IMPROVING PRODUCTION PERFORMANCE

Bachelor Thesis

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Preface

This is the report for my bachelor thesis conducted for the bachelor Industrial Engineering & Management at the University of Twente. I have conducted my bachelor thesis at Power-Packer B.V. in Oldenzaal. I have investigated whether a new production strategy would improve the performance of the production.

First of all, I would like to thank my company supervisor Jaco Schmal for giving me this opportunity. Jaco has helped me very well during the thesis and I am very grateful for that. If I had questions, I could always ask for help, also in the busy, tough and difficult times. Thereby, the feedback he provided was always very useful. Alongside, I would like to thank all other employees at Power-Packer. Although I have not been there often, I had a good time when working there.

Secondly, I would like to thank my first supervisor at the university Marco Schutte for his guidance during the thesis. His feedback was very helpful and increased the level of the project a lot.

Lastly, I would like to thank my parents and roommates for their support during the thesis.

Maxim Bos, 2021

Management Summary

Introduction

Power-Packer B.V. produces hydraulic motion control systems. These systems are used for tilting, latching, levelling, lifting and stabilizing systems in demanding markets such as the automotive market. Power-Packer specializes in custom-made products for mobile applications with high quality. The project is to improve the performance of the production with a new internal production strategy.

Production strategies

The literature does not agree on what aspects belong to the term production strategy. However, the literature does agree that the core of all the production strategies are: cost, quality, delivery and flexibility. The research focuses on the operational production strategy, meaning that only internal resources are taken into account to improve the performance. The new production strategy is constructed, researching the aspects: product delivery strategy, layout systems and inventory systems.

Production delivery strategies

There are four main product delivery strategies: engineer to order, make to order, assemble to order and make to stock. These strategies are determined by the location of the customer order decoupling point (CODP). The CODP is the point where specifications of the product get frozen. Shifting the CODP in the production brings a trade-off between operational efficiency and flexibility of products. Prominent to the location of the CODP is the integration with the companies targets and goals.

Layout systems

An cellular manufacturing layout uses grouping technology to simplify the production. In a manufacturing cell, workstations are placed consecutive to create a product flow. Creating a flow in the production is normally better suited for larger volumes. Power-Packer currently uses a job shop environment, where batches of product move between workstations. A job shop is mostly used to produce lower volumes of unique products.

Inventory systems

Considered inventory systems for the production strategy are: a cyclic inventory, a safety inventory and a Kanban inventory system. The cyclic inventory orders products with a specific lot size when the inventory is empty. A safety inventory can be added to the cyclic inventory to cope with unexpected demand. The Kanban inventory system uses cards and boxes according to a just-in-time principle to reduce the work in progress.

Simulation and experimentation

Using simulation models, the new production strategy is tested if it would improve the performance of the production. The experiments show some promising outcomes regarding throughput times, utilisation and changeovers. Unfortunately, the target throughput per day is not reached by any experiment using the current given 77% efficiency.

Recommendation

In the test case, my recommendation is to improve the efficiency of the part of the production with a manufacturing cell operated by three employees. The cell improves the employees utilisation, reduces the throughput times and the work-in-progress. In addition, the production cost are lower and less inventory investments are needed. Implementing a manufacturing cell requires to improve on the test case efficiency. Otherwise, the target output is not reached and customer demand cannot be met.

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Chapter 1: Introduction

This chapter describes an overview of the project. Information about the company and why the project started. The chapter also discusses the approach to solve the problem.

- Section 1.1 introduces the company Power-Packer B.V.
- Section 1.2 discusses the research motivation
- Section 1.3 describes the problem to be solved
- Section 1.4 introduces the project
- Section 1.5 discusses the problem approach

1.1 The company

The bachelor graduation project is performed at Power-Packer B.V. in Oldenzaal. Power-Packer engineers and produces hydraulic position and motion control systems all over the world. These position and motion control systems are used for tilting, latching, levelling, lifting and stabilizing systems in demanding markets. Markets using Power-Packer position and motion control systems are for example automotive, medical and off-highway. By specializing in custom-made products for mobile applications, Power-Packer can deliver high-quality products such as cab-tilt and convertible rooftop systems. ("About Power-Packer," 2020)

1.2 Research motivation

In the production at Power-Packer, it is known that a large number of changeovers occur. The company suspects that these changeovers in production occur because of the customer order decoupling point being located in front of the production. The extension of products and markets strengthens the current high-mix low volume environment. Altering the production enables Power-Packer to produce in a long-term efficient way.

1.3 Problem description

The problem provided by the company is an inefficient production.

By participation in the production for two day parts, a good overview of problems at the production is constructed, gathering an understanding of the product and process. Figure 1 depicts the resulting problem cluster. Below figure 1 an explanation of the problem cluster is provided.

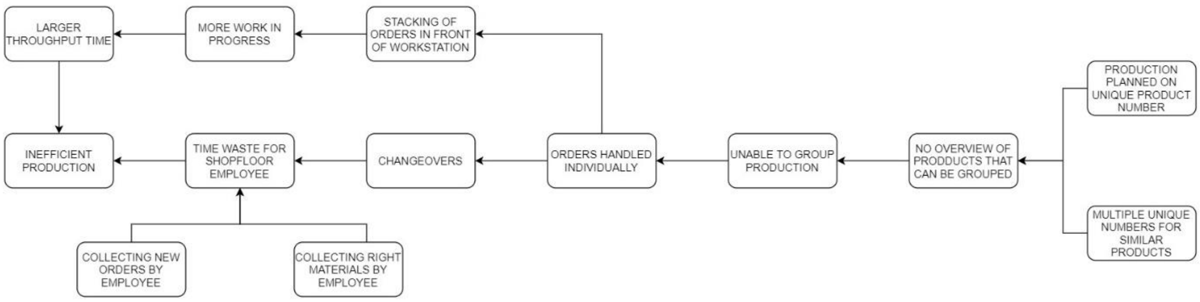

Figure 1: Problem cluster based on participation in production

The production planning is based on a unique product number. Because there are multiple product numbers for similar products and production planning is based on these product numbers, there is no overview of similarities within products. From this product number based planning, the production is not able to see what parts overlap in products to be produced. Therefore, the production cannot group the products. This results in products to be produced individually causing changeovers to occur.

Because of these changeovers, the employees on the shop floor must perform activities not related to producing the products. For example; during a changeover shopfloor employees collect the order and materials to produce the product. This is seen as time wasted for the shopfloor employees. Since the employees on the shopfloor must perform other non-operating activities, no producing activities are performed resulting in the inefficient production.

Because the orders are handled individually, each workstation operates one order at the time. This results in orders stacking up in front of the workstations. This is good for utilization of machines, because the machines are always supplied with products from the buffer. However, this inquires a lot of work-in-progress to be present. Furthermore, the stacking of orders before workstations results in a larger throughput time of products.

1.4 The project

The project is performed in the manufacturing engineering department. This project is created to increase the production performance. From the company, no limitations are set on what problem to handle in the current production.

The multiple product numbers for similar products is not solvable with research. Because Power-Packer is obligated to assign a different product number to every unique product. Even when the product differs slightly from another product, a new product number must be assigned to the product. Therefore, to improve the performance of the production, the problem to be solved is the planning of the production. However, altering the numbers in the planning requires the production to adapt the production process. For that reason, the project focuses on the overall internal production strategy.

The assignment performed for Power-Packer is:

"*Improve the production performance with a new internal production strategy"*

A full explanation on production strategies is provided in Section 3.1. The project focusses on how to improve the internal production strategy. The internal production strategy regards optimizing the resources at hand in the production. The production strategy is not changed to gain a competitive advantage, rather improving the use of the resources at hand.

By changing the production strategy, the production should improve on the performance. The performance of the production is measured with key performance indicators (KPI). These KPIs for the production are set in consultation with Power-Packer.

As is mentioned in Section 3.1, there is not a clear overview of what concepts belong to a production strategy. This project mostly focuses on the production layout and delivery strategy as part of the production strategy, also inventory systems are taken into account.

Section 1.5 presents the problem-solving approach used to solve the problem.

1.5 The problem approach and research design

To solve the action problem, the managerial problem-solving method (MPSM) is used. Figure 2 depicts the seven stages of the MPSM. In this research, the stages 1 to 5 are included which are explained below.

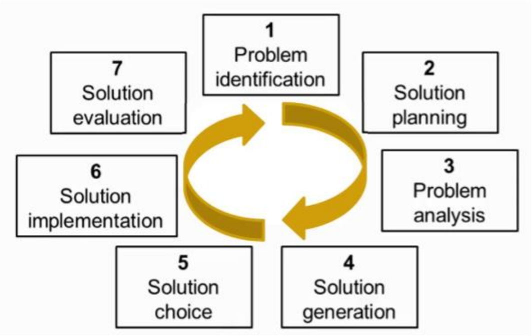

Figure 2: stages MPSM

Phases in problem approach and research design

The problem is solved according to five phases. For each phase, it is explained what is done in the phase. Thereafter, the main research question with sub-questions is presented. At last, an explanation of the data gathering method is provided.

Phase 1: Collect information on the product production at Power-Packer
In this phase information on the current production is gathered. Information on what products are produced as well as the production process are collected. Also, the modularity across the product range is assessed. This phase also looks how the production is planned.

To collect all this information, the following research question is created:

1) **How are the products currently produced at Power-Packer?**
   a. What is the production process of the products?
   b. How is the production planned?
   c. What is the product structure?
   d. To what extent share the product components/assemblies?

To find out this information, cooperation in the shopfloor is used to gain an overview of the current production process and the planning process as well as the strategy behind them. Here, the process can be observed and there are opportunities to ask questions to the shopfloor employees. Primary resources are analysed to gain an overview of the product structure and determine the modularity between products. This is discussed in Chapter 2.

Phase 2: Collect information on production strategies
This phase is used to gain knowledge about available production strategies. The first part is to determine what a production strategy actually is. Thereafter, research on product delivery systems, layout and inventory systems will be conducted before moving to the next phase.

To collect the information on the production strategies, the following research question will be used:

2) **What production strategies are available?**
   a. What is an production strategy?
   b. What production delivery systems are there?
   c. What layout systems can be used in the production?
   d. What inventory systems are there?

This information is collected through a literature study. This literature study gains insights into what way the production strategy can improve. This is important to create possible alternative solutions, phase 4 of the MPSM. The answer to this research question influences what solutions are modelled. Also, the information found during this literature study influences the conceptual model(s). Therefore, it is important to find good and reliable information by means of a systematic literature review. Chapter 3 discusses the literature study.

Phase 3: Create a conceptual model(s) for the production
In this phase, the conceptual model(s) for the production are developed. These conceptual models are based on the production strategies in phase 2. Also, the process and product structure found in phase 1 is used for the conceptual model(s). There are more solutions possible for Power-Packer that are interesting for research. In consultation with the company, and based upon characteristics of strategies, one or more of the solutions are chosen to be conceptually modelled for the simulation.

To construct the conceptual model, the following research question is constructed:

3) **What production strategy for the production could improve performance?**
    a. What delivery strategy is used?
    b. What layout system is used?
    c. What inventory system is used?

The conceptual model is needed to make a good simulation model. This is important to have a good verification. Furthermore, the conceptual model can be seen as a reference model for the eventual simulation model. For that reason, it is important to make a clear conceptual model so that all involved parties understand what the solution is going to look like. The conceptual model is constructed and explained in Chapter 4.

Phase 4: Create the simulation and perform experiments
In phase 4, the simulation model is modelled out of the conceptual model. To model this simulation model, the following research question is created:

4) **How would the production of Power-Packer perform with the new production strategy?**
    a. How to model the new production strategy?
        i. What KPIs are used in the model?
        ii. What simplifications can be made for the simulation model?
    b. What experiments are used to test the model?
    c. What are the results of the experiments?

In phase 4 the conceptual model in phase 3 is modelled into a simulation. The experiments needs to be performed in a valid way to make correct conclusions in phase 5. The experiments are also performed in this phase. In this way, the solutions get quantified in phase 4.

Input for the simulation model is determined using an analysis of primary resources. By communicating with Power-Packer and conducting interviews, outputs that need to be measured are determined. As well as what simplifications can be made in the conceptual model. The simulation model is discussed in Chapter 5. Chapter 6 discusses the outcomes of the experiments.

Phase 5: Conclusions on new production strategy
In this phase, conclusions based on the results in phase 4 are drawn. From these conclusions, an advise is presented to Power-Packer for the new production strategy. Lastly, a reflection on the project is provided.

5) **What production strategy is optimal for Power-Packer?**
    a. What conclusions from the experiments can be drawn?
    b. What production strategy is recommended for Power-Packer?
    c. What are limitations in the simulation model?

The advice on the production strategy for Power-Packer is given in phase 5. This advice is drawn from results during the experiments performed in phase 4. At last, the simulation model is discussed on limitations. Since these limitations can influence the outcome and accuracy of the simulation model. Chapter 7 discusses the final phase.

Chapter 2: Current production

This chapter discusses the current production process. This chapter gives an answer to the research question: “How are the products currently produced at Power-Packer?” To give an answer to this research question, the chapter is divided into the following sections:

- Section 2.1 describes the production process
- Section 2.2 describes how the production is planned
- Section 2.3 provides insight in the structure of the products
- Section 2.4 shows the modularity of the products regarding components, assemblies and workstations

When speaking about the production at Power-Packer, the entire production is meant from the beginning of the product to finishing the product. During the research, only the production before the paint shop is taken into account. In the production before the paint shop, workstations are located where one or more operating activities are performed. Because of confidentiality agreements the workstations are not named after the assemblies created at the workstations but given a letter. For example, workstation A or workstation L. The operating activities at the workstations can be done by hand, by a machine under supervision of a shopfloor employee or by a fully automated machine.

2.1 Production process of products

This section describes the process of the production. Because of confidentiality agreements with the company, a full description of the production process is not part of this report. Instead, a flow chart of the production with high level descriptions is given in figure 3. This flow chart shows which activities need to be performed to produce the end product. Left to figure 3, a small explanation of the process is provided. Relevant aspects of the production process are discussed later in this chapter.

The production starts with the pre-assembly where components are assembled that are used in workstation A, C and E. The pre-assembly consist of several workstations, but because this is the high level flow of the production these are not represented in figure 3. Workstation D is not dependent on parts processed in the pre-assembly. After workstation C and D a technical buffer is needed where the products must be stored for at least 2 hours. After the technical buffer, the products proceed to workstations E and F. After workstation F, the product is not yet finished, the product goes to the paint shop before fully completed, but this is not part of this project.

The production makes use of an job-shop layout and produces in batches. The job-shop layout is explained in more detail in Section 3.3. A batch consists of one unique product to be produced. The size of the batch can differ depending on the product ordered by the customer. Most of the batches produced in the production are of size Y, which is shown in Section 5.2.

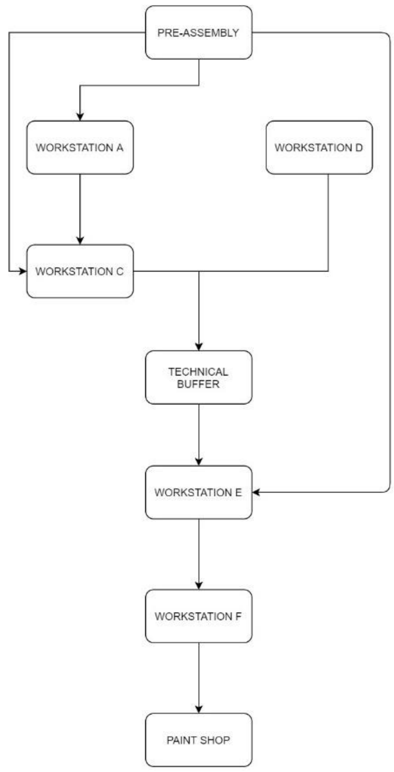

Figure 3: Flow chart production

2.2 Planning of the case study production process

Power-Packer uses two planning types. During this research, the two types are called an online and offline planning. This section provides an explanation on how the offline and online planning is constructed. What is being planned is also discussed in this section.

