 47 onto the reference week results in a good assumption over the amount of each product during each shift. A summarise of the reference week is shown in Table 5.2 where every products weekly volume can be deducted. The tale orgin can be seen in Appendix A.

Table 5.2 Product volumes in the reference week.

Product	Machine	Weekly production	
		per machine	per product
Eps	M3	385	385
Eps	M4	0	
VCC	M1	2 849	
VCC	M3	1 724	7 421
VCC	M4	2 849	
TTRS	M9	843	843
VW	M2	2 946	
VW	M5	2 946	
VW	M6	2 946	12 225
VW	M8	0	
VW	M9	2 103	
VW	M10	1 284	
Org. I.	M7	383	383
FXD I	M10	690	690
FXD II	M7	483	707
FXD II	M10	224	
Lambo	M7	15	15
BMW	M8	1 647	1 647
		24 317	**24 317**

To determine the inventory level of today's production, the safety stock and the buffer needs to be known. The client wants the safety stock to cover two days of sales, i.e. two days of assembling. The production during the reference week has been divided with five days and then multiplied with two to represent the safety stock. A detailed view of the reference week can be seen in Appendix Table A.2 and shows that the weekend production for each product has been used to represent the buffer. A graph describing the inventory level during one week of today's production together with a consolidated table of the inventory level in the beginning of the week is shown in Table 5.3 and visualised in Figure 4.5.

Table 5.3 Detailed inventory levels.

Product	Machines	Safety stock	Weekend processing	Start level inventory
BMW	M8	659	363	1022
FXD I	M10	276	0	276
FXD II	M7	193	91	284
FXD II	M10	88	121	209
Org. I.	M7	153	0	153
TTRS	M9	337	0	337
VCC	M1	1140	628	1767
VCC	M3	689	628	1317
VCC	M4	1140	628	1767
Lambo	M7	6	15	21
VW	M2	1178	650	1828
VW	M5	1178	650	1828
VW	M6	1178	650	1828
VW	M8	0	0	0
VW	M9	841	650	1491
VW	M10	513	286	799
		9 570	**5 358**	**14 928**

The inventory cost of today's production is determined by multiplying the product value of each product with the amount of each product that can be seen in the detailed table of inventory in Appendix C. Table 5.4 describes the cost of the safety stock and the buffer for each product.

Table 5.4 Inventory holding cost for safety stock and buffer. Censored due to confidentiality.

Product	Safety stock [SEK]	Buffert [SEK]
VCC	[illegible]	[illegible]
TTRS	[illegible]	[illegible]
VW	[illegible]	[illegible]
BMW	[illegible]	[illegible]
FXD I	[illegible]	[illegible]
FXD II	[illegible]	[illegible]
Lambo	[illegible]	[illegible]
Org.I	[illegible]	[illegible]
	[illegible]	[illegible]

5.1.5 Scenarios

The methodology for achieving the desired future state mentioned in section 2.7 is to develop different solution scenarios with various approaches. Scenarios will be evaluated and analysed with respect to eventual investment costs together with salary and inventory reductions. The first scenario is based on the client's request and investigates the required efforts for introducing a Kanban system. The other main scenario investigates the possibility of planning the production with a rotation cycle policy, an adjustment with no required investments. The result of these scenarios will provide the directions for the following suggestions.

One part of the analysis will be based on empirical data from the near future. A second part, one or several scenarios will be made of forecasted volumes over the three next years.

Scenario 1 - Implementing Kanban

As mentioned above, the first scenario creates a JIT-type production flow and an ability to implement a well functioning Kanban system, since BorgWarner's current Kanban system is not working in a preferable way. The advantages of a Kanban system is the absence of manual production planning, since the built-in card system handles the planning itself. To be able to accomplish this case, the parts manufacturing and the assembly needs to keep the same pace during the same period of time, which is five days a week. Since the assembly has a higher capacity than the parts manufacturing, investments in the parts manufacturing needs to be done.

According to instructions from the client, the flexibility of the assembly can be seen as the demand. Using a Kanban system requires that whenever a demand occurs, the production must be able to meet the demand. In BorgWarner's case, this means that the parts manufacturing needs to be able to produce each combination of products that the assembly asks for. It should be noted that the maximum production capacity of the assembly sets up the requirements for the sizing of the capacity in the parts manufacturing. The actual customer demand is not relevant in this scenario.

Today's material movement can roughly be divided in to two separate production flows due to the product distribution within the assembly lines in the production, see Table 4.1. To maintain a high level of flexibility in the production, the parts manufacturing will be divided into two separate resources that will supply the assembly lines. The first resource will feed assembly lines 7, 9 and 10 and the second creates a separate flow to line 8. An advantage of the sectioning will be low investment costs compared to if the parts manufacturing was used as one resource, since it would require even more machines and more fixtures. The independence between the two flows might effect the risk of production downtime, but with the investment cost and historical data in mind this is considered as an irrelevant risk. A well functioning Kanban system as the one described requires investments in new machines and new fixtures. With the required investments, the inventory buffer and the weekend production is eliminated, which results in annual savings. The investment costs, the annual savings and the resulting pay back time are compiled below. For more detailed calculations, see Appendix B.

Costs, new machines	32 176 000 kr
Costs, new fixtures	19 062 947 kr
Savings, reduced inventory holding cost	48 707 kr/year
Savings, eliminated weekend production	2 128 143 kr/year
Pay back time	23,5 years

A visualisation of the scenario with the Kanban system with new invested machines is shown in Figure 5.1.

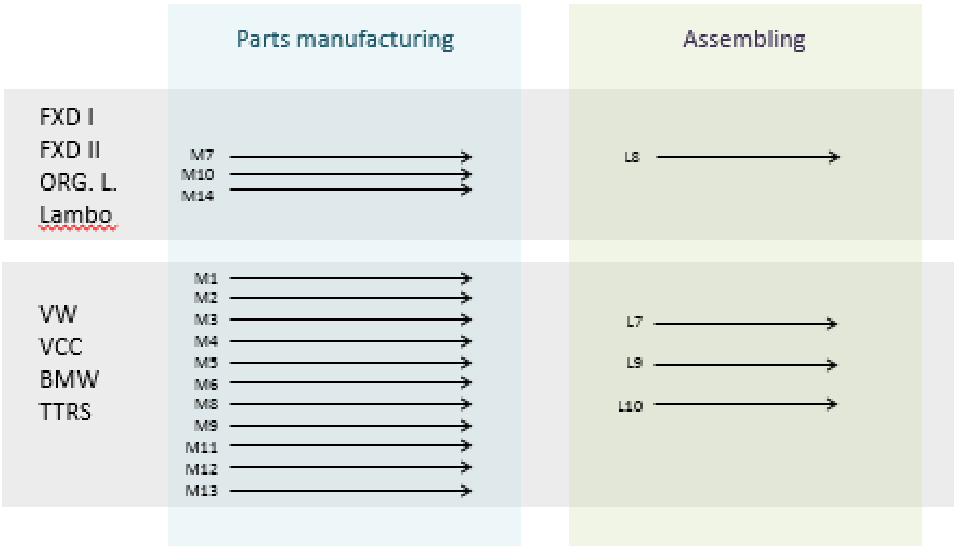


Figure 5.1 Illustration of two flow Kanban system.

