CHALMERS

Throughput Time Reduction of Complex, High Volume, Spare Parts

A Study within the Assembly Department of an Automotive Components Manufacturer

Iris van Sommeren and David Tempel

Master Thesis E2018:040

MSc Supply Chain Management

MSc Quality and Operations Management

Chalmers University of Technology

Bunschoten-Spakenburg, The Netherlands 2018

MASTER'S THESIS E2018.040

Throughput Time Reduction of Complex, High Volume, Spare Parts

A Study within the Assembly Department of an Automotive Components Manufacturer

Iris van Sommeren
David Tempel

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Supply and Operations Management
Chalmers University of Technology
Gothenburg, Sweden 2018

Throughput Time Reduction of Complex, High Volume, Spare Parts
A Study within the Assembly Department of an Automotive Components Manufacturer

IRIS VAN SOMMEREN
DAVID TEMPEL

Supervisors: van den Berg, D., Reuvekamp, N. and Hedvall, K.
Examiner: Medbo, L., Department of Supply and Operations Management

Master's Thesis E2018.040
Department of Supply and Operations Management
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Abstract

The need for shorter lead times has always been one of the many desires for organisations in the automotive industry. It allows for quick adaption, higher margins and less uncertainties, however can be difficult to accomplish due to the large product portfolio and high product complexity. Especially in the spare part segment, where demand fluctuates and serial production is prioritised, it is challenging to comprehend. This thesis aims to contribute towards an understanding of how organisations, and more specifically the case company voestalpine, can reduce its lead time of the spare parts production without damaging risk and planning control.

An extensive review of literature has led to the identification of potential causes and its accompanying effects on long lead times. These causes include the utilisation rate, preparation time, production time, discrepancies and waiting time. To gain more insight in possible disturbers within the voestalpine, an interactive AIM workshop has been executed. The outcomes combined with the cause-effect relationship has been the foundation for the assessment of a current process analysis. From this research, a portion of the aforementioned causes were eliminated as major lead time disturbers, since degree of influence was insignificant. A future process analysis of the remaining disturbers resulted in a generic decision tree, which will guide the improvements of production steps of spare parts in the assembly department. Restructuring bill-of-materials and adapting planning behaviour and production strategies has been proven in this research to the reduction of lead times. An average lead time reduction of 20,5%, or translated to 38 days, will allow the case company to approach customer demands and increase production flexibility.

Acknowledgements

With this master thesis coming to an end, the last chapter of our student life has been concluded. We look back on a period of personal growth, enjoyment and synergy. This would have not been possible without the support and devotion of our families.

This research would not have been possible without our colleagues at voestalpine. Your warm welcome and curiosity has made us feel a part of the team instantly. We would like to apologise for the occasional whirlwind of craziness through the department, but above all we hope you enjoyed our presence as much as we enjoyed our time here.

Due to David van den Berg we have had the privilege to explore the many ways of voestalpine. You have created time and made an effort to involve us in multiple projects, supported us wherever needed and valued but also challenged our insights. David, your personality stimulates a safe and joyful environment, which has made our collaboration a pleasure. Thank you for this, and we hope that our paths will cross again in the near future!

We owe many hours (read days) to Nico Reuvekamp, our query guru. You have been our go-to guy for questions, discussions and advise. Only one question left to ask: Do you dare to drink with the big leagues? All jokes aside, your knowledge on logistics and system thinking has been of great help and it's something we really appreciate. We sincerely hope that your career path will challenge you, but most of all will give you a lot of energy and fun!

Furthermore, we would like to thank Klas Hedvall and Lars Medbo for their guidance throughout the project. Taking the time to visit The Netherlands has been of tremendous support for the progress of our research by denouncing our finding and thoughts on side. You have *pushed* our line of thought and creativity, which has *pulled* the best out of us and has enabled us to proudly conclude our master's degree.

I.E. van Sommeren

D.J. Tempel

Table of Content

Table of Tables

Table of Figures

Abbreviations

BOM	Bill-Of-Material
CONWIP	Constant Work in Progress
DAG	Daimler
EC	Electro Coating
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
EX	Exact Batch Size
FIFO	First-In-First-Out
FX	Fixed Batch Size
JIT	Just-In-Time
LT	Lead Time
MRP	Material Requirement Planning
MPS	Master Production Schedule
OEM	Original Equipment Manufacturer
PPC	Production Planning and Control
PVB	Produktionsversorgungsbereich • *Undefined location on assembly floor to store items temporarily*
SAP	Systems, Applications and Products
SFDC	Shop Floor Data Collection
SMED	Single Minute Exchange of Dice
TTM	Time To Market
VACBU	voestalpine Automotive Components Bunschoten B.V.
VSM	Value Stream Mapping
VW	Volkswagen
WBZ	Wiederbeschaffungszeit • *German definition of agreed final order lead time*
W&D	Warehouse and Distribution Department
WIP	Work in Process
ZB	Zusammenbau • *German translation of assembling*