Offline

The offline planning Power-Packer uses comes from the ERP system of the company. The ERP system collects all known incoming orders and places the orders in a production plan. The production plan is based on the due date of an order and the utilization of the test bench.

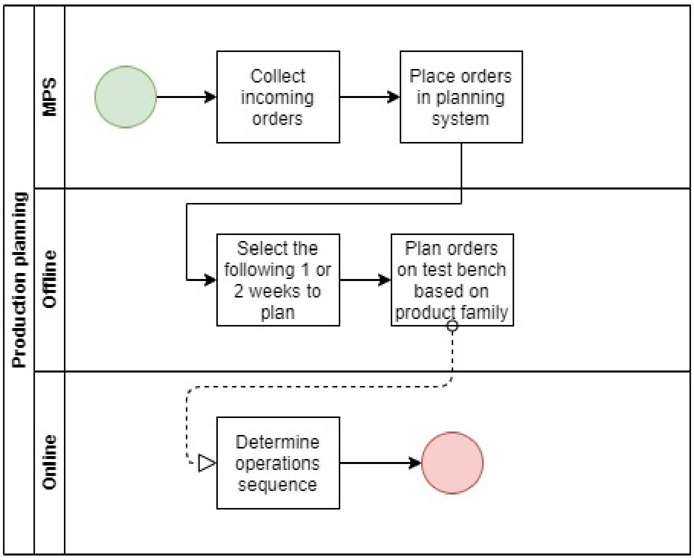

Figure 4: Planning process

Online

The online planning takes place during production. The production department receives the offline production plan for the following one or two weeks. The production team leader makes an own production plan derived from the offline planning.

Making this online production plan, the production team leader takes into account whether the order is Kanban and the due date of the order. Kanban is an inventory system used at Power-Packer. In case the order is not Kanban, it may be that assemblies are not in inventory. A more detailed description of Kanban can be found in Section 3.4.

Another task for the online planning is to plan the products on the test benches. All products produced are tested in a test bench at the shop floor. However, there are limited test benches available. To reduce the changeovers, the products are planned on the test benches. This is done based on product family types.

For example, when an product of family type A is planned on test bench 7. The goal is to plan a product from family type A on test bench 7 to reduce the number of changeovers.

The production team leader assigns one shopfloor employee to a production activity in the production. There is not a standard sequence in these activities. The sequence depends on the availability of shopfloor employees and the operations that are already performed on an order.

Figure 4 depicts the planning process in a flowchart. In table 1 an overview of the production planning levels is provided.

Planning level	***Concerns department***	***Typical horizon***	***Function***
Offline planning	Production	1-2 weeks	Determine which orders to produce
Online planning	Operations	1 day	Sequencing

Table 1: Production Planning Levels

Table 1 shows the difference between the online and offline planning. The offline planning has a larger timeframe with one to two weeks. While the online planning focuses on a single day regarding the sequencing of the operation activities to be performed. The online planning does not need to decide what products to produce, since this is already been done by the offline planning.

Planning orders

The planning is based on an order number. Although an order can consist of several products, only one product is planned at a time. This means that an order number can appear multiple times in the planning.

In case an order arrives with a size larger than Y, the order is split up into multiple smaller production orders in the planning with size Y. This is done for the production to cope with the size of the order. Because of physical constraints such as storage capacities in the production, it is not possible to handle an order with size larger than Y.

In the planning, the product number is assigned to an order. This product number is unique, which means that each product is assigned to a customer. This product number is used by shopfloor employees to search for components to be produced. Because the overarching product number is used, the shopfloor employee has no overview which components are shared within products in the planning.

2.3 Product structure

This section describes the product structure. The structure of the product is determined by the assemblies and components used in the product. An component is a single unique part used within assemblies. To create a new assembly, a component can be assembled to an already existing sub-assembly creating a new sub-assembly. Figure 5 presents an example of a possible assembly flow of a product where each block represents an assembly of the product.

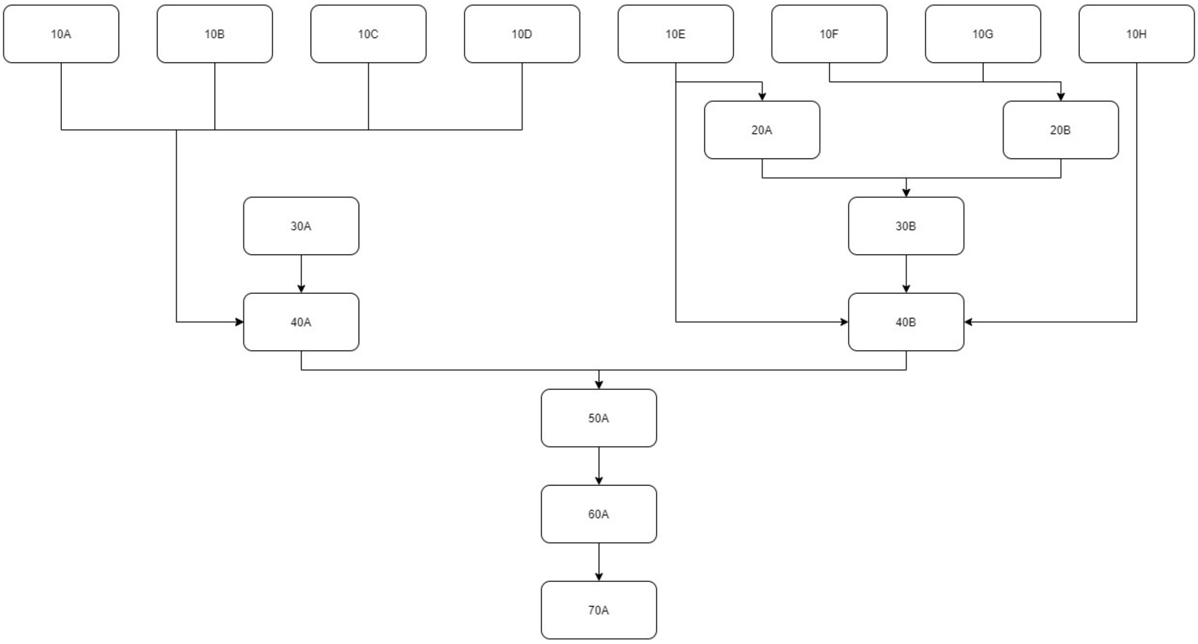

Figure 5: Assembly flow of the products at Power-Packer

Because of confidentiality agreements, the full description of the assemblies is not used. Instead, for an assembly, an number with an letter is used.

The number indicates the sequence in which the assembly is used. The production starts with the lowest number and ends with the highest number. In other words, an assembly with a lower number must be performed before an assembly with a higher number can start. The letter allows for differentiation between assemblies.

An example: The assemblies 10A and 10D are different assemblies. Both assemblies are used in assembly 40A. To start with assembly 40A, both assemblies 10A and 10D along with assemblies 10B, 10C and 30A must be performed because these have a lower number.

2.4 Modularity in the product sample

This section discusses the modularity of the product sample. Modularity searches for similarities across products. First, the modularity of the products concerning the assemblies is assessed for all products in the product sample. Thereafter, a comparison is made on the operations performed to produce the products.

Assemblies within the product sample

The products are produced with the use of assemblies. With use of the bill of material, figure 6 is constructed and shows what assemblies are used for each of the 11 products in the sample group. The sample group is constructed by the company supervisor and consists of 11 products. Because of confidentiality agreements, the product number and assembly type and assembly number are renamed. The assemblies are in chronological order.

	Product A	*Product B*	*Product C*	*Product D*	*Product E*	*Product F*	*Product G*	*Product H*	*Product I*	*Product J*	*Product K*
Assembly A	Type A	Type C	Type A	Type C	Type A	Type A	Type B	Type B	Type B	Type B	Type B
Assembly B	Type A	Type C	Type A	Type C	Type A	Type A	Type B	Type B	Type B	Type B	Type C
Assembly C	Type A	Type A	Type A	Type A	Type A	Type A	Type B	Type B	Type B	Type B	Type B
Assembly D	Type A	Type A	Type A	Type A	Type A	Type A	Type B	Type B	Type B	Type B	Type B
Assembly E	Type A	Type A	Type A	Type A	Type A	Type A	Type B	Type B	Type B	Type B	Type B
Assembly F	Type A	Type A	Type A	Type A	Type A	Type A					
Assembly G	Type A	Type C	Type A	Type C	Type A	Type A	Type B	Type B	Type B	Type B	Type B
Assembly H	Type A	Type C	Type A	Type C	Type A	Type A	Type D	Type E	Type B	Type B	Type F
Assembly I	Type D	Type C	Type A	Type C	Type D	Type A	Type E	Type F	Type B	Type G	Type B

Figure 6: Assembly types in product sample

The columns in figure 6 represent the product and the rows represents an assembly of the product. The modularity of the product sample is in the rows of figure 6. Because in a row, one unique assembly can occurs in more products. Because of confidentiality agreements, the actual assembly numbers cannot be shown. Instead, the rows show a type of the assembly in that row. When the type in a row is the same, it is highlighted with the same colour. The type refers to what assembly is used in a product. An example; type A occurs several times in assembly B. This means that the products with type A in row assembly B have the same unique assembly B. Hence, Product A, D, E and F have the same unique assembly for assembly B.

From figure 6, it is clear to see that in the product sample there is modularity within the products. Across products, a lot of assemblies are shared. Until assembly I, four of the first six assemblies are the same. The products become different at assembly I. Same holds for the last five products, where four of the five products are the same in front of assembly H.

This means that in the product sample, there are assemblies shared across the products. Not only single unique assemblies, but also later in the production where multiple assemblies are combined.

In case no assembly is shared across the product sample, the product sample would consist of 94 unique assemblies. The 11 products in the product sample do share assemblies and make use of 30 unique assemblies.

Operations in the product sample

In the production, operations are performed at workstations to produce the product. For example, an operation can consist of mounting a base to a tube. However, it can be that not all bases are mounted in the same way to a tube. An operation can differ in activities performed and the sequence in which the activities are performed. When different assemblies are used in the product, it can be that the operations for the product also differ.

Since operations differ in sequences and the amount of activities performed, not all operations are the same for every product. To distinguish between differences in the operations, types are identified. A type is seen as the same production activities performed in the same sequence. Figure 8 presents the different types of operations per product. When an type occurs several times in an operation it is provided the same colour. Because of confidentiality agreements the operations and product numbers are hidden.

	Product A	Product B	Product C	Product D	Product E	Product F	Product G	Product H	Product I	Product J	Product K
Operation A	Type B	Type C	Type B	Type C	Type B	Type B	Type A	Type A	Type A	Type A	Type A
Operation B	Type A	Type A	Type A	Type A	Type A	Type A	Type B	Type B	Type B	Type B	Type B
Operation D	Type B	Type B	Type B	Type B	Type B	Type B	Type A	Type A	Type A	Type A	Type A
Operation E	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A
Operation H	Type A	Type A	Type A	Type A	Type A	Type A					
Operation I		Type A		Type A							
Operation J							Type A	Type A	Type A	Type A	Type A
Operation K	Type A	Type C	Type A	Type C	Type A	Type A					
Operation M	Type A	Type A	Type A	Type A	Type A	Type A	Type B	Type B	Type B	Type B	Type B
Operation N	Type C	Type C	Type A	Type A	Type A	Type A	Type B	Type B	Type D	Type D	Type B
Operation O	Type A	Type A	Type A	Type A	Type A	Type A	Type B	Type B	Type C	Type C	Type B
Operation P	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type A	Type B	Type B	Type A
Operation Q							Type B	Type B	Type A	Type A	Type B
Operation R	Type A	Type B	Type A	Type B	Type A	Type A	Type D	Type D	Type C	Type C	Type E
Operation S	Type A	Type A	Type A	Type A	Type A	Type A	Type B	Type B	Type C	Type C	Type B

Figure 7: Operations in product sample

Figure 7 has the same layout as figure 6, the columns are the product and the rows show the operations performed for the product. Then per operation, types are identified which means for that operation the product has the same operating activities and same sequence in which they are performed. An example, product B and product D have the same operating activities as well as the same sequence for operation A.

Figure 7 shows that the products share activities performed during production. Nevertheless, the different assemblies and components require for different proceedings during production.

An example; product A and product C differ in Assembly I (figure 6). In the production, only Operation N is different between product A and product C. This means that the production activities do differ across the products. Or in other words, because assembly I is different the products are assembled differently in operation N.

Furthermore, an assembly used in the product can also influence the amount of operations that needs to be performed. For example product B, who needs operation I but product A does not. This means that the different assembly types can result that the product is produced with different number and types of operations.

Overall, there are some differences in the way products are assembled. Nevertheless, products require similar operations to be performed during production.

2.5 Conclusion on current situation

In this chapter, the production process of the product is discussed. The online and offline planning as well as the difference between these is discussed; the offline has a larger timeframe and concerns orders. The online planning concerns the sequencing of producing activities for one single day. After that, it has been established that there is modularity across the product sample. Not only assemblies are shared, but products in the product sample follow the same assembly operations.

Chapter 3: Production strategies: A literature review

This section covers the available production strategies. Collecting information on what production strategies are and what production strategies are available is done by means of a literature study. The systematic literature review can be found in Appendix B. The chapter seeks an answer for the research question: "What production strategies are available?"

- Section 3.1 explains the concept production strategy in the literature
- Section 3.2 discusses the product delivery strategies
- Section 3.3 discusses layout systems
- Section 3.4 discusses inventory systems

3.1 What is a production strategy?

This section explains what a production strategy is. In the literature there is no consensus on what belongs to a production strategy. The first part of this section tries to explain what is meant with a production strategy. Thereafter, an explanation is provided on what aspects are taken into account during this research concerning the production strategy.

The production strategy, also referred to as manufacturing strategy, was first introduced in 1969 by Skinner where he addresses the strategic alignment of the manufacturing function. (Thun, 2007)

There is not a universal scope on the production strategy, it is unclear what aspects belong to the production strategy and which do not. Hayes and Wheelwright (1984) describe the aspects within a production strategy as: capacity, facilities, technology, vertical integration, workforce, quality, production planning / materials control, and organization. (Nurcahyo, Wibowo, Robasa, & Cahyati, 2019)

While (Cagliano, 2005), comprise the following aspects within a production strategy: manufacturing innovators, caretakers, technology exploiters, cost minimizers, high performance producers, and marketers.

According to (Matthias Brönner & Lienkamp, 2020), the production strategy is part of an larger corporate strategy representing functional elements. Where strategies in production include strategic and operational components, and aim to minimize cost and time as well as to provide optimal quality and flexibility. (Matthias Brönner & Lienkamp, 2020)

There is no consensus of what aspects belong to the production strategy. But overall, there are four types of strategies at the core of production strategy experienced by all manufacturing: cost, quality, delivery, and flexibility. (Nurcahyo et al., 2019)

Alongside these four core types of strategies, the production strategy can be divided into two viewpoints. As Brönner & Lienkamp state: "strategies in production include strategic and operational components. This strategic viewpoint is also seen as the market-based view (MBV). The operational components in a production strategy are also referred to as resource based view (RBV)". (Nurcahyo et al., 2019)

In the MBV, the external perspective is represented. From the external perspective, the manufacturing strategy is derived from the business strategy. Deriving this manufacturing strategy, the needs of the markets are of focus. (Nurcahyo et al., 2019)

The RBV uses the internal perspective to determine the production strategy. The resources and capabilities are regarded when determining the production strategy. (Nurcahyo et al., 2019)

Conclusion on production strategy

The production strategy is part of an overarching corporate strategy. There are two main viewpoints on the production strategy: a strategic or market view and an operational or resource based view. The core of all the production strategies is: cost, quality, delivery and flexibility. Achieving these core strategies of the production strategy can be done in a lot of ways. Therefore, no universal dimension on the production strategy is known.