Analysis
The main issue when analysing an investment assessment is always whether the benefits are large enough to consider the disadvantages. Investment in the scenario generates annual salary savings worth more that 2 000 000 SEK since the weekend production is eliminated. The investment also reduces the average inventory level of nearly 3000 products worth almost 50 000 SEK, which represents the average inventory buffer. In a scenario where Kanban is implemented, a reduced safety stock should be possible. Today's safety stock is determined by BorgWarner and is outside the delimitations of the project, while a halved safety stock would just generate savings worth 80 000 SEK. This calculations testify that the savings in salary costs for unsocial hours when the weekend production is eliminated is of much greater importance than the saved cost of reduced inventory.

It should be noted that the Kanban system requires investments above the real customer demand to obtain high flexibility and be able to meet the demand, despite the fact that the machines are not fully utilized. According to the investments and savings stated above, the pay back time is excessively long for BorgWarner, which is the reason why this scenario is rejected.

Scenario 2 - Rotation Cycle Policy
Different from the first scenario, the second scenario will exclude investments and just planning will be done. The planning will be done according to a rotation cyclic policy, where each machine in the parts manufacturing that produce more than one model will be assigned an optimal cycle time. An optimal cycle time takes change over cost, inventory cost, demand and operation time in to consideration, for each product in the parts manufacturing. Machines in the parts manufacturing will all have different optimal cycle times with respect to the cost and capacity. As mentioned in the theory section, a minimum cycle time with respect to the capacity of the limited recourse will be determined.

Implementing rotation cycle policy to today's volume at BorgWarner will effect machine 3, 7, 8, 9 and 10 since these are machines that processes more than one product. Long cycles indicates that it is expensive with setups and less expensive to hold inventory. Short cycle times indicates that the inventory and change over cost is low but the result of short cycles generates more frequent changeovers, which will higher the cost in the long term. Unlike the short cycles, the longer cycles generates a lower cost in the long term.

Reschedule according to the rotation cyclic policy will result in a production where the total cost for change over and inventory will be as low as possible for BorgWarner. The result of the investigation do not necessarily need to generate a reduced inventory level, it provides the study with the most optimal production cycle with respect to the existing conditions. Depending on the results of a rotation cycle policy, this scenario can be used to evaluate or improve today's inventory. The results is stated in Table 5.5.

Table 5.5 Cycle times.

Machine	T^* [h]	T_{min} [h]	T_{opt} [h]
M1	-	-	-
M2	-	-1,08	-
M3	9,87	5,21	9,87
M4	-	-	-
M5	-	-	-
M6	-	-	-
M7	2,34	-0,29	2,34
M8	22,43	12,63	22,43
M9	6,79	12,92	12,92
M10	6,58	19,35	19,35

Analysis
By using the cycle times from Table 5.5 together with each cycle quantity, the optimal average inventory level can be calculated of today's production at BorgWarner, see detailed view in Appendix C. The rotation cycle policy results in an average inventory level just under 16 000 products, which is slightly higher than the current average inventory level just under 15 000 products. The small difference in volume indicates that the current level of inventory is at a good level and should not be modified. One reason for this is the low inventory holding cost and the relatively high set up costs.

It should be noted that this scenario is a theoretical way of evaluating the problem and there might be other solutions that are more suitable in practice. This solution does not take the lack of warehouse space into consideration since this is a fact without a price tag.

Scenario 3 - Manual planning
Based on the two previous scenarios the following proposal is done. The scenario investigates another possibility of planning without any investments. In opposite to a rotation cycle policy, the products are rescheduled manually. Products with a high production rate builds up a higher inventory level and will therefore be scheduled to weekdays. Products with a low production rate does not produce as much products as the ones with higher production rate and will be scheduled during weekends.

Currently, BorgWarner does not takes this fact into account in their weekly planning so the purpose of the planning is to reduce the level of built-up inventory buffer over the weekend.

Since no investment is going to be made in this scenario, it is only the machines that produces high rate products in combination with low rate products that will be affected of the planning. Machines that will be effected are machine 3 and 10. To evaluate the scenario, the produced volume for the specific machine will be translated into hours by using the production rates. The hours will be compared to the hours, during weekend and weekdays respectively. Products with low pace takes up more time than 27.7 hours that is available during a weekend, these will be scheduled backwards from Friday evening to Monday. The purpose of the scenario is to reduce high rate products during weekends to the greatest extent possible.

The result of this scenario is a reduction of the inventory level according to Figure 5.2 to the right. The annual savings in reduced inventory holding costs are 11 108 kr. The changed inventory levels for each product is compiled in Table 5.6 to the right.

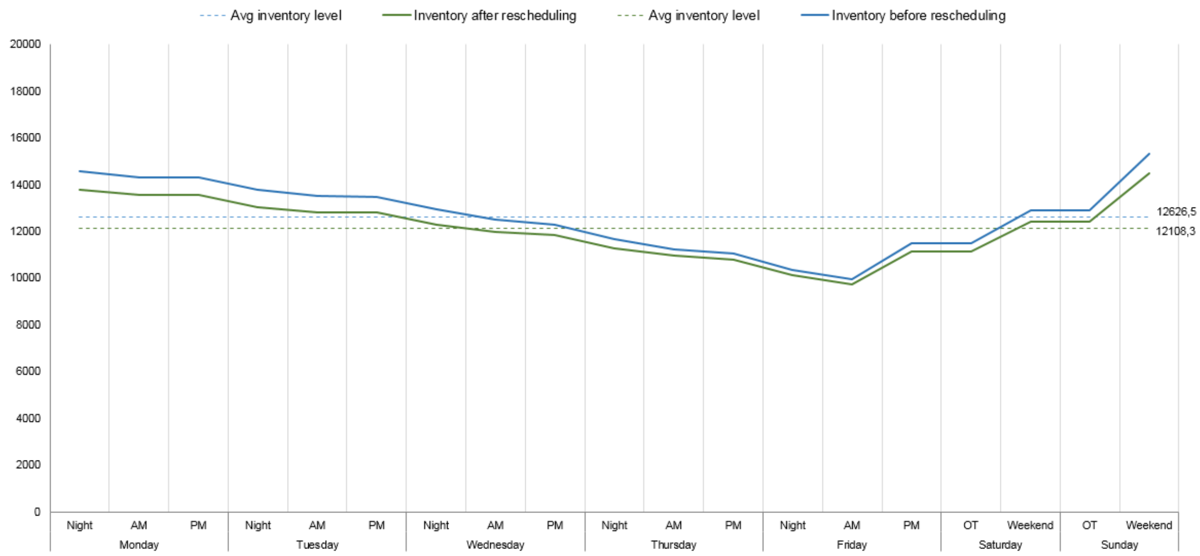


Figure 5.2 Difference in inventory level

Table 5.6 Savings due to planning.