VSM Legend

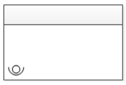
Push Arrow 

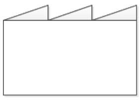
Sending Arrow 

Pull Arrow 

Manual Information 

Electronic Information 

Process 

Customer / Supplier 

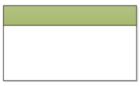
Production Control 

Table of Data 

Shipment Truck 

Inventory 

Feeding cell Inventory 

Timeline Segment 

Timeline total 

1 Introduction

1.1 Background

The automotive industry is continuously challenged by a shorter product life cycle, which puts tremendous pressure on the TTM (Time to Market). The need for shorter TTM challenges all the aspects of manufacturing. It prioritises a competitive lead time and minimisation of uncertainties, e.g. product defects and process malfunctions (Martinez Sanchez, 2005). Long lead times in the automotive industry are caused by complex- and integrated product architectures (Tu et al., 2004).

A key part in the aftermarket of the automotive industry includes maintenance, e.g. replacing damaged body parts with spare parts, which is possible due to the modular nature of the vehicle (Muffatto and Roveda, 2002). To be competitive in this circular economy, overall production cost need to be decreased and flexibility towards customers enhanced (MacArthur, 2013).

voestalpine faces these challenges. Through customer specifications the organisation has a need for a short lead time. Both the large product portfolio and variety in production lead time cause problems with promised delivery times towards its customers. Therefore, it is beneficial that lead times are investigated and that a generic solution for the organisation towards this problem is created. To facilitate this, different processes have to be mapped and compared, problems will have to be analysed and potential improvements discussed. Multiple solutions to main barriers will have to be aggregated towards this aforementioned generic model.

This report will reflect on several models to determine the process similarity and how to correspond those with the organisation's capabilities. It will aim for a customised overarching solution that could support the desire to reduce lead times in the assembly department of voestalpine. An analytical framework will support the selected research questions in the assembly department of an automotive component manufacturer.

1.2 Company Background

voestalpine AG is a steel-based technology and capital goods group with its headquarters in Linz, Austria. Its main focus is developing and producing high quality steel products in the following four divisions:

1. Steel
2. High Performance Metals
3. Metal Engineering
4. Metal Forming

voestalpine has more than 50.000 employees and over 500 production companies in over 50 countries in 5 continents. voestalpine Automotive Components covers both the development and production for the automotive industry and is part of the Metal Forming division. This coverage includes the design, engineering, development, production and project management for the original equipment manufacturer (OEM). The Automotive Components business unit has 5300 employees over four competence centers and multiple production sites per competence center. These competence centers are field experts when complex problems arise, where voestalpine Bunschoten focuses on body panels and aftermarket solutions.

1.2.1 voestalpine Automotive Components Bunschoten

voestalpine Automotive Components Bunschoten B.V. (VACBU) is one of the business units that is part of the Automotive Body Parts within the Metal Forming division. Their core activities are the design and production of steel- and aluminium body parts of the car for major European automotive companies, e.g. BMW, Volvo Cars and Daimler. The automotive division of voestalpine is a large part of voestalpine group, with a gross revenue of 850 million euros during 2016-2017. The total revenue of the automotive group that year was 2.43 billion euros, meaning that the automotive division was worth 35% of the total revenue.

VACBU's product range includes 5.370 different finished products and over 25.000 components. An illustrative product portfolio can be found in figure 1 and consists of rooftops, hoods, tailgates, front doors, backdoors, mud guards, wheel arches and car bottoms. The production facility covers around 165.000 square meters and employs 870 permanent employees and additional flex-workers when needed.

Fig. 1 Range of components

1.2.2 Organisational Structure

VACBU has the following vision:

"To strive for excellence in solutions for the transforming of metals in the automotive industry. We are a worldwide benchmark for solutions in service parts and the partner for premium assembly solutions and outsourcing within Europe."

The culture within VACBU can be described as open, informal and result-driven. The organisational chart can be found in appendix A, which shows that there are two heads of directors. This is the so-called four eyes principle and is unique to voestalpine Group.

1.2.3 Department of Logistics, Warehouse and Distribution

The department of Logistics, Warehouse and Distribution (LWD) consists of a manager, an assistant manager and five different sub-departments, as seen in figure 2. The complete LWD-organisational chart can be found in appendix B, where the beforenamed sub-departments are as follows:

1. Warehouse and Distribution
2. Material Planning
3. Production Planning
4. Sales Order and Transport Planning
5. Life Cycle Management