Aspects production strategy in this research

This research focuses on the components product delivery strategy, layout system and inventory system of the production. These are seen as components of an operational production strategy because these components concern resources within the production. Since there is no focus on external improvement. Rather how the resources in the production can be used as efficient as possible.

The product delivery strategies concerns the internal components of the production because it has an impact on the structure of the production. The product delivery strategy can also be used to gain an competitive advantage but this is not the scope of this research. In this research, the product delivery is used to improve performance by relocating the CODP. By relocating the CODP, benefits of a new product delivery can be taken and the production improved.

Layout systems is part of this research because it concerns how the resources in the production are located and used. Different layout systems require resources to be utilized in a different way. By altering the layout system of Power-Packer, the production may improve on performance because the layout is better suited for the mix of products Power-Packer produces.

The last aspect belonging to the production strategy of this research are inventory systems. Investigation into inventory systems is chosen because a need for inventory may arise when assigning a new layout or delivery strategy.

3.2 Product Delivery Strategies

In this section, product delivery strategies are explained. The characteristics of these delivery strategies are discussed. Furthermore, this section discusses the location of the customer order decoupling point in the production and the influence this has on the performance of specific delivery strategies.

Time of producing: product delivery strategy

This part explains, the four main product delivery strategies, as well as hybrid versions. Furthermore, the section discusses the location of the customer order decoupling point.

There are four main product delivery strategies recognised in literature. These product delivery strategies are originated by the location of the customer order decoupling point (CODP).
The customer order decoupling point, also known as order penetration point (OPP), is defined as the point where product specifications typically get frozen, and as the last point at which inventory is held. (Olhager, 2003)

This results that the CODP divides the stages in the manufacturing process in forecast-driven stages and customer-order driven stages. (Olhager, 2003) As long as a product is not assigned to an order, it is not related to a customer and therefore forecast-driven. When the product is related to an order, all manufacturing stages are driven by the order of the customer at that moment.

The four product delivery strategies are briefly explained below. Figure 12 provides a graphical representation of the four product delivery strategies.

Engineer-to-order

The engineer-to-order (ETO) approach is used to produce products that are very customer specific. This approach is used in, for example, shipbuilding and off-shore oil and gas installations. A typical characteristic of ETO projects is the continuous customer involvement after the order has been placed. Often leading to specification changes during the process of these projects.
While these specification changes are good for a customer, because the needs of the customer can be changed, the changes have drawbacks for the manufacturer, because the specification changes leads to continuous adjustments in procurement, engineering and execution. (Vaagen, Kaut, & Wallace, 2017)

Make-to-order

Make-to-order (MTO) environments are used by companies who sell and produce customized products. The manufacturing operations begin after the order has been made by the customer. Because of the competitive nature of the marketplace, companies using MTO should make effective and efficient decisions on capacity planning, due date setting and price quoting in order to increase profitability and customer service levels. Companies using MTO encounter problems when the arrival of order exceeds the production capacity. (Baykasoglu, Subulan, Gucdemir, Dudakli, & Akyol, 2020)

Assemble-to-order

With an assemble-to-order (ATO) strategy, an inventory at component level is hold so that the product is assembled after the customer order is placed. The ATO systems are mainly used in industry where fast delivery of customized products play an important role. The ATO is particular popular within industries as the automotive, consumer electronics and online retailing industries. (Nadar, Akcay, Akan, & Scheller-Wolf, 2018)

Make-to-stock
Producing standard items is done using a make-to-stock (MTS) system. The success of an MTS is completely dependent on forecasts. The main problems with MTS systems are the inventory management, lot size determination and demand anticipation. (Yousefnejad, Rabbani, & Manavizadeh, 2019)

Hybrid
It is also possible to combine these product delivery strategies. It is for example possible to use a MTS for one product and use an ATO strategy for a different product. Furthermore, an MTS can be used for assemblies in the production. So that an ATO environment does not have to assemble all assemblies when an order arrives. (Olhager, 2003)

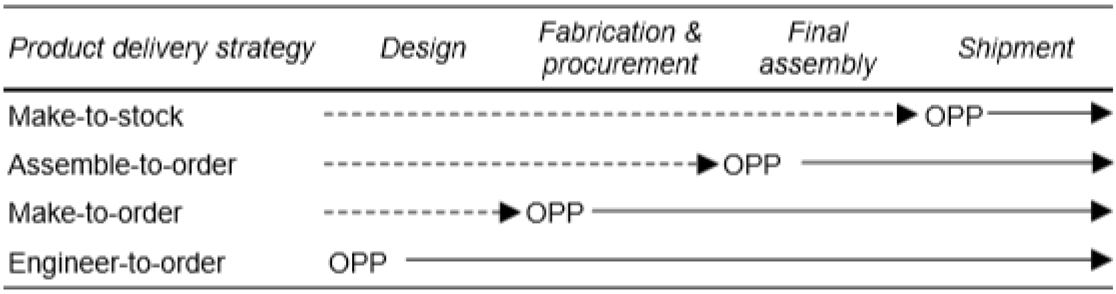

Figure 8: Product Delivery Strategies and the location of the CODP (Olhager, 2003)

Figure 8 shows the CODP per product delivery strategy. The dotted lines represent activities which are forecasted, whereas the continued line represents activities that are customer specific. Figure 8 graphically shows the difference between the location of the CODP in the production for the different delivery strategies. As well as the nature of the stages during the production, either forecast or customer driven.

Location CODP in the manufacturing process

This part further explains what for impact the location of the CODP has on the operations performed before and after the CODP. In advance, characteristics of the operations before and after the CODP is discussed.

Olhager (2003) defines three categories related to the position of the CODP: market, product and production characteristics. Thereafter Olhager differentiates between Pre-CODP operations and Post-CODP operations. Figure 9 depicts the comparison of manufacturing strategy characteristics for pre-CODP and post-CODP operations made by Olhager.

Attributes	*Pre-OPP operations*	*Post-OPP operations*
Markets and products		
Product type	Standard, commodities	Special
Product range	Predetermined, narrow	Wide
Demand	High volume, predictable	Low volume, volatile
Order winners	Price	Design, flexibility, delivery speed
Market qualifiers	Design, quality, on-time delivery	Price, quality, on-time delivery
Production (decision categories)		
Process	Line, high-volume batch	Job shop, low-volume batch
Capacity	Lag/track	Lead/track
Facilities	Product focus	Process focus
Vertical integration	Supplier relationships, OPP buffer/post-OPP operations	Customer relationships, OPP buffer/pre-OPP operations
Quality	Process quality focus	Product quality focus
Organisation	Centralised	Decentralised
Production planning and control	Level S&OP strategy Order promising based on stock availability Rate-based material planning Pull-type execution	Chase S&OP strategy Order promising based on lead time agreement, and material and capacity availability Time-phased material planning Push-type execution
Performance measurement	Cost, productivity	Flexibility, delivery lead times

Figure 9: Comparison characterstics operations (Olhager, 2003)

Figure 9 shows the comparison made by Olhager between CODP operations. What stands out is that operations before the CODP are standardized in product range for a higher demand volume to reduce the price as an order winner. This means that the production before an CODP should be in high volumes and focus on low cost and productivity.

For operations after the CODP, Olhager defines the products to be more special in a lower demand. Where the orders are won by the flexibility and design of the product. This requires for the production to produce in a lower volume focusing on the process rather than the product itself.

Production performance by shifting the CODP

This part discusses the advantages and disadvantages of shifting the location of the CODP.

There are two options for shifting the CODP. The CODP can either be shifted forward or backwards in the production process. Shifting this CODP forward and backward have different implications on the strategic position of the company. Table 2 depicts the advantages of shifting the CODP forward or backwards. (Olhager, 2003)

Competitive advantage	***Reasons***	***Negative effects***
	forward shifting	
Delivery speed	Reduce customer lead time	Rely more on forecasts
Delivery reliability	Process optimization	Reduce product customization
Price		Increase WIP
	backward shifting	
Product range	Increasing the degree of product customization	Longer delivery lead times and reduced delivery reliability
Product mix flexibility	Reduce the reliance on forecasting	Reduced manufacturing efficiency
Quality	Reduce or eliminate WIP buffers	
	Reduce the risk of obsolescence of inventories	

Table 2: Reasoning Forward or Backward shifting (Olhager, 2003)

Table 2 shows the advantages of forward and backward shifting of an CODP. What stands out is that forward shifting is regarded to optimize the process and reduce the customer lead time. Backwards shifting focuses more on optimizing the product by the customization possibilities of the product. Furthermore, an trade-off occurs regarding the inventory of the process. Moving the CODP back requires less inventories compared to forward shifting.

Efficiency and the customer order decoupling point

This part discusses what impact the position of the CODP can have on the production efficiency and what should be taken into account for the position of the CODP regarding production efficiency.

Shifting the CODP to the right gives better production efficiency because the processes can be standardized in better way. This should result in a better production efficiency reducing changeovers and the time consuming processes for specialized products.

However, the use of flexible resources and significant changeover times reduces the opportunity to select the most desirable system configuration. In the case of the most desirable system, the CODP is positioned far enough upstream in the production allowing final products are made with certain demand. (Wong, 2007)

This also applies for Power-Packer. As Power-Packer produces custom made products, certain demand can not be known. Furthermore, the specialization in the product requires the CODP not to be located at the end of the production to achieve maximum production efficiency. Instead, the CODP should be located in such a way that operating efficiency can be achieved with the current resources and product specialization taken into account. Furthermore, the location of the CODP should be in line with the overall strategy of the company.

Conclusion on customer order decoupling point

The CODP can be changed to improve production performance. Shifting all backwards leads to an ETO system, where design and flexibility are of high importance. Placing the CODP forwards in the manufacturing process leads to an MTS situation, where price and delivery speed are important aspects.

Shifting the CODP in the manufacturing process develops a trade-off between manufacturing efficiency and inventory investments. Shifting the process forwards, leads to a better manufacturing efficiency. However, these assemblies or stocks of the finished products needs to be stocked. CODP placed in the back of the manufacturing process leads to lower investments made in inventory. Nevertheless, the manufacturing efficiency is reduced.

Furthermore, the location of the CODP has an influence on the number of changeovers in the production. Relocating the CODP can reduce the changeovers during the production. However, the location of the CODP is not universal. The product design, product mix and volume limits the applicable locations of the CODP in the production. Therefore, the location of the CODP must be in line with the overall strategy of the company to reach its objectives.

3.3 Layout systems

In this part, functional layout systems are explained. These systems indicate how an production facility can be drafted. This sections clarifies on a job-shop layout and a cellular manufacturing layout. A job-shop and cellular manufacturing layout are chosen because these fit the mix of products best for Power-Packer and are in line with the demand for the product. A production line could also be interesting for Power-Packer. However, based on found literature, a production line requires a higher volume level of products. For that reason, the production line layout is not taken into account for this research.

Job-shop

This part clarifies what a job-shop environment is. A job in a job-shop production environment can be seen as a collection of specific skills and equipment ready to operate on customer behalf. The skills and equipment are used to a variety of products. The variety of both products and orders is essential for the existence of the job-shop. To what extent the products and orders vary is dependent on the overall corporate strategy. The strategic decisions can influence the configuration of the job-shop.

Because of variation in product mix, the shop facilities must be able to cope with the variation in products. These may require the shop to use multipurpose machines. This enables the job-shop to re-allocate the given resources given the mix of products at that moment.

Planning a job-shop is a fundamental problem of the layout system. For the job-shop to be efficient, the production has to be planned and controlled in detail to avoid high setup costs, high lead times and a lot of work-in-progress.

All in all, a job-shop produces a fluctuating variety of products using a collection of skills and equipment in different lower quantities. In order to make the job-shop environment efficient, the job-shop has to be planned in detail controlling the flow of the products. Otherwise, large work-in-progress will arise along higher lead times and high setup costs. The success of a job-shop is strongly related to the overarching corporate strategy, determining the product mix. (Reiter, 1966)

Cellular manufacturing

This part explains what cellular manufacturing entails. Cellular manufacturing is based on grouping technology, information is gathered on grouping technology to improve on the production efficiency. In that way, orders can be produced simultaneously. Grouping technology searches “for similarity within the production system and product structure, and using this similarity to simplify the production.” (Dixit & Gupta, 2013) A cellular manufacturing layout enables grouping technology to be used.

According to (Rolstad, 1987) , an cellular manufacturing environment consists of a number of manufacturing cells existing of a number of machines, handling devices and storage facilities set up for a defined set of families of parts.

Cellular manufacturing combines two fundamentals:

1. “The grouping of parts into families with similar manufacturing requirements” (Rolstad, 1987)
2. “The grouping of machines into cells capable of (almost) complete manufacturing of one or more families of parts”(Rolstad, 1987)

Within a cellular manufacturing environment, the job shop layout is reorganized into cells to create a material flow. Each cell in cellular manufacturing is seen as a flow line. When producing larger batch sizes, a material flow is better suited. The machines in a flow line are placed in a sequence of operations, this results in a simple and well organized material flow bringing the throughput times to a minimum. However, the machines in a flow layout tend to be more product specific. This reduces the production flexibility.

A manufacturing cell is made up of three types:

1. Machine type; perform production activities
2. Handling type; responsible for product flow
3. Storage type; stores parts/assemblies/end products

A product is not necessarily produced entirely in a manufacturing cell. In general there are two types of operations; operations performed in a cell and operations performed outside a cell. This allows operations to be supplementary or preparational. From this, three groups are classified:

1. Product completely produced within a single cell
2. Product needing multiple cells to be produced
3. Product needs one or more supplementary either preparational operations outside the manufacturing cell

Cellular manufacturing: An example

Figure 10 shows an example of a manufacturing cell.
This cell consists of five machines that perform manufacturing activities. These machines are in the same sequence as the flow of the product. When the product leaves machine 1, machine 2 is next etc.
The movement of the product can be done by a shopfloor employee, but it is also possible to do this automatically with robots. In this case, there is a storage facility in the middle. In this storage facility, materials used within the machines or the end product can be stored. Thereafter the product can be transported to another cell, or if the product is finished, delivered to the customer.

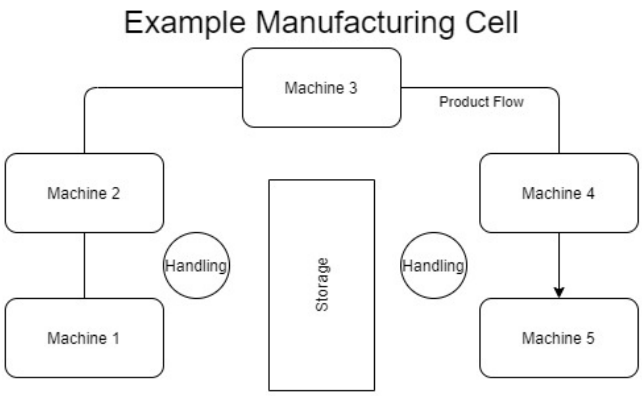

Figure 10: Example manufacturing cell

Planning a manufacturing cell

When an manufacturing cell is implemented in a production facility, the production planning changes. It is not possible to plan batches for each machine. With cellular manufacturing, a batch is seen as the resulting products after a changeover or replenishment of materials. Instead, the cell is planned as one planning unit. Because the manufacturing cell is seen as one planning unit, the planning is affected in the following way:

- The products are loaded on (multiple) machine(s) at the same time
- The whole cell is occupied as long as one machine is occupied
- Idle machines may occur in the cell

A key principle of cellular manufacturing is grouping technology. This ensures that the cell only produces similar parts or products that belong to a same product family reducing the throughput time. Consequently, the product mix and sequencing of this product mix becomes very important. Because products belong to the same family or share parts, it does not mean that there is no changeover time. With sequencing, the changeover time between product batches and the machine idle time can be kept to a minimum.