Article	Before Rescheduling	After Rescheduling	Inventory difference	Cost savings
BMW	1021,60	1021,60	0,00	0,00
FXD I	275,86	276,17	0,31	0,00
FXD II	283,79	283,79	0,00	0,00
FXD II	208,62	308,74	100,13	3 088,05
Org. I.	153,32	153,32	0,00	0,00
TTRS	337,09	337,09	0,00	0,00
VCC	1767,36	1767,36	0,00	0,00
VCC	1317,18	689,41	-627,77	-9 462,71
VCC	1767,36	1767,36	0,00	0,00
Lambo	21,32	21,32	0,00	0,00
VW	1828,28	1828,28	0,00	0,00
VW	1828,28	1828,28	0,00	0,00
VW	1828,28	1828,28	0,00	0,00
VW	0,00	0,00	0,00	0,00
VW	1491,19	1491,19	0,00	0,00
VW	798,81	513,42	-285,38	-4 732,82
			Total savings	**-11 107,49**

Analysis

As seen in Figure 5.2 the inventory will drop by reschedule the high rate products to weekends. The economic impact of planning according to this scenario are small but the effort required to implement the scenario is minimal.

As a further investigation of this scenario, a possible approach would have been to let all machines in the parts manufacturing produce products with a low rate on the weekend. This would reduce the inventory level much more, but as established earlier in the analysis, a profitable calculation is only achievable if the weekend production is eliminated when doing investments.

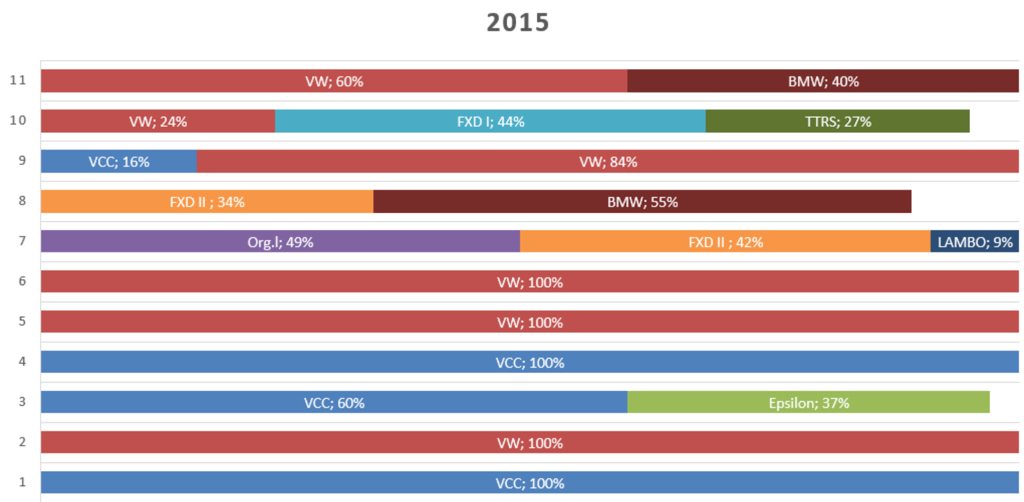
Scenario 4 – Equal capacity with MRP
According to the analysis in scenario 1 it is clear that a reduced inventory level must be combined with an eliminated weekend production to be economically viable. Of this reason this scenario should provide the parts manufacturing and the assembly an equal total capacity and a steady production flow.

The scenario will reschedule the parts manufacturing from working Monday to Sunday, to Monday to Friday and this will require investments. Different from Scenario 1, the investments in scenario 4 should provide the parts manufacturing the resources required for enable a MRP-production during weekdays.

The sizing of the capacity in the parts manufacturing is based on the actual customer demand of the products. The proposed scenario should ensure that each product can be produced during the weekdays. All individual product capacity requirements together gives the total capacity requirement.

Scheduling the products into the selected reference week manually results in how many new machines and fixtures is needed to satisfy the demand. Table 5.7 illustrates the schedule designed for a production week during 2015.

Table 5.7 Product distribution at each machine, 2015



This scenario require investments in one new machine in the parts manufacturing. The reduced inventory level and the elimination of the weekend production will be annual savings. The investment costs, the annual savings and the resulting pay back time are compiled below. In Appendix B a detailed view of the investment calculations can be regarded.

Costs, new machines	8 044 000 kr
Costs, new fixtures	1 295 133 kr
Savings, reduced inventory holding cost	48 707 kr/year
Savings, eliminated weekend production	2 128 143 kr/year
Pay back time	4,3 years

This scenario, based on data from 2015 is considered to be a relevant solution to the problem and will therefore be applied on data for the future years.

Scenario 4.1 – Long-term solution
In the long-term solution, the same methodology will be embraced as in scenario 4 since BorgWarner wishes for a solution based on a three year forecast. The given forecast is based on preliminary customer demands, provided from BorgWarner and since the demand is constantly increasing, a greater resource capacity will be necessary.

To be prepared for unpredicted events or planned stops 10 percent is added when calculating the time needed for the production. In Table 5.8 , the forecasted customer demand for 2016, 2017, 2018 is compiled.

Table 5.8 Forecasted customer demand

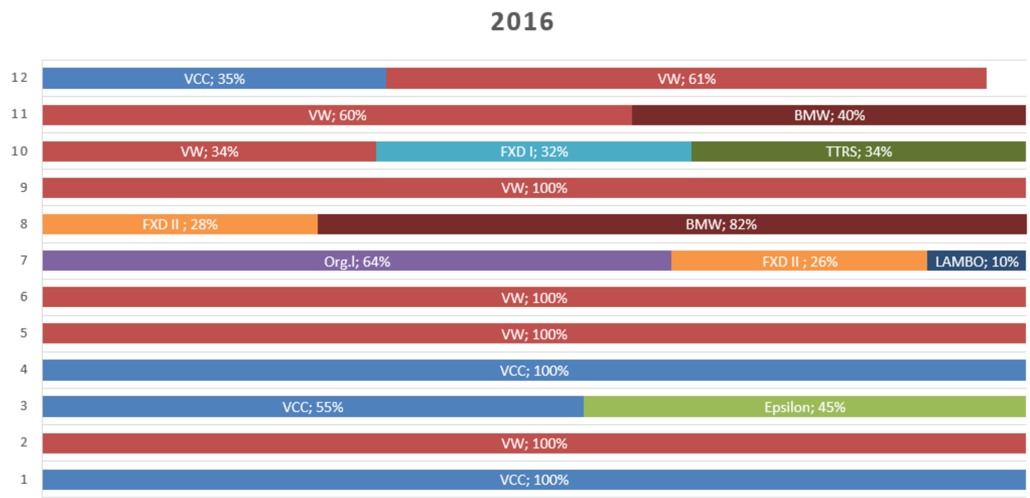
Product Type	Sum of 2016 Volume	Sum of 2017 Volume	Sum of 2018 Volume
BMW	132 880	154 000	160 000
Org.L	20 900	18 700	15 000
Volvo+LR	378 726	404 415	433 375
VW	647 063	825 130	858 263
TTRS	44 603	56 878	59 162
FXD I	20 995	27 500	25 000
FXD II	20 995	27 500	25 000
Lambo	731	731	731
EPSILON	19 800	13 200	13 200
Total products	**1 131 970**	**1 351 475**	**1 550 800**
Total products +10%	1 286 693	1 528 054	1 589 731

In the section below, distributions of products in the parts manufacturing is presented on yearly basis and constitutes the base for the investmenst of new equipment.