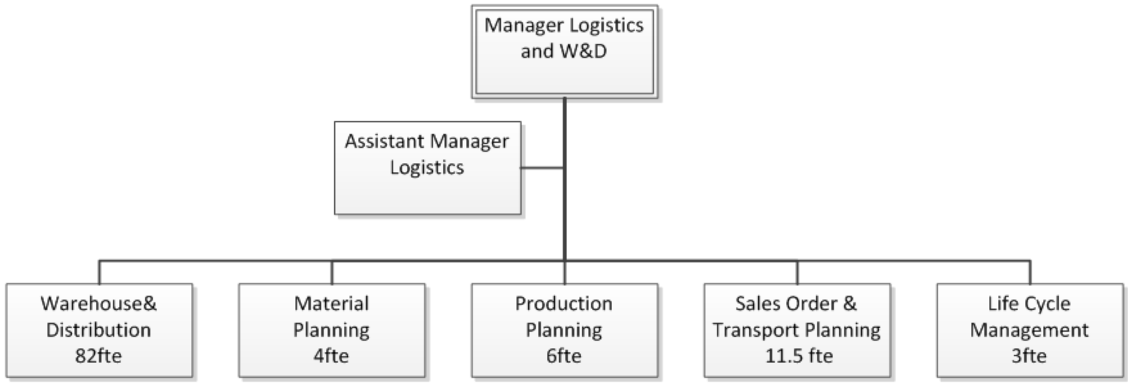


Fig. 2 Organisation chart of the LWD department

The main goal of the department is as follows:

> *"To manage the logistic processes in an efficient way in order to deliver the parts in a timely manner and in the right quantities for the calculated cost, and through a clear and consistent communication method."*

1.2.4 Overview of the Production Chain

Within the production facilities, there are three main shifts (day, evening and night). This allows for continuous production five days a week. There are three main process steps within production, which can be seen in figure 3. Firstly, the steel- and aluminium material that are delivered are processed into sheet materials, also known as platines or blanks, as needed for production. These platines move to one of six press lines with six presses each, which in several steps processes the desired shape into the materials. The second main production step is the assembly of the parts, the cells have a functional layout with mostly universal cells, but also some dedicated cells. Some of the most common operations are laser joining, resistance joining, adhesive, hemming, mechanical joining and manual operations. After assembly, the parts move to the EC (Electro-Coating) before being packed and shipped to the customer. A more detailed layout of the facilities and the different production halls can be found in appendix C.

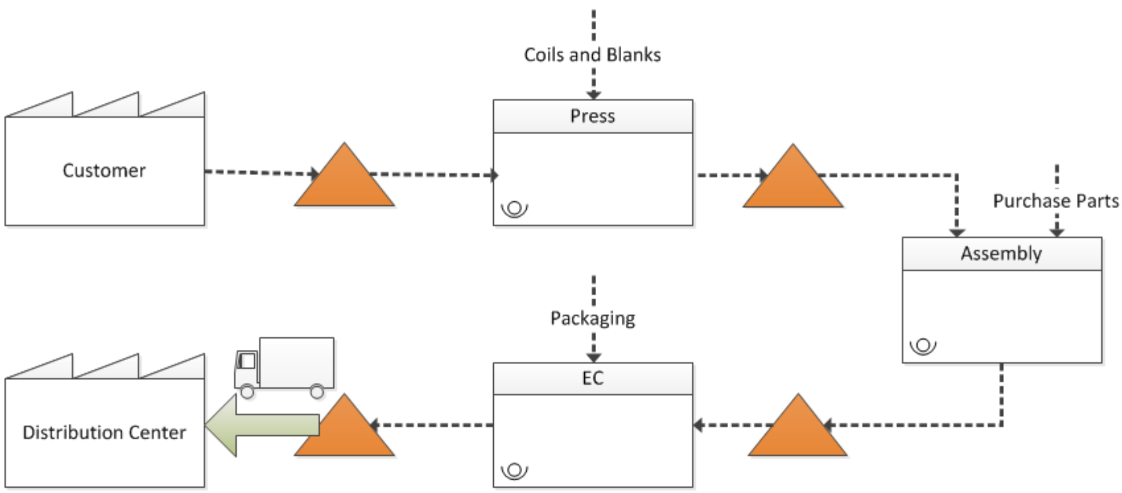


Fig. 3 Main production steps within VACBU.

1.3 Purpose of Thesis

The purpose of this thesis is twofold, as it consists of an academic research within a production company. The research questions discussed in chapter 2 are a merger between the academic- and industry purpose, however for an enhanced understanding they will be elaborated separately.

The thesis will research different types of scientific literature on, among other things, lead time, accompanying influencers, bottlenecks and production processes (see chapter 4). The academic purpose will include a framework of models and theories that are based on the reduction of lead time within manufacturing companies. The purpose is to provide analytical research and in-depth discussions on these models and theories, and their possible application into organisations. Subsequently these models and theories will be dedicated towards voestalpine, where the possible application is investigated and practical solutions can be proven and backboned.