Planning a manufacturing cell can be done with these three steps proposed by (Rolstad, 1987);

1. Select the number of batches necessary to fulfil the orders
2. Select the products to go into each batch
3. Select the optimal sequencing of products

The first step in planning a manufacturing cell is to determine the batches necessary to fulfil the orders. Thereafter, the products in each batch are determined. At last, the sequence of products in a batch is decided.

3.4 Inventory models

By relocating the CODP in the production, the need for an inventory can arise. Shifting to an MTO or MTS product delivery strategy requires an inventory to be stored. In this section, inventory models are discussed. First, an cycle inventory system is discussed before safety inventory is explained. Since Power-Packer makes use of a Kanban system in the current production for some of the products. The possibility of a Kanban system for the new inventory is also discussed in this section.

Cycle inventory

The average inventory in a supply chain by either production or purchases in lot sizes larger than the demand is called the cycle inventory. (S. Chopra, 2016)

In a cycle inventory the batch size is ordered when the inventory is empty. When this happens, the inventory is supplemented with the batch size ordered. Figure 11 shows two replenishes of a cycle inventory when the batch ordered is delivered instantly.

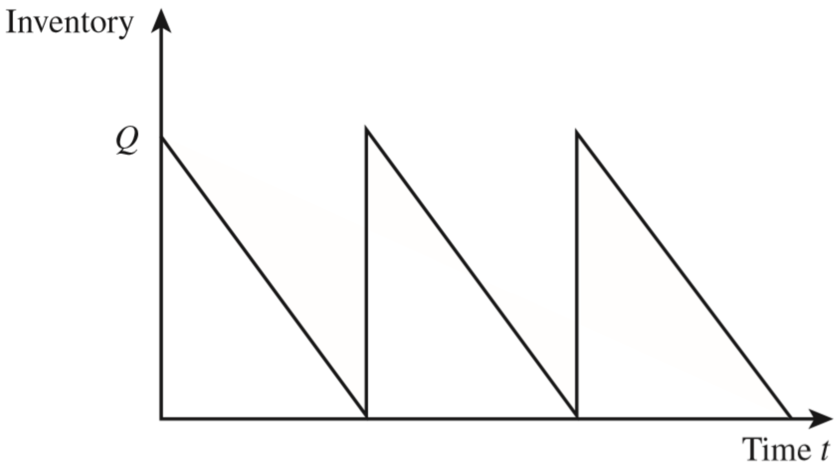

Figure 11: Cyclic Inventory (Chopra, 2016)

Over time t, the inventory Q decreases. This inventory can be anything, such as semi-finished products used in production or products delivered to the customer. When the inventory is zero, an order with lot size Q is placed and the inventory is supplemented to inventory level Q. In this case, this happens instantly with no delivery time. Furthermore, in figure 12, the demand for the product is constant resulting in the inventory to decrease constant.

Holding an inventory incurs costs since the products have to be stored. Furthermore, cost are made to place an order. To minimize the total cost of an lot size, the economical order quantity (EOQ) can be used. The formula of the EOQ is given the following notation:

$$Economical\ Order\ Quantity\ (EOQ) = \sqrt{\frac{2DS}{hC}}$$

Where: D = Demand (any time period, adapt other variables with the same time period), S = Fixed cost incurred per order, h = holding cost per year as fraction of unit cost, and C = unit cost per product

Ordering smaller lot sizes more often increases the number an order is placed but lowers the inventory cost incurred. Adversely, ordering larger lot sizes increases the cost for the inventory but lowers the total ordering cost by reducing the amount an order is placed. The EOQ finds an optimum in this trade-off which is represented by figure 12.

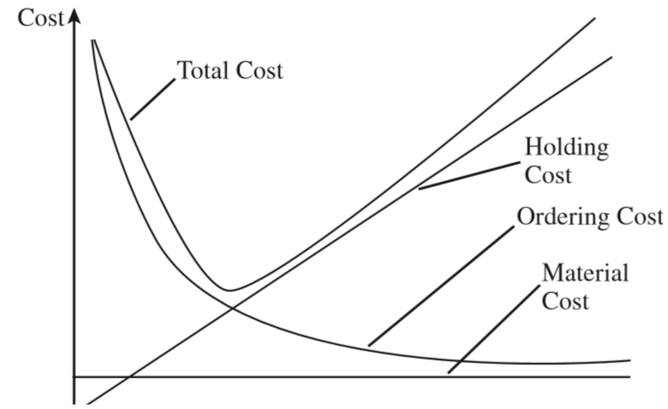

Figure 12: Total cost ordering lot size (S. Chopra, 2016)

In the EOQ formula, it is assumed the lot size immediately arrives. However, in a production environment this is not the case. The production environment produces products at rate P. Therefore, inventory builds up with rate P-D when production of P is active. The inventory is depleted with rate D when the production is inactive. With D,h,C and S defined as earlier, the EOQ formula can be modified to obtain the economic production quantity (EPQ):

$$Economic\ Production\ Quantity\ (EPQ) = \sqrt{\frac{2DS}{\left(1-\frac{P}{D}\right)hC}}$$

Safety inventory

In the cycle inventory, the demand is constant over the time. However, the demand for a product can be uncertain causing a product shortage when demand exceeds the inventory. Safety inventory can be used to satisfy the demand for a product when the demand exceeds the expected demand. Figure 13 graphically represents a safety inventory.

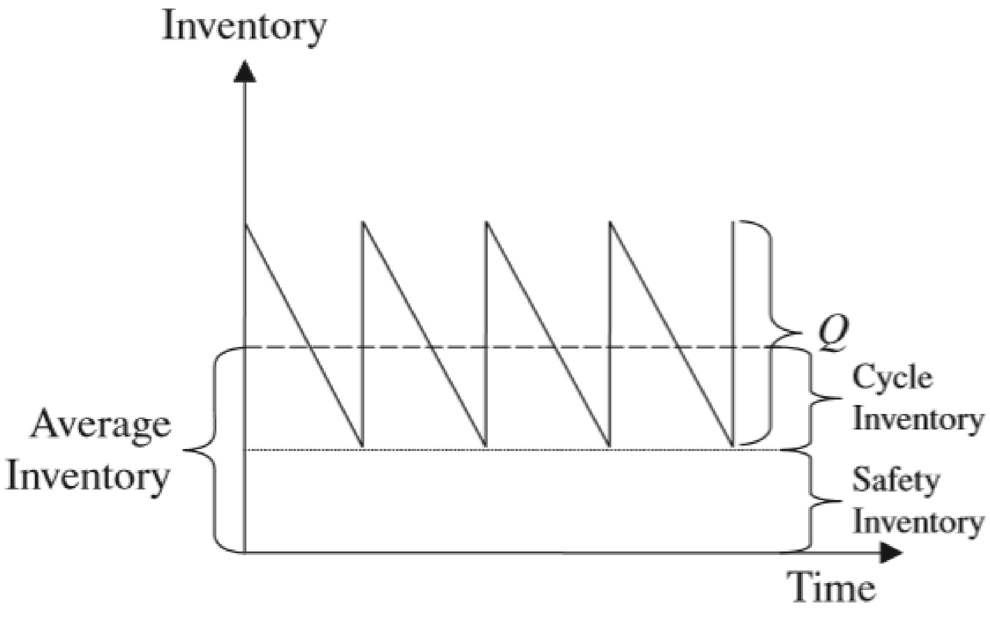

Figure 13: Safety Inventory (S. Chopra, 2016)

Above the safety inventory the cycle inventory is still present. But if the actual demand exceeds the lot size of the cycle inventory the safety inventory can be employed to fulfil demand.

The size of the safety inventory is affected by two factors; demand uncertainty and the desired level of product availability. Important input for the demand uncertainty are the average demand per period (D) and the standard deviation of demand per period (sD).

The availability of a product reflects the availability to fulfil the demand out of the existing inventory. There are multiple ways to measure the product availability, three of these ways are taken care of in this part:

1. ***Product fill rate (fr):***
   Fraction of product demand that is satisfied from products in inventory. The fill rate is equivalent to the probability that the demand is satisfied out of inventory. The fill rate should be measured over specified numbers of products delivered out of inventory rather than a period of time.
2. ***Order fill rate:***
   Fraction of orders where demand is satisfied from products in inventory. The order fill rate should be measured over a number of order rather than a period of time. When multiple products occur in an order the demand can only be satisfied when all products are available.
3. ***Cycle service level (CSL):***
   Fraction of replenishment cycles with all customer demand being met. The replenishment cycle is the interval between two lot sizes arriving. The probability of not having a stockout in a replenishment cycle is equal to the cycle service level. The CSL should be determined over a number of replenishment cycles.

To know when an order must be placed, the inventory must be checked. There are several ways to review the inventory to determine when a replenishment must be ordered. In this section we discuss the periodic and the continuous replenishment policies:

1. ***Continuous review:***
   The inventory of product is checked continuously. The order of lot size Q is placed when the inventory is equal to the reorder point.
2. ***Periodic review:***
   Inventory status is reviewed upon several moments. An order is placed to refill the inventory to a specific inventory level.

Kanban

Kanban is a Japanese ordering and delivering system. The core of the Kanban system follows the just-in-time (JIT) technique. JIT is pioneered by Toyota Motor Company just after the second world war. The principle of the JIT technique is to produce the right product, at the right time, in the right quantity. Kanban appears to be located in the centre of the JIT system, because Kanban provides the right quantity for the workstations eliminating excess inventory. Implementing a Kanban system should increase the productivity and lower the amount of WIP. (M. Ebrahimpour, 1984)

The word Kanban simply means card. These cards are attached to parts, the cards control the flow of the materials in the production. The Kanban inventory system can be seen as a pull inventory system, which means the inventory is delivered if it is asked for by the next workstation. In a Kanban system there is a special designed container for every part type and part number. The containers hold a precise quantity. The cards in the Kanban system are used to signal deliveries. So the part and the number of parts required.

There are two types of Kanban cards; withdrawal Kanban and production-ordering Kanban. In a Kanban system, the total number of withdrawal cards should be equal to the number of production cards. The withdrawal cards indicates the quantity to be withdrawn by a subsequent process in the production. While the production Kanban card shows the quantity to be produced by the preceding process. (M. Ebrahimpour, 1984)

Figure 14 provides an example of an Kanban inventory system.

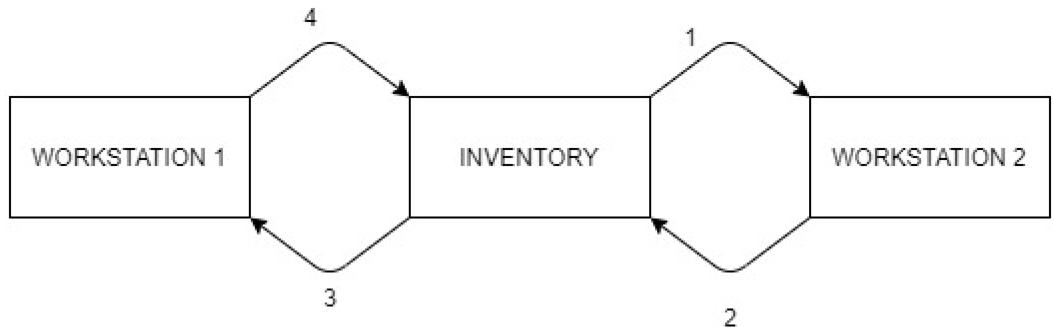

Figure 14: Kanban Inventory System Example

In this example, there are two workstations, workstation 1 and workstation 2. The inventory in the example is located in the middle. The processing of materials in this system is described by the following steps.

1. We start at point 1, a container full with parts with an attached withdrawal card is shipped to workstation 2
2. The attached withdrawal card on the container is detached. Meanwhile the container with the parts is used in work centre 2.
3. When the container is empty, a withdrawal card is attached and sent to the inventory at point 2.
4. At the inventory, the withdrawal card will detached and attached to a full container. While a production card from a full container is sent to workstation 1 and the empty container is sent to workstation 1 at point 3.
5. The production cannot start when there are no production cards at workstation 2. The production activities are triggered once a production card is present. The parts produced are put into the empty container and sent to the store with an attached production card at point 4.

4. Conceptual model of case production

In this chapter the conceptual model of the proposed production is created. This answers the research question: "What production strategy for cab-tilt production could improve performance?" This chapter has three sections and is structured as follows:

- Section 4.1 describes the strategy of the conceptual model.
- Section 4.2 describes the conceptual model in more detail.
- Section 4.3 briefly concludes on the conceptual model and the research question.

4.1 Strategy of the conceptual model

The conceptual model represents a model where the suggested improvement is implemented. The conceptual model describes how the future situation is proposed and is used during the validation process to validate the simulation.

The suggested improvement is originated out of the literature study in Chapter 3. The literature study focuses on production strategies and covers the customer order decoupling point, functional layout systems and inventory systems.

The proposal is to implement a cellular manufacturing cell for a range of products for customer X. In this manufacturing cell, the products are processed in a one-piece flow rather than the current batch manufacturing.

By means of a flow in the production, the shopfloor employees are utilised differently, implying an improvement of the shopfloor employees utilisations. Furthermore, implementing a manufacturing cell can reduce the throughput time and work-in-progress.

Figure 15 below shows the current situation and the future situation of the employees operating activities during the production. Below figure 16, an explanation of the figure is provided.

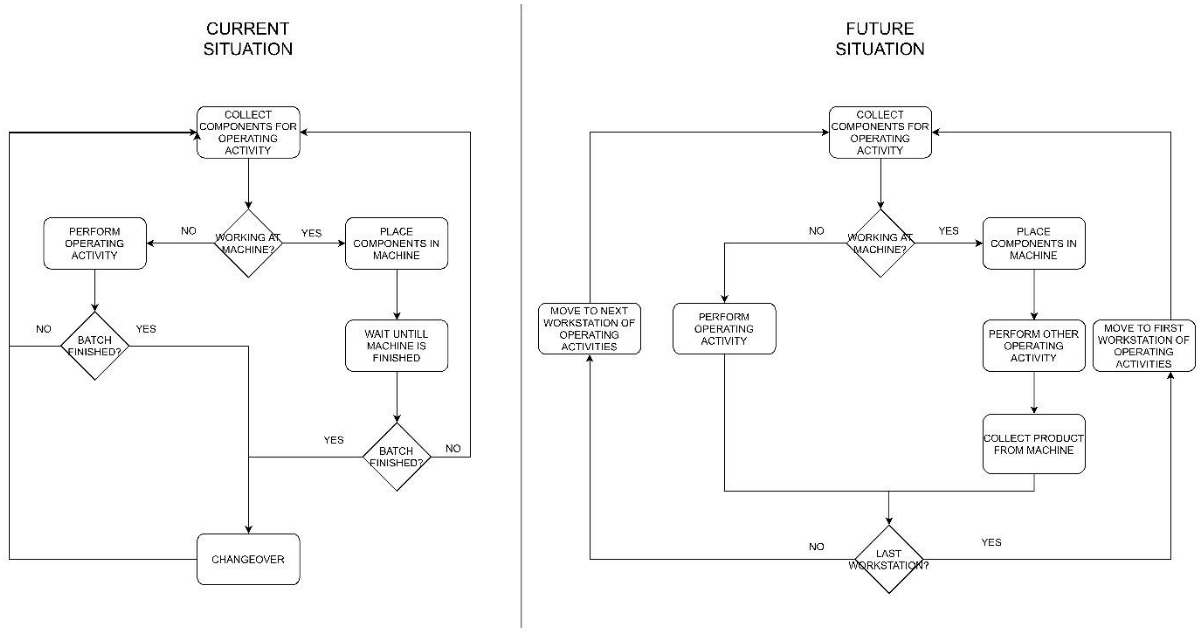

Figure 15: General Idea Conceptual Model

In the current situation, it is assumed one shopfloor employee is active at one workstation all the time. The shopfloor employees performs the operating activity either by hand or machine. In case there is a machine, the shopfloor employees provides the machine with necessary components and starts the machine. Then, the shopfloor employee waits until the machine is finished before starting the machine again. In case the batch is finished, the employees do a changeover.