2016

Table 5.9 shows the product distribution of the products at the machines at 2016. The investments corresponds the following costs, see calculations below.

Table 5.9 Product distribution at each machine, 2016



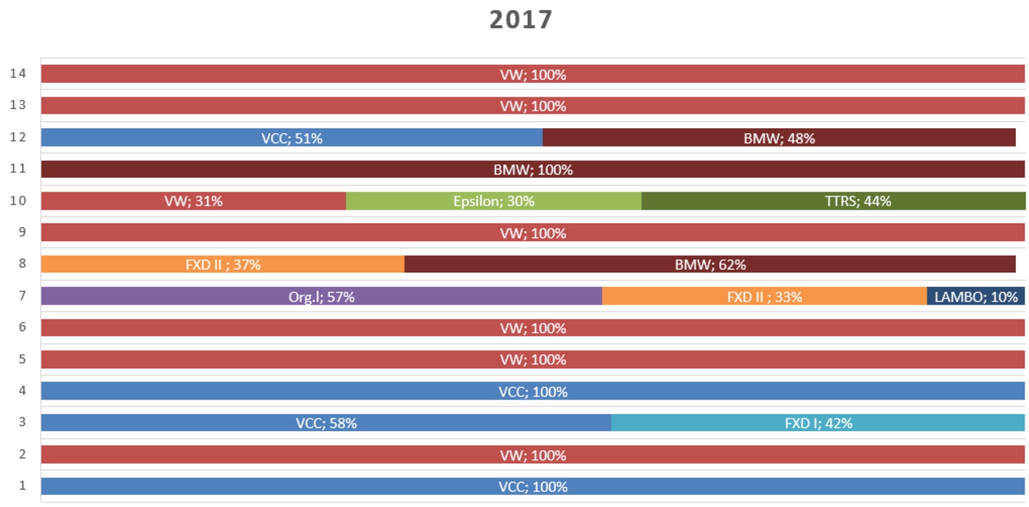
To be able to meet the required demand with a five-day production 2016, BorgWarner needs to invest one new machine in the parts manufacturing. The investment costs for 2016 are compiled below. Appendix B demonstrates a detailed view of the calculations of the costs can be regarded.

Costs, new machines	8 044 000 kr
Costs, new fixtures	0 kr
Total costs	8 044 000 kr

2017

Table 5.10 shows the product distribution of the products at the machines at 2017. The investments corresponds the following costs, see calculations below.

Table 5.10 Product distribution at each machine, 2017



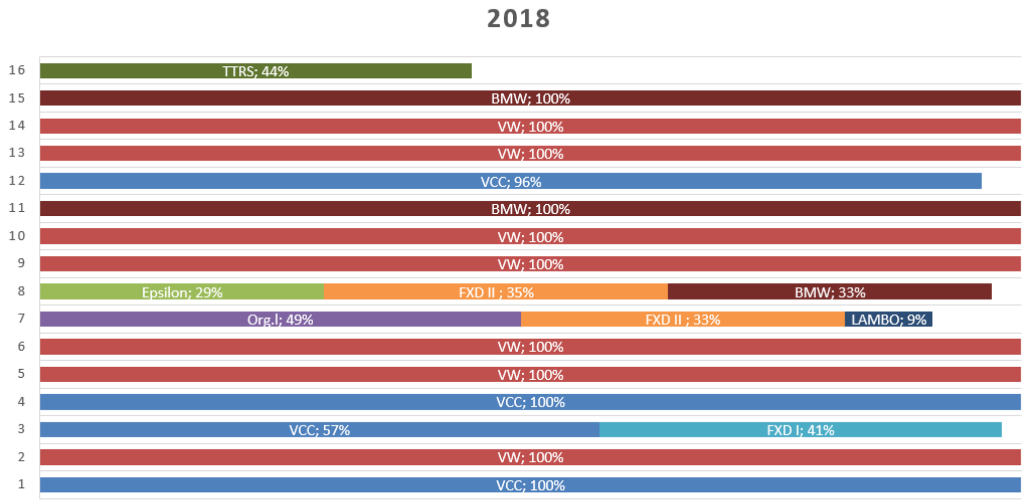
To be able to meet the required demand with a five-day production 2017, BorgWarner needs to invest two new machines and two new fixtures in the parts manufacturing. The investment costs for 2017 are compiled below. In Appendix B a detailed view of the investment calculations can be regarded.

Costs, new machines	16 088 000 kr
Costs, new fixtures	2 578 483 kr
Total costs	18 666 438 kr

2018

Table 5.11 shows the product distribution of the products at the machines at 2018. The investments corresponds the following costs, see calculations below.

Table 5.11 Product distribution at each machine, 2018



To be able to meet the required demand with a five-day production 2018, BorgWarner needs to invest two new machines in the parts manufacturing. The investment costs for 2018 are compiled below. Appendix B shows a detailed view of the investment calculations can be regarded.

Costs, new machines	16 088 000 kr
Costs, new fixtures	0 kr
Total costs	16 088 000 kr

Summary and analysis of the long-term solution

The investments 2015 can be regarded as investments for cost savings in terms of reducing the weekend production. Further investments the following years is done to meet the increasing customer demand. The investments is assumed to be motivated in the same way as the investments for an increasing customer demand for a 7-day production. The difference between the investment costs for a five-day production and for a seven-day production is compiled in Table 5.12. The extra annual costs for a five-day production will decrease the profit margin, but will in turn benefit the production flow.