According to customer requirements, the customers of VACBU have the ability to set and change spare part orders often either 60 calendar days or 42 working days in advance before the desired time of delivery to the customer. The complex, high volume, spare parts exceed this timeframe, which causes delays and unnecessary pressure These are parts such as car doors, hoods, front lids and trunks. Due to the complexity and large quantity of these parts VACBU's assembly department competes with a long lead time, where multiple operational steps and (potentially) large degree of non-value added activities push the production time over the maximum day limit. Reducing the lead time on those spare parts will be the industrial purpose of this research.

1.4 Project Scope

The research focuses on the assembly department within the organisation, which is represented by the blue process within the flow chart (see figure 4). Appendix D provides a schematic representation of the assembly floor and the different cells. Interactions from and to other departments, such as the press shop and EC, as well as any other externalities, will not be a part of the research, however will be taken in account and guarded. Externalities can include limited tools, racks and jigs.

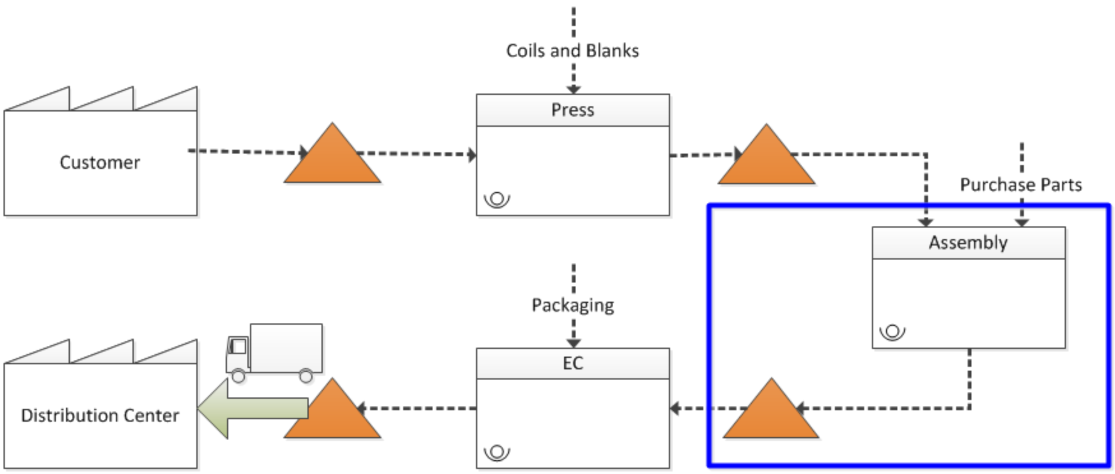


Fig. 4 Project scope within production process

Concerning products, the main focus will be on parts that exceed the time frame to deliver a part to the customer. The number of days depends on the customer conditions, e.g. Volkswagen Group sets these conditions on 60 calendar days, whereas Daimler requires a maximum of 42 working days. The project will exclude serial parts in general, because these orders are set and, therefore, more predictive than spare parts. The higher quantity results in an enhanced production flow without too many disturbances and can be a reason to dedicated cells. These serial parts will be mounted into new cars and sold as new cars.

Figure 5 shows the classification of the four spare-quantities (high, middle, low and zero). Spare parts, unlike serial parts, are meant to serve the aftermarket, e.g. replacing a damaged door. voestalpine defines the spare parts as “Spare A” when it concerns the first five years after the car has stopped being sold on the market. Therefore, quantities are still relatively high. “Spare B” covers the range from 6-10 years. The focus of the project will be one these two product groups, because the quantity is significant enough so improvement will be profitable.