In the future situation with a manufacturing cell, the shopfloor employee is not active at one operating activity but has a cycle of operating activities within the manufacturing cell. In case a machine is located in a cycle, the shopfloor employee can perform another operating activity during the time the machine is working. In the current situation, the shopfloor employees waits for the machine to complete. Letting the shopfloor employee perform another operating activity increases the utilisation of that shopfloor employee.

By moving the shopfloor employees across workstations in the manufacturing cell, a flow is created. Which prevents for larger inventories of products before each workstation reducing the work-in-progress. Another benefit of the flow is that a product does not have to wait before the whole batch is finished at workstations and moves faster to the next workstation. This improves the throughput time of the products in the production.

The components used in the manufacturing cell are supplied via an inventory. It is important to make sure the components are available for the manufacturing cell. Otherwise the manufacturing cell becomes idle because no input is provided.

Installing this inventory in front of the manufacturing cell implies the customer order decoupling point is relocated. In the current production, the CODP is at the start of the production assigning the assemblies to an end product and customer. In the proposed production, the CODP is shifted forwards in the production to the manufacturing cell. In this way, inventories supplying the manufacturing cell are not assigned to an product.

4.2 The conceptual model

In the conceptual model, one manufacturing cell is created along the current production. This manufacturing cell produces 6 products for customer X, the first 6 products of the product group. Other products are still produced according to the current production.

Figure 16 gives a graphical representation of the manufacturing cell in the conceptual model. The manufacturing cell is explained in more detail at the next page.

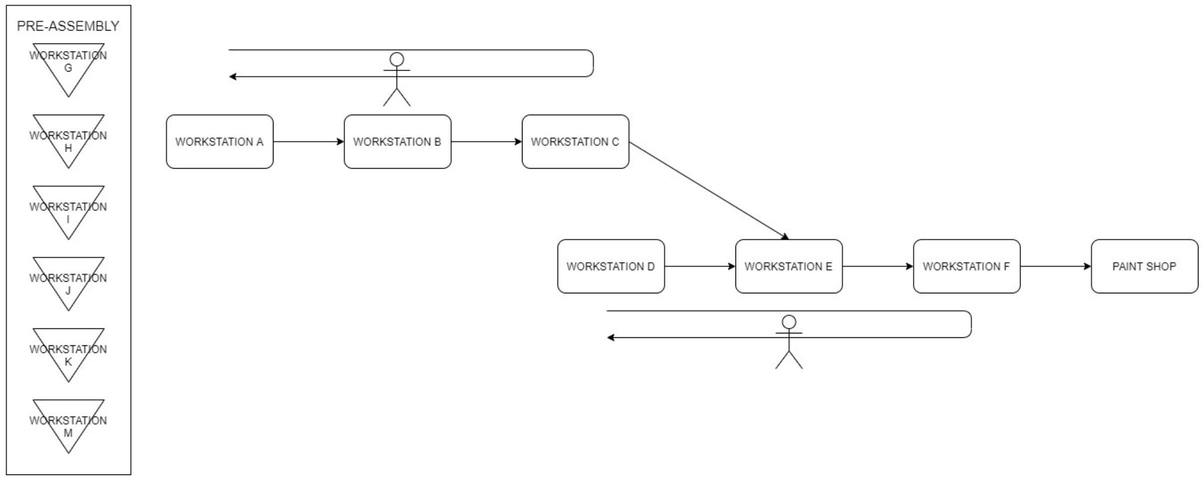

Figure 16: Manufacturing Cell In The Conceptual Model

The proposed manufacturing cell is operated by two shop floor employees. The first employee is active at workstation A, workstation B and workstation C. When these operations are finished, the employee starts over again. Workstation B is an important workstation where the product is assigned to an end product, hence the future CODP.

The second employee performs the operating activities at workstations D, E and F. When the second employee start the machine at workstation F, the employee can start the cycle again at workstation D. When the product is ready at workstation F, the product is sent to the paint shop where the product is provided with a colour.

The workload of the activities described above is reasonable to be performed with 2 employees, hence 2 employees operate the manufacturing cell. The operating activities chosen in the manufacturing cell are chosen because of the assembly structure of the product. The cycles follow a logical order regarding the assemblies.

The manufacturing cell produces 6 products for customer X. It is chosen to implement the manufacturing cell for one customer because of the modularity of products in the sample group. The products require the same or similar assemblies and operating activities. Therefore, the assemblies that needs to be stored are reduced to 8 unique assemblies.
Furthermore, around the same time for the operating activities is required. This prevents the cell to get imbalanced. More about balancing of the manufacturing cell can be found in Section 6.4. Section 2.4 covers the modularity of the products. The manufacturing cell produces the products A to product F in the product sample.

The manufacturing cell uses a cyclic inventory to store the assemblies. Detailed descriptions of the inventory systems are provided in Chapter 3. For a cyclic inventory is chosen because of the lower lead time at the production and the possibility to produce in larger quantities. When the inventory level reaches the minimum, an order at the production for the assemblies can be made any time. Therefore the lead time for these assemblies is low, hence there is no need for a safety inventory to deal with the variability in the lead time.

The Kanban system is not chosen because of the order system. An empty box in the Kanban system goes to the production where the parts in the box are produced. To keep the WIP to a minimum and keep the assemblies available, the Kanban system best works with small boxes. This however implies changeovers at the pre-assemblies, which is not wanted.

4.3 Conclusion

The future production in this research uses a manufacturing cell operated by 2 shop floor employees to produce products in a one-piece flow. The assemblies used in the manufacturing cell are supplied out of a cyclic inventory. In total there are 8 unique assemblies to be stored. The cyclic inventory is enabled by the CODP shifted forwards in the production.

5. Simulation model

In this chapter the created simulation model is discussed. The simulation model is used to test whether the conceptual model is an improvement compared to the current production.

- Section 5.1 argues the choice for a simulation model.
- Section 5.2 discusses the assumptions made in the simulation model.
- Section 5.3 discusses the inputs of the simulation model.
- Section 5.4 discusses the output chosen for the simulation model.
- Section 5.5 explains the implementation of the simulation model.
- Section 5.6 describes the verification and validation of the model.

5.1 Choosing a simulation model

A simulation model is used during the project to implement the conceptual model and test whether the conceptual model is an improvement compared with the current production. For the simulation model is chosen because of the visual representation and the possibility of integrating multiple KPIs. With other models, more computation is required for more KPIs. However, with a simulation, multiple KPIs can be determined with one simulation run. Although this takes some computational time, all KPIs can be determined at once. Furthermore, the level of detail in a simulation model can be higher and assumptions can be made more easily in a simulation model (Robinson, 2014).

The simulation model is created in Tecnomatix Plant Simulation created by Siemens. This software is used because of the available knowledge. Furthermore, there are tutorials from the University of Twente and Technische Universität Darmstat online to help with this software.

5.2 Assumptions in the simulation model

This section covers the assumptions made in the simulation model. Assumptions are made to simplify the simulation model to ease the modelling of the simulation. However, an assumption has an influence on the accuracy of the simulation. The assumptions are designed to have a minimal influence on the validity and are verified with the company supervisor. The assumptions made are discussed below. The black bullet points indicate an assumption which is explained below.

- No failures occur in the manufacturing cell
  The employees who operate the manufacturing cell uses different machines and workstations to produce the products. In the simulation, these machines and workstations do not fail. This assumption is made for simplicity and lack of data.

- Only one unique product is processed in the manufacturing cell
  The conceptual model includes 6 products of customer X. In the simulation only one unique product is produced. The 6 products in the conceptual model have a lot of similarities. Only components can differ. Given that the difference in processing times are small, it is chosen to simplify the simulation and model only one product.

- The inventory does not get obsolete
  The products in the inventory do not obsolete. When the inventory is refilled, inventories and components in the inventories can always be used. Actual assemblies in the inventory for current production do have a due date. Over time the assemblies can rust, this is specifically the case with cleaned products.

- The inventory is filled up immediately
  The assemblies are stored in a cyclic inventory. It is assumed that the inventory is refilled at the lowest point. When this lower point is reached, the inventory is immediately replenished. This assumption is seen as valid because of the low lead time. When the inventory level reaches the lowest point, an order is given to the production. Therefore, Power-Packer does not have to wait for a supplier. The lowest point is set so that there is sufficient time for the pre-assembly to deliver the assemblies. Therefore, the manufacturing cell can continue completing the order while the pre-assembly produces the inventory for the manufacturing cell.

- The employee walks 5 seconds between consecutive workstations
  The work shop employee who operates in the manufacturing cell takes 5 seconds moving to the next workstation. The machines in the manufacturing cell are placed near to each other to save space. The 5 seconds is seen as a valid time for the employee to move between the workstations.

5.3 Inputs of the simulation model

This section describes the data used in the simulation model. First the order sizes used in the simulation model is discussed. Thereafter, the processing times are discussed.

Order size

The simulation model focuses on the implementation of a manufacturing cell in the production. Therefore, the production orders instead of the customer orders are used in the simulation model. To determine the size of the orders, the times an order quantity is produced is used.

Figure 17: Order Size At Power-Packer

Figure 17 presents a graphical representation on the times an order quantity occurs. Because of confidentiality agreements, the actual numbers are not provided. The graph shows the times an order quantity occurs for all 11 products in the sample group.

As seen from figure 17, many orders have a large order quantity because of the large increasement in the graph to the right circled in red. This represents 72.91% of the orders. In consultation with the company it is chosen to implement an uniform distribution with the quantities at the beginning and at the end of the peak. This is seen as a valid assumptions since it is expected for the manufacturing cell to handle orders in larger quantities because it is implementing product families therefor high number products. The manufacturing cell is able to produce larger orders than the current maximum of Y. Because there is no physical limitation for the shopfloor employees. The shopfloor employee is only busy with one product at the time. Hence, there is no need to lift or move Y components of the product. Therefore, the peaks at lower order quantities are expected to disappear in the future situation.

In the simulation, for experimenting purposes, the lower and upper bound of the uniform distribution can be changed.

Processing Times

In the simulation model, the product is processed at a workstation. For these workstations, processing times have been determined.

Not all processing times for the workstation in the simulation model were available. The company provided some processing times for the operations performed at the workstations. These processing times were checked by performing measurements in the production and found valid. Where there was a lack of timings, the operations in the workstations were measured for at least 10 times or more.

However, not all processing times for the workstations could be measured. In order to complement the processing times, product specific timings for the operating activities are used. But these processing times were deterministic. To provide these deterministic times with a variation, the average variation of my measurements regarding other workstations with the product specific timings are used.

Figure 18 presents the processing times per workstation in the simulation model. Because of confidentiality agreements, I am not able to publish the actual processing times. However, figure 18 gives an indication on the difference between the time an workstation needs. As can be seen in figure 18, the timings has been split in manual times and machine times.

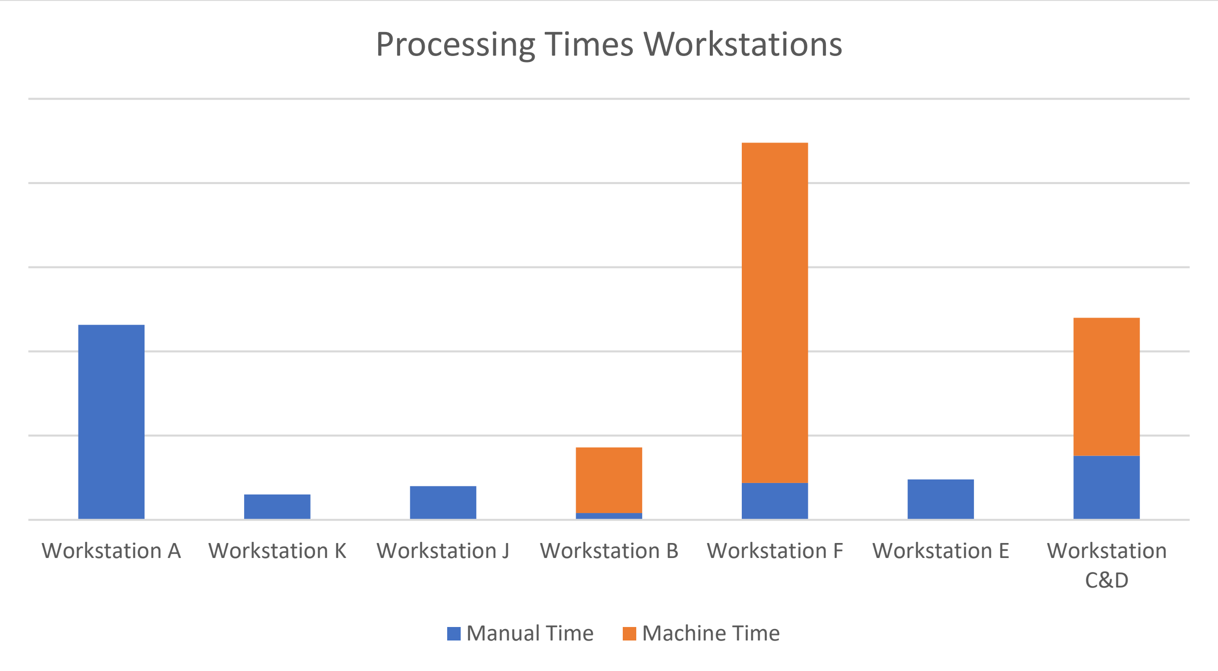

Figure 18: Processing Times Used In Simulation

5.4 Outputs of the simulation model

In this section, the outputs of the simulation are discussed. Regarding what the outputs are and why these outputs are chosen.

The list below presents the outputs used in the simulation model. The outputs are divided within three categories: throughput, changeovers and utilisation. For these categories, the corresponding outputs are provided and explained.

1. Throughput
    a. Total throughput
    The first output of the simulation is the number of produced products. This output is chosen to measure how many products the proposed production can produce. This is important to know for Power-Packer to decide whether this throughput is enough to fulfil customer demand.
    b. Average throughput time
    This output is chosen to see how long the product spends in the manufacturing cell. The throughput time starts when the manufacturing cell begins with a product, it ends when the product leaves workstation F at the end of the manufacturing cell.
    c. Average time between products
    This output is the average time it takes between the finishing of products. In other words, the average time before a finished product exits the manufacturing cell.
2. Changeovers
    a. Total changeovers manufacturing cell
    The output of total changeovers of the manufacturing cell is chosen to see how often the manufacturing cell has to change.
    b. Total changeovers pre assembly
    The output of total changeovers of the pre assembly is chosen to see how often the pre assembly in the production has to change.
    c. Total changeover time manufacturing cell
    This output is chosen to see the total time the workers in the manufacturing cell are not operating the manufacturing cell because of changeovers.
3. Utilisation
    a. Waiting percentage shopfloor employee manufacturing cell
    This output is chosen to see how many times the shopfloor employee has to wait before the next operating activity can be performed. Power-Packer wants to avoid the shopfloor employees waiting in the manufacturing cell. Instead, the shopfloor employee operating in the manufacturing cell has to perform an operation as much as possible.
    b. Working percentage manufacturing cell machines
    The manufacturing cell makes use of machines to produce the products. This output provides an insight how much the machines are used in the manufacturing cell.

5.5 Implementation of the simulation model

This section covers the implementation of the simulation model. First the general representation of the simulation model is discussed. The last part of this section explains how the simulation model works.