Table 5.12 Investment calculations

Investments 5-day production		**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Cost savings	9 339 133	-1 334 162	-1 334 162	-1 334 162	-1 334 162	-1 334 162	-1 334 162	-1 334 162
Savings		2 128 144	2 128 144	2 128 144	2 128 144	2 128 144	2 128 144	2 128 144
Result		**793 982**	**793 982**	**793 982**	**793 982**	**793 982**	**793 982**	**793 982**
Volume increase			8 044 000	18 666 438	16 088 000			
Products			1 286 693	1 528 054	1 589 731			
Product value			**6,25**	**12,22**	**10,12**			

Investments 7-day production	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Volume increase			8 044 000	8 044 000	0	0	0
Products			1 528 054	1 589 731			
Product value			**5,26**	**5,06**			

A clear advantage of this solution is that no new material and capacity planning method needs to be implemented. To change essential working routines always implies a period of apprenticeship that ends up costing the the company money in the form of lost production time and extraordinary resources for training. This is avoided with in this solution since MRP already is implemented. This solution also implies the highest ulilization of the equipment as possible, something that is of great advantage from a manufacturing economic perspective.

An MRP-solution is a good alternative when the demand varies since the production schedule is done manually every week.

6

Conclusion

THIS CHAPTER AIMS TO PROVIDE BorgWarner a summary of the study results and a reconnection to the purpose and the problem discussion stated in the introduction chapter. The chapter consists discussion of different aspects of the problem and thoughts about the analysis. The conclusion ends up with a recommendation and proposals for further researches.

6.1 Discussion

The purpose with the study was to improve the material flow at BorgWarner and reduce the capital tied up in the semi-finished goods inventory. The process of developing different solution scenarios in order solve to the problem has provided insights about the area and answers to many questions regarding the problem.

The main problem with the large inventory is the fact that it takes up large space and prevents the production to have a good material flow. The inventory holding cost of the buffer that are built up during the weekend is a cost of around 50 000 kr per year, which is a quit small sum in context. To invest in new equipment in order to just reduce this inventory will never pay off if no other savings will be implemented in conjunction with this. During the project, the authors have realize the benefits with eliminate the weekend production. This would eliminate the inventory buffer in combination with reduced expenditures in form of costs for unsocial hours, savings of approximately 2 000 000 kr per year.

There are many positive effects when reducing the production during the weekend. The flexibility is increasing in many aspects, something that can benefit BorgWarner in a range of situation. It is important to have available production time if something unpredictable happens or if any installations or other planned stops need to be done. With scheduled production time during the weekends, there are hardly any time left for these events. Large re-organisations such as extension of the machinery may take considerable time if there are lack of unplanned production time. But with available time during the weekend, these re-organisations can be done faster.

Another benefit with available space during the weekends is when temporary fluctuations in the demand occurs. First when the demand is stabilised, new investments needs to be done, instead of being forced to do rapid investments in purpose to meet the demand temporarily.

The impact of these aspects is not something the study takes into consideration when doing the calculations since it is too complex and therefore regarded as a limitation of the project. But the aspects is something BorgWarner should be aware of.

6.1.1 Data collections, delimitation and assumptions

The data used in this report are carefully evaluated and assured. The data in the production planning is taken from BorgWarners weekly planning in which the various production rates are those that the production planners are using when they do the scheduling. There are some difference between the assumed production rates and the actual production rates, but in all cases the actual rate is faster than the assumed one. In this report, the assumed rate is the rate that all the calculations are based on. This compensate for various uncertainties and ensures the credibility of the results.

Another data that has been used in the report, for example production-related costs, is assured by various employees of BorgWarner and ultimately by the supervisor at BorgWarner, Johan Cederfeldt. Elections of data and assumptions that's been necessary to make has always been discussed and approved by Johan Cederfeldt.

The delimitation's that have been made during the report has been necessary to carry out the study for 20 weeks and the main delimitation's are developed by BorgWarner themselves. The assumption that the washing and leak testing has enough capacity to handle the potential volume increases is something that should be reviewed in the event of a further study of this paper. But the investment costs in a higher capacity in the wash and the leakage test is on the other hand much lower than for the parts manufacturing. Of that reason, possible extra costs for this would just affect the result slightly.

6.2 Recommendation

The only way of improving the material flow in an economically justifiable way is to eliminate the production during the weekend. The best way of doing this is to follow the investment proposal according to scenario 4 and then follow the accompanying long-term solution.

If BorgWarner do not want to do any investments at all, the best scenario to follow is scenario 3. The effects of this scenario is a small reduction of the inventory level but no improvements of the material flow.

6.3 Further research

This Master thesis can be regarded as a preliminary study to the problem. Before implementing the recommendations from the authors, BorgWarner has to perform further investigation and calculations of possible costs and the aspects mentioned in Section 6.1.

A further research BorgWarnet needs to investigate is the effects of an increasing inventory buffer as a result of an ongoing weekend production. Will BorgWarner reach the point where the inventory level is too high to fit in their own warehouse? Outsourcing the inventory is an expensive solution in many aspects, such as warehouse hire, material handling, transport, administration etc.

It is valuable to have defined Key Performance Indexes within the company, i.e. the cost of one downtime hour or different production rates. A recommendation of a further research from the authors is to develop well known KPIs which all employees are aware about. This will engage the employees in the improvement work and enrich them with an over all understanding of the organisation.

References

Axsäter, S. (2006). *Inventory control.* New York: Springer. ISBN: 978-0387332505.

BorgWarner Inc (2015). *The Company.* URL: http://http://www.borgwarner.com/en/Company/default.aspx. Accessed: 2015-08-11.

Cederfeldt, J. *Inventory levels.* Personal interview. Landskrona, 2015-05-21.

Hej (2015). *Teknisk Tidskrift.* URL: http://runeberg.org/tektid/1960/1205.html. Accessed: 2015-08-11.

Höst, M., Regnell, B. and Runesson, P. (2006). *Att genomföra examensarbete.* Lund: Studentlitteratur. ISBN: 978-91-44-00521-8.

Lekvall, P (2001). *Information för marknadsföringsbeslut.* Göteborg: IHM Publ. ISBN: 978-91-86-46085-3.

Manikas, A, Guptaa, M and Boyda, L (2014). "Experiential exercises with four production planning and control systems". *International Journal of Production Research* 53, pp. 4206–4217. DOI: 10.1080/00207543.2014.985393.

Nicholas, J. (1998). *Competitive Manufacturing Management: Continuous Improvement.* Boston: Irwin/McGraw-Hill. ISBN: 0-256-21727-0.

Olhager, J. (1989). *Produktionsekonomi: Principer och metoder för utformning, styrning och utveckling av industriell produktion.* Lund: Studentlitteratur. ISBN: 978-91-44-06766-7.

Sandras, W. (1989). *Just-in-Time: Making It Happen: Unleashing the Power of Continuous Improvement.* New York: John Wiley & Sons. ISBN: 0-471-13266-7.

Soiferman, L. K. (2010). *Compare and Contrast Inductive and Deductive Research Approaches.* Tech. rep. University of Manitoba.

Ståhl, J. (2012). *Industriella tillverkningssystem, Del II - Länken mellan teknik och ekonomi.* 2nd. Lund: Longman.

The Productivity Press Development Team (2002). *Kanban for the shopfloor.* Portland, Or: Productivity Press. ISBN: 9781563272691.