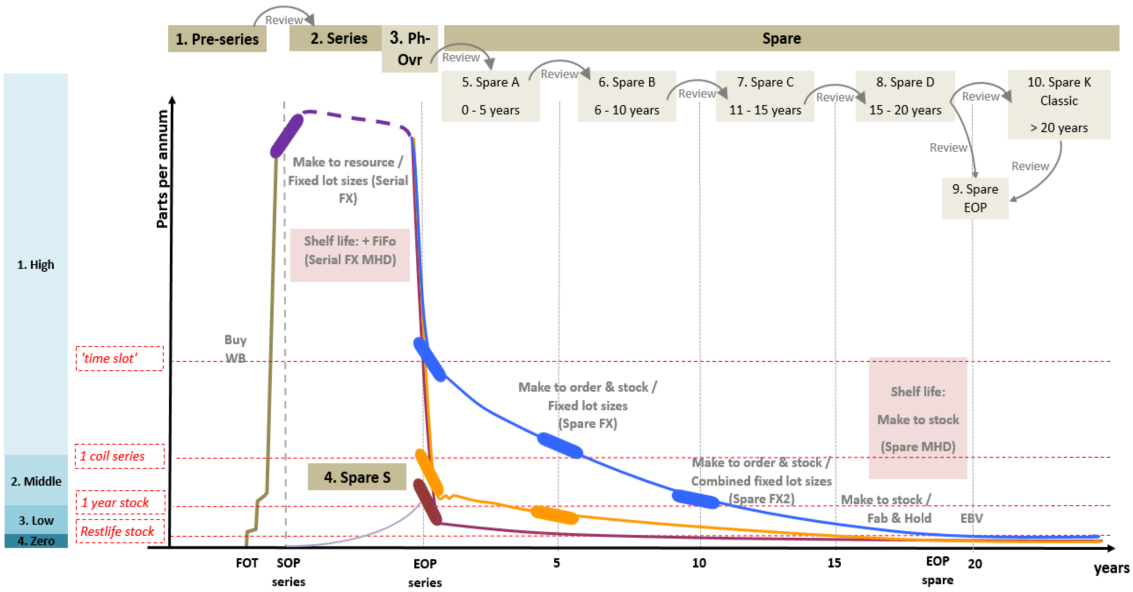


Fig. 5 Progress of part identification

1.5 Expected Outcome

The expected outcome is to provide a substantiated and self-explaining advise, so that further development and implementation could be done afterwards by the organisation itself.

Within this advice, the goal is to create a long-term model that has a generic solution to the long lead time problem in voestalpine’s assembly department. By doing this, not only nowadays’ production will benefit, but future products can also follow this framework. It might be necessary for specific products to adjust the generic solution somewhat, but the overall goal is a framework to enhance the lead time of the assembly line. By approaching the problem with a holistic view, overlap can be found between sub-processes or products on semi-finished product levels, since the uniqueness of products at this moment does not allow for full standardisation.

Company restrictions dictates that the results should cut a minimum of 15% in costs in order to make major changes or invest in enhancements of reasonable scales. This means that any recommendation to the company will be on a higher process level and not focus on small operational improvements. Reduction of lead time will be the main expected outcome, however reduction of the inventory level might be an after effect.

2 Problem Analysis

The problem analysis has the purpose to serve both the academic- and industry perspective of this research, which means that the research questions show an iterative behaviour between managerial issues and scientific research. Practical findings within the organisation have to be scientifically proven, so potential solutions become more credible to the organisation, and literature findings require a practical verification to indicate applicability. The scientific perspective of the problem analysis will be supported and answered in the analytical framework of this paper and can be found in chapter 4.

2.1 Research Questions

Considering the time limitations and the complexity of the project, a research structure needs to be determined. In order to support the main objective, several research questions were developed as a guideline to follow during this process. The main objective that will be challenged is:

Lead time reduction of complex, high volume, spare parts

The research questions are created in such a way that there is a natural flow between the managerial- and scientific issues. They create a guiding funnel and will be stated and clarified accordingly.

1. *From literature, what are the factors affecting lead time, and are there any guiding principles to be drawn from this?*

Lead time can be affected by several different factors, and to determine what causes the lead time within voestalpine to exceed its limits, the different factors have to be found and defined using literature. Some factors will be of higher influence than others, where the correlation to lead time will be investigated. Utilising problem-solving tools from literature will support this research. These factors will then be evaluated upon the current process within voestalpine, merging the academic and industry perspective for the first time.

2. *What is the current state of assembly at voestalpine, in terms of time and operational steps?*
    a. *How can these be reflected upon in terms of found literature?*

Insights need to be gained on the current state of the processes and its influencers. This is required to create an understanding of the assembly department. Barriers that affect a smooth throughput need to be identified as well as anything that disrupts a well-flowing system. To eventually reduce the lead time, the current times and operational steps need to be mapped. This question will include researching a lot of raw data and interviews with e.g. operators and managers.

The analytical framework will be formed in chapter 4, where several guiding principles from scientific research will be conducted. Guiding principles can include steps, frameworks and / or models that should be taken in order to reduce or eliminate problems, to optimise e.g. flows or to enhance lead time.

3. *Which principles could be utilised in order to reduce lead time of complex, high volume, spare parts?*

Analysing the findings from the previous two questions will enable this research to put available principles into context and determine their relevance. The analysis will consist of, among other things, comparing applicabilities and impact rates. The outcome supports the run-up towards different solutions and their hypothetical consequences and restrictions.

4. *How could the findings be operationalised and what are their expected impacts?*

The findings will form the recommendations towards voestalpine. Well substantiated conclusions provide suggested improvements to reduce lead time in the assembly. Finding a generic solution should be stressed here, as this implicates a long-term solution that also can be applied to the future, whereas a non-generic solution is solely a short-term solution. To see the implication of the generic solution, the current state needs to be compared to the theoretical future state after implementation.

3 Methodology

The different research methodologies chosen for this paper are explained and motivated below. This is structured down from research approach to design, data collection and analysis. This structure has been used as the design for this study and supports the research of the aforementioned research questions.