General representation simulation model

Because of confidentiality agreements, the figure is provided in appendix E. In appendix E, an explanation of the figure is also provided.

How the simulation model operates

This section describes how the simulation model works. This is done by looking at four activities performed by the simulation: initialization, producing, order change and calculating outcomes.

Initialization

During the initialization, the production is set up to produce the first product. The inventories are filled up and the workers are created. The first order to be produced is created so that the workers know how many products they have to produce. After the initialization, the workers can start on producing the products and the simulation moves to the producing phase.

Producing

In the production phase of the simulation the products are produced per product. The worker moves to the workstation before the workstation can perform the job. After the worker has performed the job at the workstation, the product and worker proceeds to the next workstation. When the product is tested the product moves to the paint shop, which is where the product leaves the production in the simulation model. Here, a counter is located to keep track on the amount of produced products. There is also a counter in the production to keep track on the number of products produced for the current order. When the order size equals the number of products produced of the current order the simulation model performs an order change.

Order change

The simulation produces one type of product. However, if implemented for all products as was the general idea, the manufacturing cell produces 6 products. When the manufacturing cell is finished with the current order, the cell changes to a new order with the same or a different product. In the simulation, an order change happens when the order size equals the counter of products produced for the current order. When an order change occurs, the workers go into pause state. This means that the workers cannot perform activities and go back to the workerpool resource in the simulation. The workers leave the pause state after the changeover time and can start producing products again. The amount and total time of the order changes are recorded.

Outcomes calculation

The outcomes are calculated when a product leaves the simulation model. Product specific outcome variables are calculated, such as the throughput time and time between products. Thereafter, statistics of the model are updated. Such as working rate of the workers, total throughput and workstation utilisation.

Operating the manufacturing cell

The cell is operated by the shopfloor employees active in the manufacturing cell. Figure 19 shows a model how the employee behaves in the simulation.

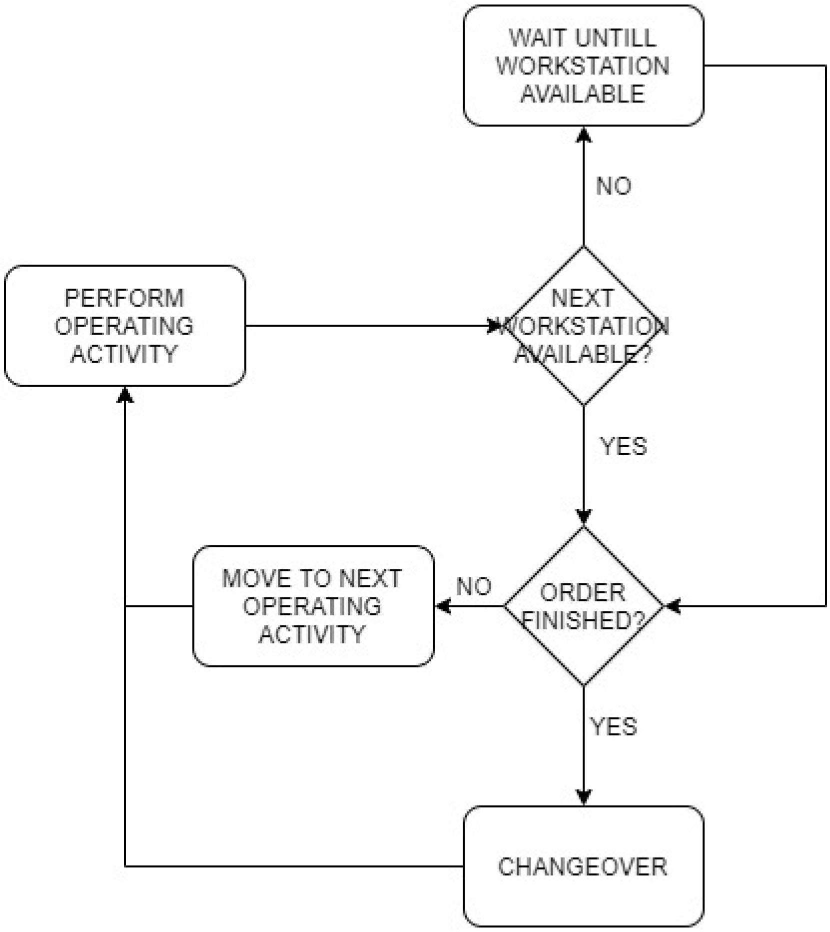

Figure 19: Movements Employees In Manufacturing Cell

The shopfloor employee performs an operating activity within the manufacturing cell. Once the employee is finished with the activity, the employee can proceed to the next workstation. However, the next workstation must be available for the shopfloor employee to perform the next operating activity. It can be that the employee must wait for the machine to complete before the employee can perform the next operating activity. The employee must also wait if there are components or assemblies that are not finished yet. It can be that the employee is supplied with assemblies by the other employee in the manufacturing cell. If the other employee has not finished the assemblies, the employee cannot start the operating activity and should wait. Before moving to the next workstation, it is checked whether the order has been fulfilled. If that is the case, a changeover occurs where the employees do not perform operating activities.

5.6 Verification and validation of the simulation model

In this section the methods of verification and validation are discussed. First the methods to verify and validate the model are discussed. Thereafter, an explanation on the verification and validation of the model is provided.

5.6.1 Verification and white-box validation

With verification the simulation model is compared to the conceptual model. White box validation ensures that the content of the model is true to the real world (Robinson, 2014). Although verification and white-box validation are different, they are both performed continuously throughout model coding (Robinson, 2014).

Robinson (2014) discusses three methods of verification and white-box validation: checking the code, visual checks and inspecting output reports. Checking the code is done during the development of the simulation. The code is also explained to my supervisor at Power-Packer. Also visual checks are performed with the simulation. By running the simulation slowly, the movement of workers and products can be inspected. Running the simulation step by step and predicting what happens next is also done to see whether mistakes occur. At last, the output reports are checked on the output of the KPIs, workstation utilisation and employee working rate.

5.6.2 Verification and white-box validation of the simulation model

For white-box validation and verification, the code is checked in a chronological order, visual checks are performed and the output reports are inspected. The codes are checked in chronological order, this means each code is checked when the code was called step by step. Also visual checks are performed on movement of the product in the production as well as the movement of the workers in the manufacturing cell.

Special attention is given to the changeover process. This is called when the order size is completed. The workers then collect the new order and corresponding materials. The visual check was important to see whether the worker stops with his job and pauses in the worker pool resulting the manufacturing cell to become idle.

At last, the output reports are inspected. To see whether the outputs of the model is feasible given the input parameters. There are no outputs found that could not be explained given the inputs of the simulation model.

5.6.3 Black-box validation

In black-box validation the overall behaviour of the model is considered (Robinson, 2014). This form of validation can be done with two approaches. The first approach is to compare the simulation model to the real world. The second approach is to make a comparison with another model, which is particularly useful when there are no real data that can be compared.

The simulation model cannot be tested with input data from the current case study production to see whether the output data corresponds. This is not possible because the current production line differs too much from the proposed production. Through the implementation of the new layout and the one-piece flow, the simulation results are not representable of the current production.

The simulation model cannot be compared to the real world, since the production line is not build. To solve this, the following solution is proposed by Robinson (2014): the expectations and intuitions from someone with detailed knowledge of the system can be compared to the output reports of the simulation.

Robinson (2014) emphasises the importance of both black-box and white-box validation to guarantee the validity of the model. Different models can provide the same output with different input. The white-box validation ensures these kind of mistakes do not occur.

5.6.4 Black-box validation of the simulation model

Because I am not able to perform a black-box validation against the real-world, the expectations and intuitions of my supervisor is used to validate the model. Estimations are made for the throughput time of the manufacturing cell and the average time between products. Where the estimation of my company supervisor was respectively 5.1% and 12.2% away from the output of the simulation model.

5.6.5 Conclusion on verification and validation

With the code checking and visual checks, no errors are found in the resulting simulation model. The product flows correctly through the manufacturing cell. In addition, the shopfloor employees move accordingly across the workstations.

My supervisor estimated an average throughput time which is not provided because of confidentiality. The estimation of my supervisor differs 5.1% with the output of the simulation model. This is regarded to as a close estimation to see the simulation model valid.

The other estimation is that the average time between products. Here, the estimation of my supervisor differs 12.2% to the output of the simulation model. Again, the simulation is seen as valid as the estimation and output of the simulation model are regarded as close.

5.7 Conclusion on simulation model

In this chapter, the simulation model constructed is explained. The chapter discusses how the simulation model operates and discusses its output, as well as input parameters used. The production process is simulated in four stages: initialization, production, order change and outcomes calculation.

As regards the verification and white-box validation of the simulation model, no errors are found by myself and the company supervisor. The output of the simulation model is close to the estimations made by my company supervisor. Therefore, looking at these points, the simulation model is considered to be correct, since it is verified and validated.

As the simulation model is implemented, verified and validated, experiments with the manufacturing cell can be conducted. The conducted experiments are described in chapter 6.

6. Experiments

This section covers the experiments performed with the simulation model from a fictional case study. The experiments are performed to determine whether the solution is an actual improvement on the current production. This chapter discusses what experiments are performed, how the experiments are performed and what the outcomes of the experiments are.

- Section 6.1 provides the model settings
- Section 6.2 presents the overview of the current situation
- Section 6.3 presents the performed experiments
- Section 6.4 discusses the influence of the manufacturing cell on the current production

6.1 Model settings

To obtain accurate output, the settings of the model is determined. The accuracy of the measurements are influenced by several aspects; warm-up period, run length and replications. An overestimation of the results is used to build in a margin of safety. Appendix C provides the results for determining the model settings. The determined settings for the model are:

- Warming-up period: 1 day
- Run length: 10 days
- Number of replications 5 replications

6.2 Current Situation

This section discusses the value of the KPIs for the current production. These values are used to compare the results of the experiments and serve as the starting point.

The outcomes of the experiments are discussed in Section 6.3. Since the simulation differs too much from the current situation, we cannot use the output of the simulation model as the starting point. Therefore, data from the actual production is used. Table 6 presents the values for the KPIs in the current situation. Due to confidentiality agreements the table is added to appendix F along with an explanation on how the values are calculated.

Note that the values in Table 6 cannot be directly compared to the outcomes of the simulation. However, the outcomes of the simulation are meaningless itself. Power-Packer wants to know whether the implementation of a manufacturing cell improves production performance. The values in Table 6 are used to show the difference in KPIs with the simulation output. Although the values cannot be compared directly, comparing the output of the simulation with the reality of the production can indicate whether the production performance improves or not.

To be able to compare in line with the confidentiality agreement, the values in table 6 are set to 100%. Meaning that these values are the starting point for the simulation. For example, when there the output of the current situation is 100 products, these 100 products are set as 100%. If the simulation shows an output of 120 products, this output is described in an 20% increase or 120% of the current situation.

6.3 The performed experiments

This section discusses the performed experiments. The first experiment performed is the initial experiment. The initial experiment is the model as in the conceptual model. After the initial experiment, four follow-up experiments on the initial experiment are conducted. In a follow-up experiment, first the results of the previous experiment are analysed. Then, based on the analysis, an improvement is suggested in the model and the model is constructed. With this new model, an experiment is conducted to see whether this improvement has worked and whether a new improvement can be made.

The resulting simulation models for the follow-up experiments are not discussed because the models slightly changed. As the models did not drastically change, there is no need to explain the model again. The same input and output values as well as assumptions are used, these are explained in Chapter 5. An exception for the assumptions for the use of current machinery, because workstation L from follow-up experiment 1 on entails the need for a new machine. All the results of the follow-up experiments can be found in Appendix A.

Initial experiment

The initial experiment is the implementation of the conceptual model where an manufacturing cell is implemented. The conceptual model is explained in Chapter 4, the simulation model derived from the conceptual model is explained in Chapter 5.

Figure 20 shows the layout of the manufacturing cell proposed in the conceptual model. Because of confidentiality agreements, the actual processes of the workstations are not provided. Instead, the workstations are anonymized.

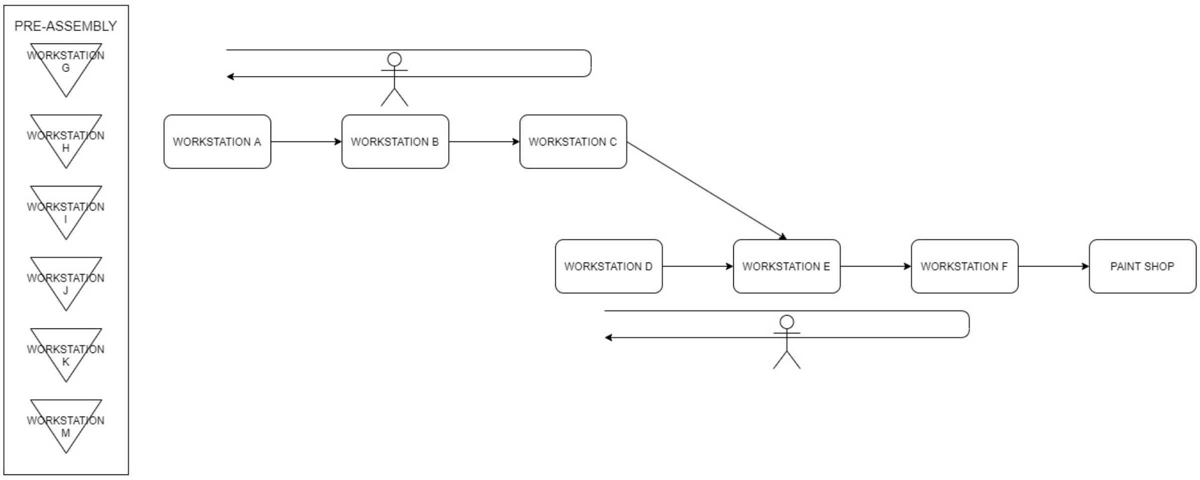

Figure 20: Manufacturing Cell Conceptual Model

The manufacturing cell should reduce the throughput time according to the information found during the literature study in Chapter 3. This is also a result the simulation shows, the average throughput time of the products is reduced drastically to 6.1% compared to the current situation, a large decrease of 93.9%. The manufacturing cell also reduces the number of changeovers during the production. For the 10 days producing in the simulation, 15.33% of the current amount of changeover were needed to produce 57.74% of the products without efficiency alignment.

The throughput is not at the desired target output. Furthermore, the shopfloor employees have some waiting time and the utilisation of the machines is too low to even 25% for workstation D. The low utilisation of the machines is probably caused by the fact the employees are not able to supply the machines with the input fast enough. When the machine is loaded and started, the employee needs too much time to perform the other operating activities and start the machine again. That the employees takes too long before returning to the machine is strengthened by the waiting time the employee has.

In addition, the employee has to complete the cycle before the operating cycle can start again. This is not beneficial for the employee producing the at workstation A, workstation B and workstation C. For workstation C, the employee needs to be twice at workstation C. Between these operations at the machine, the employee is not able to perform any other tasks. Meaning the employee has to wait at the machine.

Follow-up experiment 1

In the conceptual model it is assumed only the current machines at Power-Packer are used. During the project, the automation of the workstations C and D into workstation L became more concrete. To see how much improvement the new workstation L has, the workstation is implemented in the simulation model. The outcome of the model with workstation L is discussed in this section.

The automation of workstations C and D into L brings some benefits to the manufacturing cell. First of all, the workstation L can perform the activities of workstations C and D in one go. Furthermore, the employee is only needed once at workstation L. Here the employee supplies the workstation L of the parts processed in the machine. Thereafter, the employee does not need to be present anymore. In the current situation, the employee needs to return to the workstation. Because the current workstations cannot be loaded once, but is filled in two times. The employee does not need to wait between the two times activating the new machine, resulting in less waiting time of the employee within the manufacturing cell.