Yamashina, H., Arnström, A. and Gröndahl, P. (1982). *Japansk tillverkningsfilosofi och Kanban-systemet.* Stockholm: Sveriges Mekanförbund. ISBN: 91-524-0638-5.

Zammori, F, Braglia, M and Frosolini, M (2011). "Stochastic overall equipment effectiveness". *International Journal of Production Research (Impact Factor: 1.32)* 49, pp. 6469–6490. DOI: 10.1080/00207543.2010.519358.

A

Production weeks

Table A.1 Reference week, production plan

	Ref. week	Mo 6,6 Night	Mo 7 AM	Mo 8,1 PM	Tu 5,8 Night	Tu 7 AM	Tu 8,1 PM	We 5,8 Night	We 7 AM	We 8,1 PM	Th 5,8 Night	Th 7 AM	Th 8,5 PM	Fr 5,8 Night	Fr 7,5 Am	Fr 8 Weekend	Sa 6,5 OT	Sa 7,5 Weekend	Su 6,5 OT	Su 12,2 Weekend	Reference week Products	Reference week Total	Mo-Fr	Weekend	Hours
Eps	M3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	54,15	62,61	44,84	54,15	66,00	44,84	58,38	0,00	0,00	0,00	0,00	0,00	384,98	384,98	384,98	0,00	41,62
	M4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00				
VCC	M1	149,76	158,22	183,61	131,15	158,22	183,61	131,15	158,22	183,61	131,15	158,22	192,91	131,15	170,07	181,07	0,00	170,07	0,00	276,68	2848,86		2221,05	627,82	102,66
	M3	149,76	158,22	183,61	131,15	158,22	183,61	131,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	181,07	0,00	170,07	0,00	276,68	1723,53	7421,26	1095,72	627,82	62,11
	M4	149,76	158,22	183,61	131,15	158,22	183,61	131,15	158,22	183,61	131,15	158,22	192,91	131,15	170,07	181,07	0,00	170,07	0,00	276,68	2848,86		2221,05	627,82	102,66
TTRS	M9	0,00	164,15	189,53	135,38	164,15	189,53	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	842,73	842,73	842,73	0,00	30,37
VW	M2	154,84	164,15	189,53	135,38	164,15	189,53	135,38	164,15	189,53	135,38	164,15	198,84	135,38	175,99	187,84	0,00	175,99	0,00	285,99	2946,17		2296,35	649,81	106,17
	M5	154,84	164,15	189,53	135,38	164,15	189,53	135,38	164,15	189,53	135,38	164,15	198,84	135,38	175,99	187,84	0,00	175,99	0,00	285,99	2946,17		2296,35	649,81	106,17
	M6	154,84	164,15	189,53	135,38	164,15	189,53	135,38	164,15	189,53	135,38	164,15	198,84	135,38	175,99	187,84	0,00	175,99	0,00	285,99	2946,17	12225,49	2296,35	649,81	106,17
	M8	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00
	M9	154,84	0,00	0,00	0,00	0,00	0,00	135,38	164,15	189,53	135,38	164,15	198,84	135,38	175,99	187,84	0,00	175,99	0,00	285,99	2103,44		1453,62	649,81	75,80
	M10	154,84	164,15	189,53	135,38	164,15	189,53	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	285,99	1283,55		997,57	285,99	46,25
Org. I.	M7	33,00	35,54	40,61	28,77	35,54	40,61	28,77	35,54	40,61	28,77	35,54	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	383,29	383,29	383,29	0,00	55,25
FXD I	M10	0,00	0,00	0,00	0,00	0,00	0,00	94,76	114,23	132,84	94,76	114,23	139,61	0,00	0,00	0,00	0,00	0,00	0,00	0,00	690,43	690,43	690,43	0,00	49,76
FXD II	M7	22,85	24,54	27,92	20,31	24,54	27,92	20,31	24,54	27,92	20,31	24,54	49,07	33,84	44,00	46,54	0,00	44,00	0,00	0,00	483,13	707,35	392,60	90,53	69,64
	M10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	44,84	58,38	62,61	0,00	58,38	0,00	0,00	224,22		103,23	120,99	23,09
Lambo	M7	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	15,23	15,23	15,23	0,00	15,23	9,98
BMW	M8	86,30	91,38	105,76	76,15	91,38	105,76	76,15	91,38	105,76	76,15	91,38	111,69	76,15	98,15	104,92	0,00	98,15	0,00	159,92	1646,54	1646,54	1283,55	362,98	105,95
																					24317,29	24317,29	18958,85	5358,43	1093,65

Table A.2 Week 47, production plan

	Week 47	Mo 6,6 Night	Mo 7 AM	Mo 8,1 PM	Tu 5,8 Night	Tu 7 AM	Tu 8,1 PM	We 5,8 Night	We 7 AM	We 8,1 PM	Th 5,8 Night	Th 7 AM	Th 8,5 PM	Fr 5,8 Night	Fr 7,5 Am	Fr 8 Weekend	Sa 6,5 OT	Sa 7,5 Weekend	Su 6,5 OT	Su 12,2 Weekend	Week 47 Products	Week 47 Total	Mo-Fr	Weekend	Hours
Eps	M3								64,00	74,00	53,00	64,00	78,00	53,00	69,00						455,00	455,00	455,00	0,00	49,19
	M4																				0,00				0,00
VCC	M1	177,00	187,00	217,00	155,00	187,00	217,00	155,00	187,00	217,00	155,00	187,00	228,00	155,00	201,00	214,00		201,00		327,00	3367,00		2625,00	742,00	364,00
	M3	177,00	187,00	217,00	155,00	187,00	217,00	155,00								214,00		201,00		327,00	2037,00	8771,00	1295,00	742,00	220,22
	M4	177,00	187,00	217,00	155,00	187,00	217,00	155,00	187,00	217,00	155,00	187,00	228,00	155,00	201,00	214,00		201,00		327,00	3367,00		2625,00	742,00	364,00
TTRS	M9		194,00	224,00	160,00	194,00	224,00														996,00	996,00	996,00	0,00	107,68
VW	M2	183,00	194,00	224,00	160,00	194,00	224,00	160,00	194,00	224,00	160,00	194,00	235,00	160,00	208,00	222,00		208,00		338,00	3482,00		2714,00	768,00	376,43
	M5	183,00	194,00	224,00	160,00	194,00	224,00	160,00	194,00	224,00	160,00	194,00	235,00	160,00	208,00	222,00		208,00		338,00	3482,00		2714,00	768,00	376,43
	M6	183,00	194,00	224,00	160,00	194,00	224,00	160,00	194,00	224,00	160,00	194,00	235,00	160,00	208,00	222,00		208,00		338,00	3482,00	14449,00	2714,00	768,00	376,43
	M8																				0,00		0,00	0,00	0,00
	M9	183,00						160,00	194,00	224,00	160,00	194,00	235,00	160,00	208,00	222,00		208,00		338,00	2486,00		1718,00	768,00	268,76
	M10	183,00	194,00	224,00	160,00	194,00	224,00													338,00	1517,00		1179,00	338,00	164,00
Org. I.	M7	39,00	42,00	48,00	34,00	42,00	48,00	34,00	42,00	48,00	34,00	42,00									453,00	453,00	453,00	0,00	48,97
FXD I	M10							112,00	135,00	157,00	112,00	135,00	165,00								816,00	816,00	816,00	0,00	88,22
FXD II	M7	27,00	29,00	33,00	24,00	29,00	33,00	24,00	29,00	33,00	24,00	29,00	58,00	40,00	52,00	55,00		52,00			571,00	836,00	464,00	107,00	61,73
	M10													53,00	69,00	74,00		69,00			265,00		122,00	143,00	28,65
Lambo	M7																			18,00	18,00	18,00	0,00	18,00	1,95
BMW	M8	102,00	108,00	125,00	90,00	108,00	125,00	90,00	108,00	125,00	90,00	108,00	132,00	90,00	116,00	124,00		116,00		189,00	1946,00	1946,00	1517,00	429,00	210,38
																					28740,00	28740,00	22407,00	6333,00	3107,03