3.1 Research Approach

According to Bryman and Bell (2003), the two different research approaches are deductive- and inductive research. The inductive approach is applicable when there is lacking research within a certain area, meaning that there is lack of knowledge or insight within a subject (Bryman and Bell, 2003). This inductive research is considered the foundation of this topic's research. Deductive, on the other hand, is an approach that is based on previous theories or hypotheses used during an inductive approach. It thus digs further into areas with already existing theories, but with a new research question, statement or hypothesis and new data collection (ibid.). During the deductive investigation, findings are analysed and the hypothesis is either confirmed or rejected, which then can lead to a revision of the theory (Bryman and Bell, 2003).

The thesis consists of an iterative behaviour between the preparation-, observation-, data collection- and analysis phase. This ensures the quality of the research methodology and enhances the continuity. The iterative process allows for continuous adaptation of the research and finding, detecting finding and problems earlier on (Bryman and Bell, 2003). Therefore, the majority of these phases are overlapping, i.e. presence of continuous interplay between theoretical knowledge and the empirical world. Research methods were reframed and improved whilst data was further collected and analysed. This provided the research with an enhanced research flexibility, so the risk of missing and misinterpreting data was reduced. Maxwell (2008) describes a model that resembles and emphasises this pattern (see figure 6). It consists of different components, that correspond to the different project phases, which may affect and/or be affected by another component. Creating research questions is an iterative process as, by gaining a higher level of understanding in the methods, goals, conceptual framework and validity, the research questions will need to be tweaked. Insights about the assembly hall gave a clearer view on the goals, and the methods needed to use these goals. By building a conceptual framework, one can discover new interesting theories or frameworks helpful for the research questions, and thus possibly changing the goals.

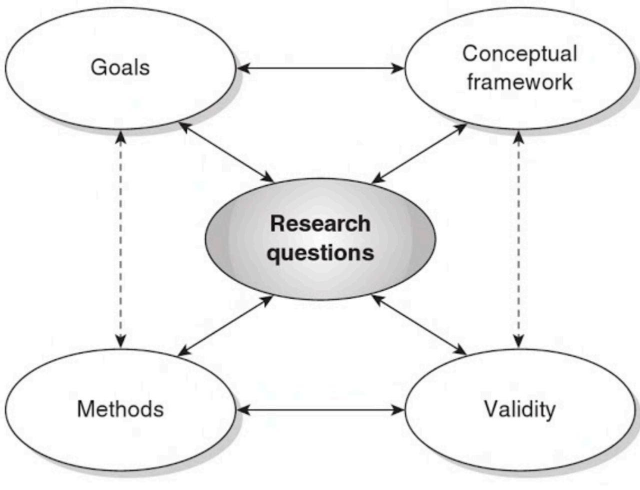


Fig. 6 Interactive research model (Maxwell, 2008)

Furthermore, the iterative behaviour between these phases enhanced the quality (validity) of gathered data as well, i.e. incomplete results from the analysis had the possibility to be re-investigated using similar analysis methods, however with an adjusted data collection approach. This is also illustrated in the model above. The behaviour could be classified as deductive since it is based on scientific methods and logics. There is a set goal to accomplish during this process, where there is an idea of what is expected from observations and based on this expected outcome of the observations recommendations for changes and enhancements will be made.

For the above-named reasons, this thesis has been based on a systematic combination of both term, which is called an abductive research (Dubois and Gadde, 2002).

3.2 Research Design

Next to having two types of research approaches, Bryman and Bell (2003) also defines two types of research strategies, which are qualitative and quantitative research. Qualitative research is inductive and interpretive whilst quantitative research is deductive and objective. Quantitative research gathers measurable data whilst qualitative research focuses on gathering data that is interpreted at hand (ibid.).

As the project has been abductive, it can be said that the outcome is based mainly on a combination of interviews, process charts, status reports, but also quantitative data and assessments. Some interviews have been done with engineers, operators, management et cetera, but for the most part data was collected and measured from the production line, which then was analysed. Borrego et al. (2009) defines qualitative data as answering the research questions by using rich and contextual description of data. So even though this project contains a lot of quantitative data, the final result is advisory report towards the company. Therefore, the project was mainly a qualitative one as the conclusions and recommendations will be drawn in a qualitative manner.

3.3 Data Collection Method

In order to collect information and provide findings for the research questions, three methodologies were utilised. The first method contains the collection of empirical data that enables a more practical view on current states, which could help building theories (Eisenhardt et al., 2007). The second method allows to verify found quantitative data with stakeholders according to an interactive AIM workshop. The last method provides elaboration on practical performances and the possibility to evaluate suggestions and future states. Previous knowledge gained during different courses throughout the bachelor and master program was used as a foundation to build upon continuously.