The new operating cycles of the employees in the manufacturing cell is presented in figure 21.

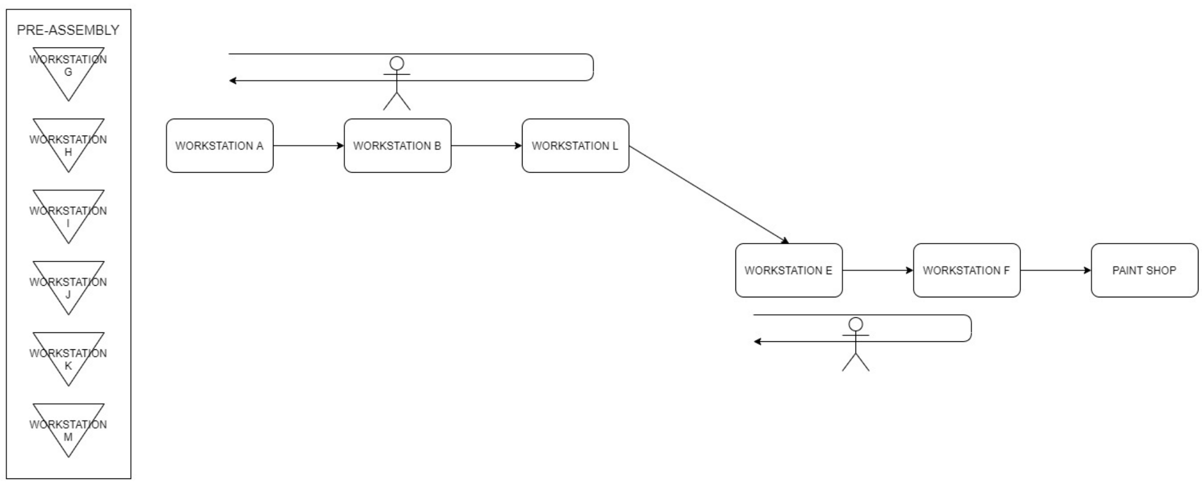

Figure 21: Manufacturing Cell Follow-Up Experiment 1

All the results of the first follow-up experiment can be found in Appendix A. Looking at the results of the first follow-up experiment, the throughput did increase compared to the initial experiment. Because of the higher throughput, there is also an increase in changeovers. However, the total throughput and average time between products do not reach the target output. The higher throughput also causes higher occupation for workstation F.

The occupation of workstation L is much better compared to the initial experiment with 68.80%. The same holds for the waiting percentage of employee 1, which is reduced to zero. This means that the employee always has a task to perform when the employee finishes a task. However, the waiting percentage of the second employee increased. This is reasonable because the employee performs fewer operating activities.

The higher throughput and occupation of machines can be explained through the new workstation L. Workstation L requires the employee only once for workstations C and D. Therefore, the employee does not have to wait and can start the operating cycle again at workstation A. The employee starts the operating cycle sooner, and thus restarts workstation L sooner with the input required resulting in a higher output of the manufacturing cell.

Follow-up experiment 2: extending the manufacturing cell

From the first follow-up experiment, it is seen that the second employee has a relatively large waiting portion. Which means that the employee is waiting until a new task needs to performed. Within this waiting time, the employee is able to perform other tasks. Therefore, the second follow-up experiment is about extending the tasks performed by employee 2.

Employee 2 is responsible for the workstations E and F. However, from follow-up experiment 1, it is concluded the employee still has a large waiting portion. Therefore, the tasks for employee 2 are expanded with workstation J and workstation K.

For the workstation J and workstation K is chosen, because the employee needs the output of workstation J and workstation K in workstation E. Furthermore, the products can be produced in the waiting portion the employee has.

Adding the workstations J and K to the manufacturing cell leads to the manufacturing cell presented in figure 22.

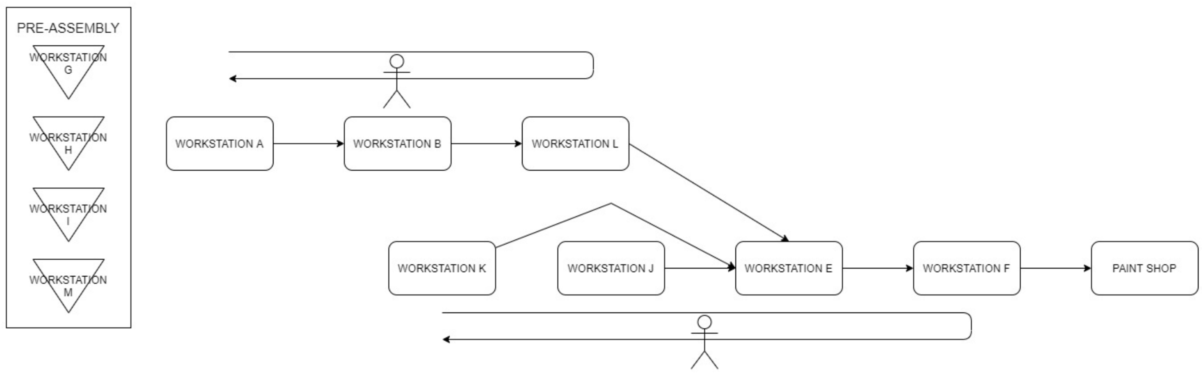

Figure 22: Manufacturing Cell Follow-Up Experiment 2

In the new manufacturing cell, the workstations J and K are added as tasks to the employee who also performs workstation E and F. Since the manufacturing cell now encompasses workstations J and K, the workstations are removed from inventory.

The results are almost identical to the results of the first follow-up experiment except for the waiting time of the second employee. The waiting time is significantly lower compared to the first follow-up experiment to around 15%. This is in line with the expectations, because the second employee has to perform more operating activities in the same time. The conclusion can be drawn that within the waiting time an employee has, other operating activities can be performed without significantly changing the output of the simulation model. The second employee does perform more operating activities while not influencing the results compared to the first follow-up experiment.

Follow-up experiment 3: balancing the manufacturing cell

From the second follow-up experiment, the target output is still not met. Therefore, in this follow-up experiment, the tasks performed by the employees are divided to make the manufacturing cell more balanced. Balancing the manufacturing cell may also increase the throughput of the manufacturing cell. An increase in throughput is necessary since the target output is not reached by the second follow-up experiment.

When one employee needs more time to perform the tasks in the manufacturing cell, the cell is unbalanced. When the tasks are divided evenly over the employees, the employees should take around the same time to perform the tasks. Therefore, when the cell is perfectly balanced, there is always a new task available for the employee to perform. Reducing the waiting time for the employees in the manufacturing cell.

To balance the manufacturing cell for the production at Power Packer. The total manual time is divided by two; the number of employees who operate the manufacturing cell. This is the available time for one employee within the manufacturing cell. For both employees the task with longest processing time is set as the starting point. Thereafter, the available time is filled up to a minimum deviation of the available time. At last, the tasks are put in the right order for the production. Because of the confidentiality agreements, the times are not published. The resulting tasks for the employees are provided below, and graphically represented by figure 23:

Employee 1: Workstation B → Workstation L → Workstation E → Workstation F
Employee 2: Workstation A → Workstation J → Workstation K

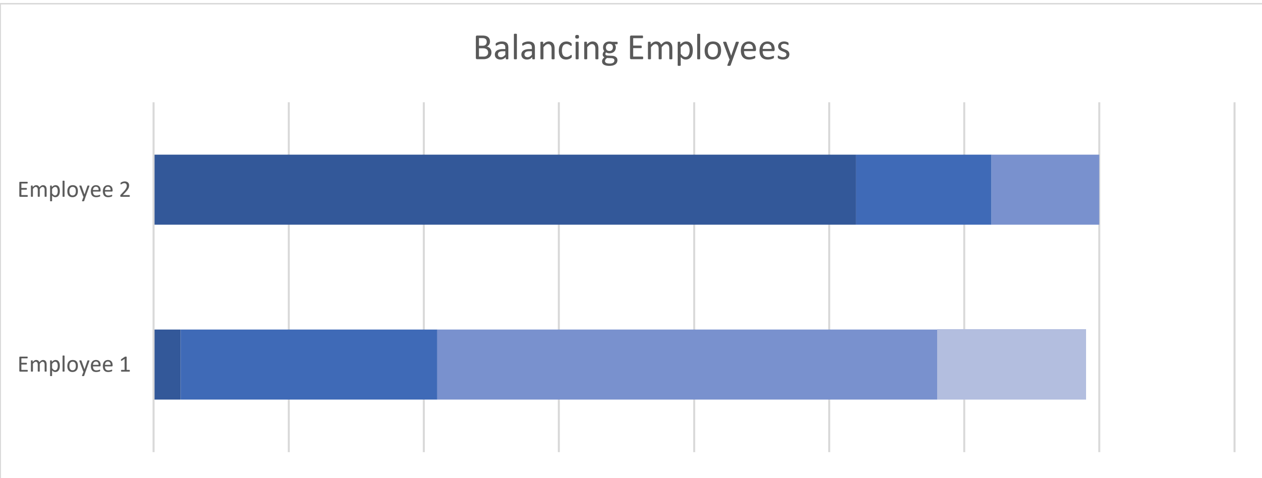

Figure 23: Balancing The Manufacturing Cell

As seen from figure 23, the time difference between the employees in figure 23 is small. Employee 2 takes 2 seconds longer to perform all tasks compared to employee 1. Therefore, the manufacturing cell is seen to be properly balanced.

Figure 24 shows the manufacturing cell graphically where the new division of tasks are assigned to the employees.

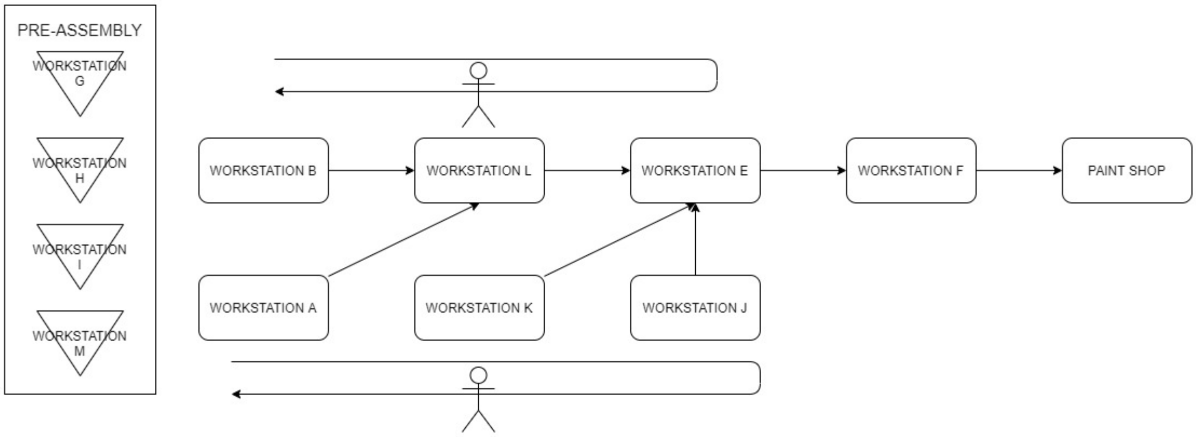

Figure 24: Manufacturing Cell Follow-Up Experiment 3

The results of the third experiment show an increase of the total throughput which is seen as a good thing. Furthermore, the average throughput time increased a lot. This is due to the initialisation phase of the simulation and the difference in the working activities performed in front of workstation L.

In the first two hours of the simulation, there are no products tested. Because the product needs to be buffered for technical reasons. In these two hours, the employees supply workstation L with products to be produced. In previous experiments, the time before a product reached workstation L was shorter compared to the third experiment. Therefore, a maximum of 34 products were present in the buffer during the first few experiments. In the third follow-up experiment, a maximum of 63 products were present in the cooling phase after workstation L. Although this is an increase in the WIP, workstation F is better supplied resulting in a higher throughput.

After the initialisation phase, the employee supplying workstation L also operates the workstation F. Once workstation F can be operated when the products are sufficient time in the buffer, the employee cannot supply workstation F with products fast enough. This results in more products waiting before workstation F, that cannot be supplied fast enough to workstation F by the employee. Hence, the higher throughput time of the products in this layout.

Thereby, the 63 products in the buffer are not enough to completely supply workstation F. Hence the workstation F can handle slightly more than 71 products in two hours This can also be seen in the waiting times of workstation F, laying around the 40%.

The increase in changeovers in the manufacturing cell as well as the pre-assembly are in line with the increase in the total throughput. At last, workstation F occupation slightly increased with 5% compared to the second follow-up experiment.

Follow-up experiment 4: Balancing three employees

The outcomes of the third experiment are the most promising yet. What stood out is the increase in the buffer after workstation L and thereby the increase in throughput time. However, the target output is still not reached. In order to reach the target output, the last follow-up experiments tests a setup where three employees are active in the manufacturing cell. In this way, workstations L and F should be fully supplied during the production increasing the total throughput. The resulting manufacturing cell is depicted in figure 25.

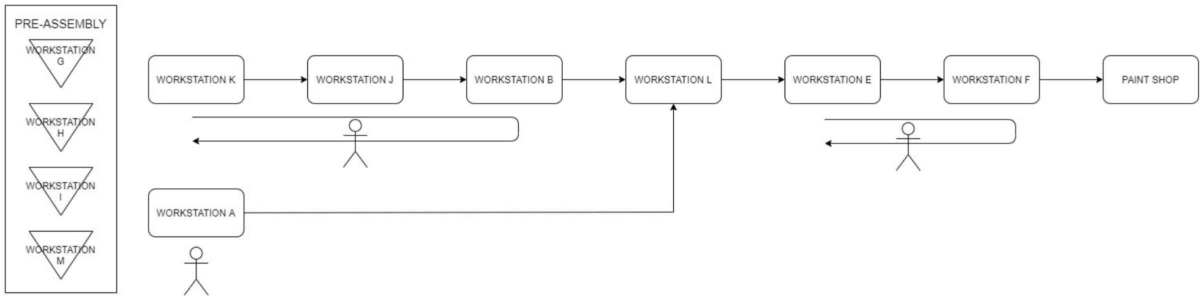

Figure 25: Manufacturing Cell Follow-Up Experiment 4

The outcomes of the fourth follow-up reveal the highest throughput with an 13.2% decrease compared to the current situation. Applying the current 77% efficiency, the throughput is just 2.9% short for the target output. Compared with follow-up experiment 3, workstation F is better occupied resulting in a higher throughput, lower waiting time for workstation F and the average throughput time is lower to 2.9% compared to the current situation. The occupation of workstation L reaches the maximum, which indicates a limitation of the throughput of the manufacturing cell. The changeovers increase in line with the increase in throughput.

The utilisation of the shopfloor employees is decreased compared to the third follow-up experiment. But, the waiting times of the employees are considerably low. The fourth follow-up experiment also uses 3 shopfloor employees to operate the manufacturing cell. For that reason, the increase in waiting time for the employees and machines occupation is also reasonable. The 3 employees can supply the machines with the input while performing the other operating activities.

Overall conclusions on the experiments performed can be found in Section 7.1

6.5 Manufacturing cell influencing the production

This section discusses how the manufacturing cell influences the current production. First is discussed how the job-shop environment alongside the manufacturing cell is influenced. Secondly there is a discussion how the manufacturing cell can gain soft benefits for the production that are not taken into account during the simulation study.

Manufacturing cell influencing the production

The experiments performed in Section 6.3 consider one manufacturing cell producing 6 types of products for customer X. However, Power-Packer produces more products supplying more customers. These products are still produced in a job-shop environment but left out in the simulation. There are no reasons to expect a different behaviour of the job-shop environment producing the other products. The other products are still using the same machines available at the job-shop environment. The 6 products of customer X are not stored in front of workplaces reducing the WIP in the job-shop environment and maybe slightly reducing the throughput time. All in all, there is no expected change in the performance of the current job-shop production.