B

Investments

Table B.1 Investments in new machines, Scenario 1 and 4.1

	Kanban	Long-term solution, based on Scenario 4		
	2015	2016	2017	2018
Number of prcoessing machines	10	11	12	14
Processing machines to cover the demand	0	12	14	12
Number of new machines	1	1	2	2
Cost processing machine	8 000 000	8 000 000	8 000 000	8 000 000
Installation time	80	80	80	80
Wage cost	550	550	550	550
Cost new machine	**8 044 000**	**8 044 000**	**8 044 000**	**16 088 000**
Total Cost Processing Machines	**8 044 000**	**8 044 000**	**16 088 000**	**16 088 000**

Table B.2 Investments in new fixtures, Scenario 1

Parameters	Unit	VCC	VW	BMW	TTRS	FXD I	FXD II	Org.L.	Lambo	Epsilon
Assembling rate	[st/h]	75,00	75,00	68,00	75,00	11,84	11,84	19,50	0,00	0,00
Number of assembly Lines	[st]	2,00	3,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Total assembling rate	[st/h]	150,00	225,00	68,00	75,00	11,84	11,84	19,50	0,00	0,00
Processing rate	[st/h]	30,00	30,00	16,80	30,00	15,00	9,00	7,50	1,65	10,00
Number of available processing machines	[st]	3,00	6,00	1,00	1,00	1,00	2,00	1,00	1,00	2,00
Total processing rate	[st/h]	90,00	180,00	16,80	30,00	15,00	18,00	7,50	1,65	20,00
Machines to cover the assembly Lines	[st]	5,00	8,00	5,00	3,00	1,00	2,00	3,00	0,00	0,00
Machines to fullfill Kanban	[st]	8,00	8,00	5,00	3,00	1,00	2,00	3,00	0,00	0,00
Number of machines to be provided	[st]	5,00	2,00	4,00	2,00	0,00	0,00	2,00	0,00	0,00
Number of new tools	[st]	5,00	2,00	4,00	2,00	0,00	0,00	2,00	0,00	0,00
Tool cost	[kr/st]	307 033,00	322 553,00	260 620,00	322 553,00	241 129,00	339 388,00	348 775,00	376 419,00	318 583,00
Total Tool cost		**1 535 165,00**	**645 106,00**	**1 042 480,00**	**645 106,00**	**0,00**	**0,00**	**697 550,00**	**0,00**	**0,00**
Number of new fixtures	[st]	10,00	4,00	8,00	4,00	0,00	0,00	4,00	0,00	0,00
Fixture cost	[kr/st]	414 050,00	374 920,00	462 735,00	374 920,00	357 175,00	393 120,00	313 950,00	416 734,50	374 920,00
Pair? (1=no, 2=yes)		2,00	2,00	2,00	2,00	1,00	2,00	2,00	2,00	2,00
Total Fixture cost		**4 140 500,00**	**1 499 680,00**	**3 701 880,00**	**1 499 680,00**	**0,00**	**0,00**	**1 255 800,00**	**0,00**	**0,00**
Hourly downtime cost	[kr/h]	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00
Downtime cost due to installatioin	[h/fixtur]	80,00	80,00	80,00	80,00	80,00	80,00	80,00	80,00	80,00
Downtime cost	[kr/fixtur]	80 000,00	80 000,00	80 000,00	80 000,00	160 000,00	80 000,00	80 000,00	80 000,00	80 000,00
Total Downtime cost		**800 000,00**	**320 000,00**	**640 000,00**	**320 000,00**	**0,00**	**0,00**	**320 000,00**	**0,00**	**0,00**
Total Cost		**6 475 665,00**	**2 464 786,00**	**5 384 360,00**	**2 464 786,00**	**0,00**	**0,00**	**2 273 350,00**	**0,00**	**0,00**

Table B.3 Investments in new fixtures, Scenario 4.1 – 2016

Parameters	Unit	VCC	VW	BMW	TTRS	FXD I	FXD II	Org.L.	Lambo	Epsilon
Assembling rate	[st/h]	7 890,12	13 480,49	2 768,33	929,24	437,39	437,39	435,42	15,23	412,50
Number of assembly Lines	[st]									
Total assembling rate	[st/h]	27,75	27,75	15,54	27,75	13,88	8,33	6,94	1,53	9,25
		284,33	485,78	178,14	33,49	31,52	52,54	62,76	9,98	44,59
Processing rate	[st/h]									
Number of available processing machines	[st]	98,10	98,10	98,10	98,10	98,10	98,10	98,10	98,10	98,10
Total processing rate	[st/h]	2,90	4,95	1,82	0,34	0,32	0,54	0,64	0,10	0,45
		3,00	5,00	2,00	1,00	1,00	1,00	1,00	1,00	1,00
Machines to cover the assembly Lines	[st]									
Machines to fullfill Kanban	[st]	4,00	6,00	2,00	1,00	1,00	2,00	1,00	1,00	1,00
Number of machines to be provided	[st]	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Number of new tools	[st]	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Tool cost	[kr/st]	307 033,00	322 553,00	260 620,00	322 553,00	241 129,00	339 388,00	348 775,00	376 419,00	318 583,00
Total Tool cost		**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Number of new fixtures	[st]	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fixture cost	[kr/st]	414 050,00	374 920,00	462 735,00	374 920,00	357 175,00	393 120,00	313 950,00	416 734,50	374 920,00
Pair? (1=no, 2=yes)		2,00	2,00	2,00	2,00	1,00	2,00	2,00	2,00	2,00
Total Fixture cost		**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Hourly downtime cost	[kr/h]	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00
Downtime cost due to installatioin	[h/fixtur]	80,00	80,00	80,00	80,00	80,00	80,00	80,00	80,00	80,00
Downtime cost	[kr/fixtur]	80 000,00	80 000,00	80 000,00	80 000,00	160 000,00	80 000,00	80 000,00	80 000,00	80 000,00
Total Downtime cost		**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Total Cost		**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**