3.3.1 Empirical Data

Within voestalpine forecasting-, historical- and real time data is gathered for the entire production, including the assembly hall (i.e. Industry 4.0). Production data is held in systems as SAP and Excel in order to create overview, plans and analyse. Unfortunately, this often contains a bulk of unorganised raw data that is not meaningful to this research yet. Important during the gathering of production data is that it has to be made sure that the right and useful data is collected, before considering its validity. Quantitative data as such was used to measure process flow, bottlenecks, critical points et cetera which was complemented by qualitative data. For an enhanced understanding, the research applied all analysis and potential improvements on a single product. All found relevant products experience the same analysis and potential improvements, however this method ensures the consistency throughout research.

3.3.2 Interactive AIM workshop

For the translation of quantitative data to explanations and other qualitative data a workshop was facilitated. Based on the guiding principles of Alänge (2009) a multidisciplinary team was invited to perform a surface investigation. The purpose of the workshop has been to get a first understanding of bottlenecks within the assembly department. The participants were chosen based on their variety in skills and direct influence in the assembly process. Due to the purpose of the workshop no operators have been involved. This would potentially damage the progress and results, because discussion could be too specified on cell- or product level. Participants were provided beforehand with the chosen principles and relevant data, so preparation and awareness were triggered. Compared to an individual interview the workshop was a group activity. Therefore, all data found during the workshop was kept safe, e.g. anonymously, among the participants and researchers. Data collected is subjective, so the workshop has only supported further research directions. It has been based on the following question and is thoroughly discussed by a planner, process improvement officer, life cycle coordinator and manager operations engineering.

What were bottlenecks in the production of complex, high volume,
spare parts within the assembly hall

Through different stages, which contain several steps (see guiding principles of Alänge (2009), information has been collected, grouped, levelled and correlated that eventually led to the three most influential factors and concluding statement. The three factors are chain synchronisation, material accessibility and factory layout. Combining these with the correlations the concluding statement can be formulated.

Occurring bottlenecks were chain synchronisation, material accessibility and
factory layout, where the future assembly flow influences
the capacity levelling via process design

The results (found in appendix H) were utilised to perform concentrated research action to determine and proof applicability and weight on the research questions. Individual findings were further analysed to get a deeper understanding and can be found in sections 7.3 and 7.5.

3.3.3 Interviews

Chadwick et al. (2008) states that the most ways to gather empirical data in qualitative research are through focus groups or through interviews. For this project the choice has been made to gather the qualitative data for the first impressions of the company through interviews. It is then stated that there are three methods to perform interviews: structured, unstructured and semi-structured (ibid.). In a structured interview the questions are prepared and set, which means that there is no room for follow-up questions and thus does not give the opportunity for an in-depth analysis (Chadwick et al. 2008). Unstructured interviews have a minimum to no organisation whatsoever, and the questions are not based upon ideas or theories. This can make these interviews very time consuming. The last structure is the semi-structured interview, which consists of several predetermined questions. This gives the interviewer more flexibility and also allows for a more open answer and additional information that was not thought of when writing the interview questions (ibid.).

The interviews that were held at voestalpine were conducted in a semi-structured matter to ensure a certain grip on the subject, but also to have to possibility to ask follow-up questions and go into detail when needed. Furthermore, the interviews only contributed to the preliminary stage of the research to get a first impression on certain topics. The main interviewees were planners, process improvement officers, shift managers, life cycle coordinator and project champions. The quality of the interviews, group meetings and brainstorm sessions were ensured due to the usage of Scheinberg's (2017) methodology and the testing phase. Often the interviewees had a busy schedule and to keep a certain flow within the interview it was necessary to set direction, but was interesting to deviate when desired.

3.4 Trustworthiness

To ensure the quality, the trustworthiness of the findings and recommendations has been considered. Triangulation, which is the use of multiple sources, has been used throughout the process (see figure 7). Moreover, to ensure the trustworthiness, Bryman and Bell (2015) suggest four criteria to evaluate this trustworthiness which includes credibility, transferability, dependability and confirmability. The first criteria, credibility, is ensured through the transcriptions of the company interviews to check and confirm the analyses, findings, results. This process is called respondent validation (ibid.), which was done in weekly meetings and feedback sessions with people from different layers within the company. Transferability was increased through thorough documentation of the findings and by following and executing the chosen methods. Throughout the whole process, documentation and records were kept ensuring that the appropriate procedures had been followed. By doing this, the dependability of the project was strengthened. Lastly, the confirmability has been ensured, which was done by making sure that personal values did not interfere with the research and the project. Analytic induction has covered the guidance and analysis of data capturing through the various methods (Bryman and Bell, 2015).