Where the job-shop environment does need to change is the planning. The job-shop environment must be able to produce assemblies used in the manufacturing cell. Meaning the assemblies must be able to be planned individually in the current job-shop environment without an order or product assigned.

Soft benefits manufacturing cell

The experiments performed give an output where some assumptions are made. Assumed is that no failures occur, employees work all the time and the machines do not break down. In reality, these are not valid assumptions. It is not reasonable the manufacturing cell reduces the machine break downs. But it might be the manufacturing cell has a positive influence on the quality of products and failures.

In the current situation, employees want to finish their batch and move on to the next one. The employees are seriously skilled and perform the operating activities real quick to complete the order as quick as possible. In the manufacturing cell, it does not matter whether the employee is x seconds quicker than the time given, since the employee eventually has to wait for a machine. Furthermore, the time gain is not enough to take a break or do something else. It could be that the quality of the products slightly increase and fewer failures of products occur because the products might be assembled more exact or failures in the components do get noticed in the meantime.

The efficiency of the manufacturing cell can improve with the time a changeover needs. In the manufacturing cell, the employee does not need to search for the right components or assemblies belonging to the product. The employee only needs to collect the new order so the employee knows what product to produce. The assemblies and components are nearby the manufacturing cell so the employee does not need to search for them, reducing the time needed to do a changeover may improve efficiency slightly.

7. Conclusion, recommendation and discussion

This chapter concludes on the experiments performed in Chapter 6 before recommending Power-Packer how to tackle the problem statement. At the end of this chapter, a discussion on my bachelor thesis is provided. The chapter is structured in the following way:

- Section 7.1 concludes the experiments in chapter 6
- Section 7.2 provides my recommendation for Power-Packer
- Section 7.3 discusses the bachelor thesis

7.1 Conclusion on experiments

This section discusses the main findings of the experiments performed in Chapter 6.

None of the experiments reaches the target output of products per day to be produced with the given efficiency of 77%. Nevertheless, the implementation of a manufacturing cell does show some improvement points for the production. The last setup of a manufacturing cell provides the best overall results.

To start, the time a product spends in the production is reduced significantly. In the latest experiment, the time a product spends is reduced to 2.9% compared with the current situation.

Despite the lower throughput time, there are not more products produced. The total throughput lowers 14.8% per day with the given 77% efficiency. The last setup of the configuration model produces 85.20% of the current output. Which is 2.9% short to meet the target output per day. If the output of the last setup increase with 3.1% the target output is reached.

However, an increase in output of the manufacturing cell is not foreseen. This is because workstation L is fully exploited. In the last setup, the machine had an utilisation of 99.98%. Because workstation L is already fully exploited and is the bottleneck in the manufacturing cell. The output generated by the last setup is the highest output a cell can provide.

Although workstation L is fully utilised in the current situation, workstation F hand in some working time. In the cell, workstation F is await for a product for at most 20% of their time. This is more compared to the current situation. However, there is need for two machines at workstation F. Otherwise, one machine cannot handle the incoming products reducing the total throughput. Therefore, the reducing utilisation of the machines at workstation F is necessary to fully output the potential of the manufacturing cell.

Another benefit for Power-Packer B.V. is the decreasing amount of changeovers when implementing an manufacturing cell. The cell produces components of current workstations that do have to change in the current production. Because these workstations now belong to a manufacturing cell, the workstations can all change in one changeover when a changeover at the manufacturing cell occurs. This results that 20.7% of the current changeovers occur in the manufacturing cell.

The last benefit is that the manufacturing cell enables Power-Packer to better utilise the employees. In the manufacturing cell, 40% less appeal is made on shopfloor employees. In addition, almost all waiting times per employee are reduced to upmost 19.88%. This enables Power-Packer B.V. to utilise the shopfloor employees in a better way.

7.2 Recommendations for Power-Packer B.V.

This section provides my recommendation for Power-Packer. The section is divided into two different sections. The first section provides my recommendation on how to improve the production performance. The second section discusses topics for further research.

Recommendation on improving the production efficiency

The project performed for Power-Packer is to improve the production performance. To do this, research has been conducted to implement a different production strategy. In chapter 3, different aspects of a production strategy are discussed before implemented in a conceptual and simulation model. The simulation model is used to run experiments on the production strategy chosen.

Unfortunately, no experiment has proven to reach the target output with the current given 77% efficiency. Nevertheless, my recommendation for Power-Packer is to improve the production performance with the last setup of the manufacturing cell where three employees are present.

The implementation of a manufacturing cell shows promising performance improvements, especially for employees utilisation and throughput times. Furthermore, the amount of changeovers and work-in-progress is reduced by the implementation of an manufacturing cell.

The fewer, and better utilised, employees used within the manufacturing cell provide a good reason for Power-Packer to implement the manufacturing cell in terms of cost. Furthermore, the decreasing amount of work-in-progress also saves investments made during the current production.

Although the current production planning must change when implementing a manufacturing cell. The manufacturing cell simplifies the current production planning. Because the cell must be planned as one single unit compared to the current online planning where all workstations present in the manufacturing cell must be planned individually.

Though, before the production performance can be improved using a manufacturing cell. The calculating efficiency of Power-Packer should improve with 2.38% to 79.38% in order to reach the target output. This calculating efficiency is the error margin of the whole production. Reducing the error margin would mean the manufacturing cell becomes a good option for improving the production efficiency.

When it is not possible to not improve on the calculating efficiency. My recommendation for Power-Packer is to research the possibility of extending the working hours for the manufacturing cell. Around 20 minutes of extra working time of the manufacturing cell enables the manufacturing cell to reach the target output. In my view, the improvements made in terms of cost and efficiency by implementing the manufacturing cell outweigh the extra cost of running the manufacturing cell longer. However, this has to be an achievable solution to Power-Packer B.V.

Recommendation for further research

This section recommends topics for further investigation.

Product families qualifying for cellular manufacturing

This research focuses on eleven products in the total product range of Power-Packer. For 6 of these products, the implementation of a manufacturing cell is recommended. However, this does not mean that all products benefit a cellular manufacturing environment. Different products can differ too much in components and assemblies. Resulting in too much differentiation of processing times within the manufacturing cell causing the manufacturing cell to get out of balance. Further research could be performed to detect more product families beneficial for cellular manufacturing.

Vulnerability of the manufacturing cell
In this research, the machines are always available. However, in the real world, the machines do not always have to be available. A machine can break down and needs to be maintained. In particular for a manufacturing cell, this is a problem. Because not only the machine is down, but the whole manufacturing cell breaks down. This is something to keep in mind. My recommendation is to investigate the impact on the manufacturing cell when machines are not available.

Data collection in the production
In my opinion, Power-Packer would benefit if they would collect more data on the production process. During my research, in my opinion, simple data was sometimes not available. Collecting more data in the production process enables further research to improve.

Thereby, collecting more data of the production process enables Power-Packer to monitor the production process better. Detecting improvement points easier to perform research on.

My recommendation for Power-Packer is to investigate how to collect data of the production process. This benefits later researches and enables Power-Packer to monitor the production better. When implementing a new production environment such as cellular manufacturing, it might be beneficial to implement data collection simultaneously.

7.3 Discussion

This section discusses different aspects of the research and is divided into two sections. At first, the lack of data is reviewed thereafter a discussion on the simulation model during the research.

Lack of Data

During the research, data useful for the simulation was missing. It was hard to determine the distribution input for the simulation model. With the discrete times provided by the company and using the deviation of the other measurements, distributions were constructed. Although it is assumed this provides an accurate representation of the actual distribution, the real distribution and times for workstations is still unknown. This could have influenced the outcome.

During the research, efforts were made to measure more input data for the simulation. However, the covid lockdown resulting in a closure of the production for several weeks. As well as, not the right products being produced when measurements were taken resulted in the fact that there occurred a lack of data.

Simulation Model

In the research, a simulation model is used to perform experiments. Black-box and white-box validation is used to validate the model. However, there is no real data to compare the outputs of the simulation model. It is assumed the simulation model is valid and provides accurate results. Nevertheless, this does not mean that the output of the simulation model will be the output when the production strategy is implemented. The real true output of the production strategy can only be known when implemented.

Thereby, it is chosen to keep the production running in the simulation. There are no events that stop the simulation. However, it might have been better to implement a terminating simulation at the end of the day. Since all products of the previous day would be ready for workstation F the next day. This could have given the total output a step up reaching the target output. However, during the research is chosen for a non-terminating simulation because it would better resemble the working activities of the employees.

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Appendix A: Experiment Results Confidential

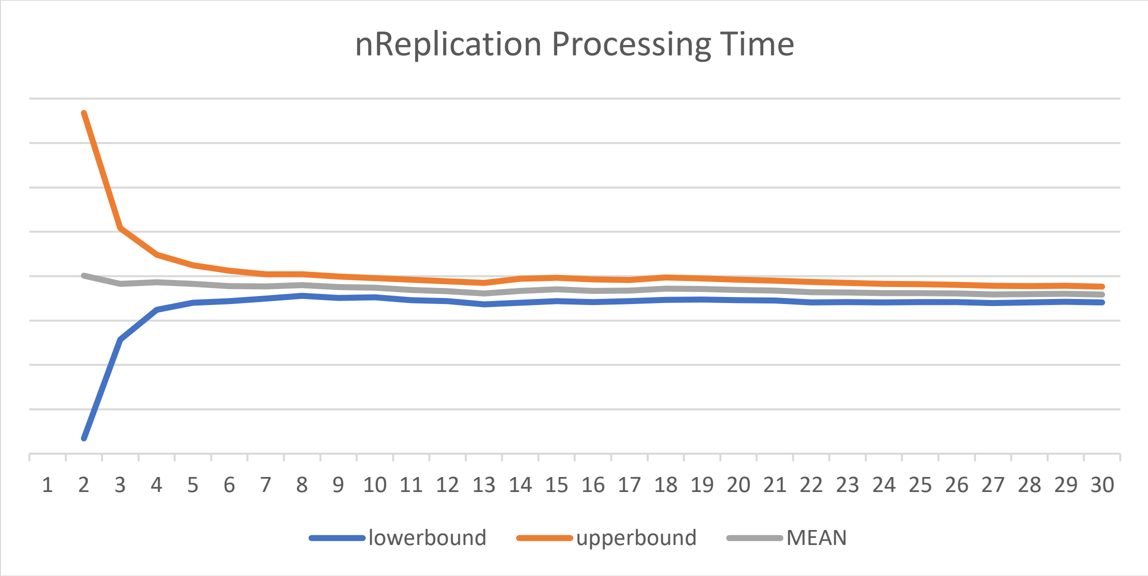
-This appendix is confidential-

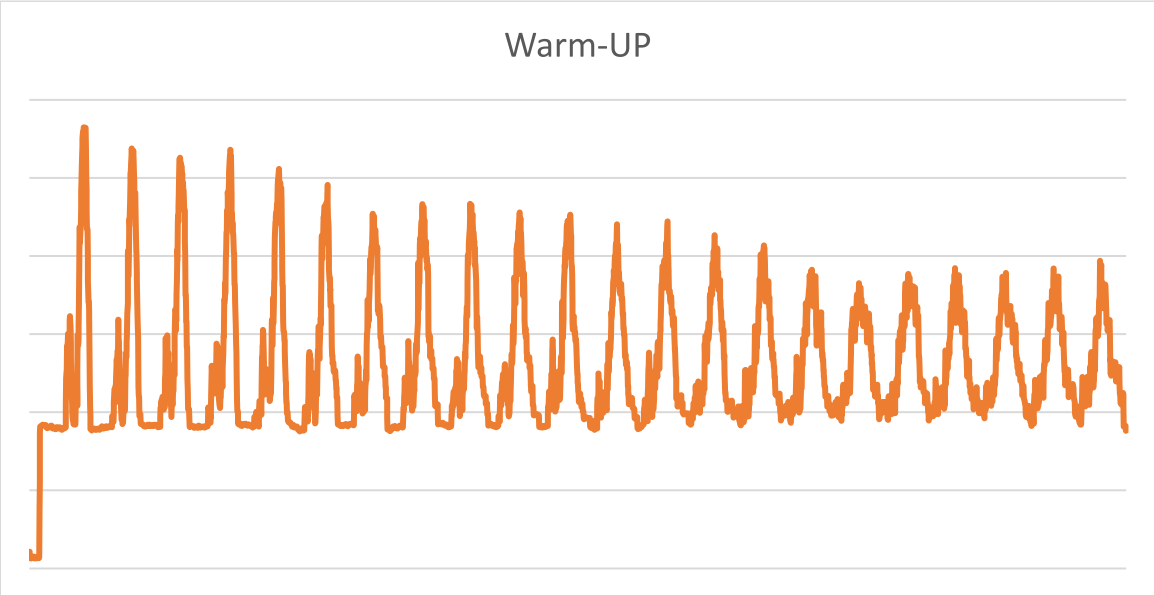
Appendix B: Systematic Literature Review

Search string	***Scope***	***Date***	***Date range***	***#Articles***
		Scopus		
("Production strategy" OR "Manufacturing strategy" OR "Product delivery strategy") AND ("Lean manufacturing" OR "Just-in-time manufacturing" OR "cell* manufacturing")	TITLE-ABS-KEY	14-4-2020	until present	201
("Production strategy" OR "Manufacturing strategy" OR "Product delivery strategy") AND "Changeover*"	TITLE-ABS-KEY	14-4-2020	until present	17
("Production strategy" OR "Manufacturing strategy" OR "Product delivery strategy") AND ("Planning heuristic" OR "Prio* rule*")	TITLE-ABS-KEY	14-4-2020	until present	1
("Planning heuristic" OR "Prio* rule*") AND "Changeover*"	TITLE-ABS-KEY	14-4-2020	until present	6
("Lean manufacturing" OR "Just-in-time manufacturing" OR "cell* manufacturing") AND "Changeover*"	TITLE-ABS-KEY	14-4-2020	until present	106
("Lean manufacturing" OR "Just-in-time manufacturing" OR "cell* manufacturing") AND ("Planning heuristic" OR "Prio* rule*")	TITLE-ABS-KEY	14-4-2020	until present	11
		Web of Science		
("Production strategy" OR "Manufacturing strategy" OR "Product delivery strategy") AND ("Lean manufacturing" OR "Just-in-time manufacturing" OR "cell* manufacturing")	TOPIC - TITLE	14-4-2020	until present	65
("Production strategy" OR "Manufacturing strategy" OR "Product delivery strategy") AND ("Changeover*" OR "Grouping")	TOPIC - TITLE	14-4-2020	until present	47
("Production strategy" OR "Manufacturing strategy" OR "Product delivery strategy") AND ("Planning heuristic" OR "Prio* rule*")	TOPIC - TITLE	14-4-2020	until present	1
("Planning heuristic" OR "Prio* rule*") AND("Changeover*" OR "Grouping")	TOPIC - TITLE	14-4-2020	until present	14

("Lean manufacturing" OR "Just-in-time manufacturing" OR "cell* manufacturing") AND "Changeover*"	TOPIC - TITLE	14-4-2020	until present	34
("Lean manufacturing" OR "Just-in-time manufacturing" OR "cell* manufacturing") AND ("Planning heuristic" OR "Prio* rule*")	TOPIC - TITLE	14-4-2020	until present	5
			TOTAL (END NOTE)	508
			Removing duplicates	-112
			Removing based on exlusion criteria	-342
			Removed after reading abstract	-41
			Removed after more extensivereading	-10
			Added by recommendation	1
			TOTAL	4

Appendix C: Simulation Settings





Appendix D: Workstations

-This appendix is confidential-

Appendix E: Simulation Model

-This appendix is confidential-

Appendix F: Current Situation

-This appendix is confidential-