Table B.4 Investments in new fixtures, Scenario 4.1 – 2017

Parameters	Unit	VCC	VW	BMW	TTRS	FXD I	FXD II	Org.L.	Lambo	Epsilon
Assembling rate	[st/h]	8 425,31	17 190,20	3 208,33	1 184,96	572,92	572,92	389,58	15,23	275,00
Number of assembly Lines	[st]									
Total assembling rate	[st/h]	27,75	27,75	15,54	27,75	13,88	8,33	6,94	1,53	9,25
		303,61	619,47	206,46	42,70	41,29	68,82	56,16	9,98	29,73
Processing rate	[st/h]									
Number of available processing machines	[st]	98,10	98,10	98,10	98,10	98,10	98,10	98,10	98,10	98,10
Total processing rate	[st/h]	3,09	6,31	2,10	0,44	0,42	0,70	0,57	0,10	0,30
		4,00	7,00	3,00	1,00	1,00	1,00	1,00	1,00	1,00
Machines to cover the assembly Lines	[st]									
Machines to fullfill Kanban	[st]	4,00	6,00	2,00	1,00	1,00	2,00	1,00	1,00	1,00
Number of machines to be provided	[st]	0,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Number of new tools	[st]	0,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Tool cost	[kr/st]	307 033,00	322 553,00	260 620,00	322 553,00	241 129,00	339 388,00	348 775,00	376 419,00	318 583,00
Total Tool cost		**0,00**	**322 553,00**	**260 620,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Number of new fixtures	[st]	0,00	2,00	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Fixture cost	[kr/st]	414 050,00	374 920,00	462 735,00	374 920,00	357 175,00	393 120,00	313 950,00	416 734,50	374 920,00
Pair? (1=no, 2=yes)		2,00	2,00	2,00	2,00	1,00	2,00	2,00	2,00	2,00
Total Fixture cost		**0,00**	**749 840,00**	**925 470,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Hourly downtime cost	[kr/h]	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00
Downtime cost due to installatioin	[h/fixtur]	80,00	80,00	80,00	80,00	80,00	80,00	80,00	80,00	80,00
Downtime cost	[kr/fixtur]	80 000,00	80 000,00	80 000,00	80 000,00	160 000,00	80 000,00	80 000,00	80 000,00	80 000,00
Total Downtime cost		**0,00**	**160 000,00**	**160 000,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Total Cost		**0,00**	**1 232 393,00**	**1 346 090,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**

Table B.5 Investments in new fixtures, Scenario 4.1 – 2018

Parameters	Unit	VCC	VW	BMW	TTRS	FXD I	FXD II	Org.L.	Lambo	Epsilon
Assembling rate	[st/h]	9 931,51	19 668,53	3 666,67	1 232,54	572,92	572,92	343,75	16,75	275,00
Number of assembly Lines	[st]									
Total assembling rate	[st/h]	28,68	28,68	16,06	28,68	14,34	8,60	7,17	1,58	9,56
		346,35	685,91	228,34	42,98	39,96	66,60	47,95	10,62	28,77
Processing rate	[st/h]									
Number of available processing machines	[st]	98,10	98,10	98,10	98,10	98,10	98,10	98,10	98,10	98,10
Total processing rate	[st/h]	3,53	6,99	2,33	0,44	0,41	0,68	0,49	0,11	0,29
		4,00	7,00	3,00	1,00	1,00	1,00	1,00	1,00	1,00
Machines to cover the assembly Lines	[st]									
Machines to fullfill Kanban	[st]	4,00	7,00	3,00	1,00	1,00	2,00	1,00	1,00	1,00
Number of machines to be provided	[st]	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Number of new tools	[st]	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Tool cost	[kr/st]	307 033,00	322 553,00	260 620,00	322 553,00	241 129,00	339 388,00	348 775,00	376 419,00	318 583,00
Total Tool cost		**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Number of new fixtures	[st]	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fixture cost	[kr/st]	414 050,00	374 920,00	462 735,00	374 920,00	357 175,00	393 120,00	313 950,00	416 734,50	374 920,00
Pair? (1=no, 2=yes)		2,00	2,00	2,00	2,00	1,00	2,00	2,00	2,00	2,00
Total Fixture cost		**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Hourly downtime cost	[kr/h]	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00	2 000,00
Downtime cost due to installatioin	[h/fixtur]	80,00	80,00	80,00	80,00	80,00	80,00	80,00	80,00	80,00
Downtime cost	[kr/fixtur]	80 000,00	80 000,00	80 000,00	80 000,00	160 000,00	80 000,00	80 000,00	80 000,00	80 000,00
Total Downtime cost		**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Total Cost		**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**

C

Inventory

Table C.1 Product inventory holding cost. Censored due to confidentiality.

	Product Value [kr/st]	Inventory Holding Cost [kr]
BMW	[illegible]	[illegible]
VCC	[illegible]	[illegible]
VW	[illegible]	[illegible]
FXD I	[illegible]	[illegible]
FXD II	[illegible]	[illegible]
LAMBO	[illegible]	[illegible]
TTRS	[illegible]	[illegible]
ORG.L	[illegible]	[illegible]
EPSILON	[illegible]	[illegible]

Table C.2 Change in inventory level due to Rotation Cycle Policy

Article	Machine	Average Weekly Sales	Production Days	Average Daily Sales	Safety Stock	Weekend Processing Before Rotation Cycle Policy	Weekend Processing After Rotation Cycle Policy	Safety Stock + Weekend Processing Before Rotation Cycle Policy	Safety Stock + Weekend Processing After Rotation Cycle Policy
BMW	M8	1647	5	329	659	363	363	1022	1021
FXD I	M10	690	5	138	276	0	152	276	428
FXD II	M7	483	5	97	193	91	106	284	300
FXD II	M10	219	5	44	88	121	49	209	137
Org. l.	M7	383	5	77	153	0	84	153	238
TTRS	M9	843	5	169	337	0	186	337	523
VCC	M1	2 849	5	570	1140	628	628	1767	1767
VCC	M3	1723	5	345	689	628	1265	1317	1954
VCC	M4	2 849	5	570	1140	628	628	1767	1767
Lambo	M7	15	5	3	6	15	3	21	9
VW	M2	2 946	5	589	1178	650	650	1828	1828
VW	M5	2 946	5	589	1178	650	650	1828	1828
VW	M6	2 946	5	589	1178	650	650	1828	1828
VW	M8	0	5	0	0	0	0	0	0
VW	M9	2 103	5	421	841	650	463	1491	1305
VW	M10	1282	5	256	513	286	283	799	795
								14 928	**15 729**