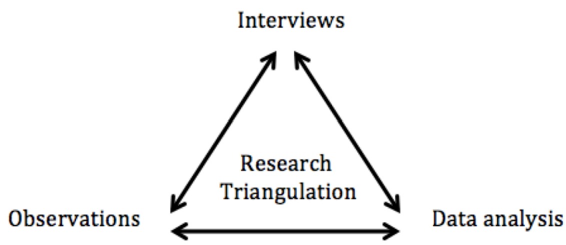


Fig. 7 Research triangulation (Bryman and Bell, 2015)

3.5 Ethics

Ethics within research has four aspects to it, namely harm to participants, lack of informed consent, invasion of privacy and lastly deception (Bryman and Bell, 2015). To keep these ethics high throughout the project, people have been treated with respect and any information that they have given has been handled in a discrete manner by e.g. anonymous interviews. Interviewees were given the possibility to participate in the interview based on background information about the interview. Full transparency towards the participants but also in general has given stakeholders more insight and knowledge. Both the industrial and the academic stakeholders were kept up to date to make sure that code of conduct was held. Scheinberg (2017) discusses four aspects on the check-in and check-out principles that were used at all times.

4 Analytical Framework

Literature research will be done in order to create a broader understanding of any similar cases, background information and to establish an analytical platform that will support the research questions. This chapter aims to answer research question 1. The literature study will increase credibility and substantiate arguments towards a strong statement (Bryman and Bell, 2015). Scientific databases as Google Scholar, Chalmers library and ScienceDirect was used as main search databases as their database is large and the literature is often found relevant and trustworthy.

The analytical framework first highlights individual lead time influencers before it elaborates on paradigms, models, systems and other principles. The influencers together with the time compression paradigm are merged into a cause-effect diagram towards lead time. PPC (Production Planning and Control) and planning manners are then discussed to view the production on a more holistic level. Lastly, mapping of the factory is discussed in terms of layout and VSM (value stream mapping). This chosen structure will strengthen awareness and clarity, so the discussion of research findings is enhanced.

4.1 Lead Time Influencers

The term disturbance has a wide meaning and could be interpreted differently, e.g. disruption, failure, error, defect, loss and waste (Bellgran et al., 2002). Therefore, specification and classification are required to allow further discussion on the topic. Ylipää (2000) describes disturbance as "All the activities that are carried out or should be carried out in correction, prevention, and elimination of production disturbances and potential production disturbances in both existing and future systems during their life cycles".

Bottlenecks are any process activities, constraining organisation performance (Hill, 2011; Slack and Lewis, 2005) which arise from any type of process disturbance (Fitzsimmons and Fitzsimmons, 2008). A bottleneck analysis is defined as systematically locating bottleneck areas and defining their causes, and/or problems within the system (de Bruin et al., 2005; Zhang et al., 2007). To understand a bottleneck, one has to have a greater understanding of the larger system as no parts of the system move faster than the slowest bottleneck component (Slack and Lewis, 2005; Belasco, 1998).

To investigate disturbers influencing lead time, Johnson (2003) analysed four different lead time reduction cases in four different plants, multiple queueing theory principles and studied previous research papers on time reduction factors. His conclusion is that there are five main categories influencing the lead time (processing time, production and transfer batch sizes, setup and move time, variability and utilisation), where internal categorical interactions also have an influence.

4.1.1 Production Time

Lead time is defined as the sum of the cycle time per single product, the changeover between two identical products, the lot size, the defect rate percentage and the machine downtime (Wacker, 1996). Extracting the downtime will lead to the production time and dividing that by the lot size result in the cycle time of a single product (Suresh and Meredith, 1994; Johnson, 2003). These three types of times need to be understand clearly to be able to enhance research actions. A more visual representation of this can be seen below in figure 8.

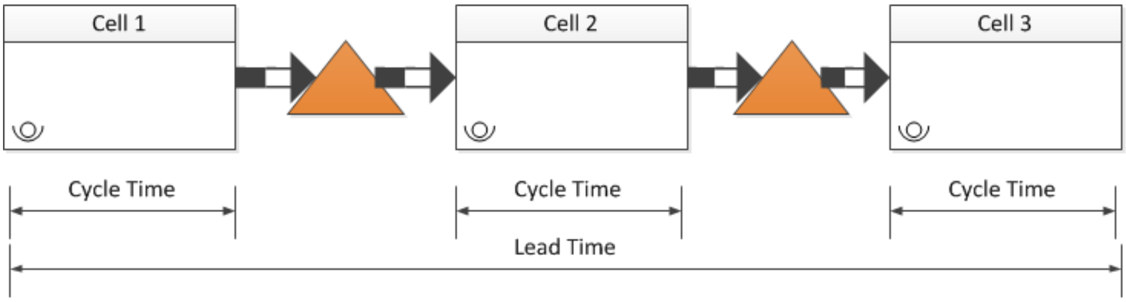


Fig. 8 Definition of time

Internal benchmarking is the comparison between the present state and theoretical worst-case scenario, which can be enabled by Little's law relation between WIP (Work in Process), throughput and lead time (Hopp and Spearman, 2008). Ignizio (2009) has found a distinct relation between lead time and factory loading, where the lead time increases with a higher workload as will be discussed in the utilisation section. This relationship should be considered when evaluating the performance of a factory, where often both the relationship and the performance are visualised through factory performance curves. The comparison of different factory lead times as a benchmark is only fair when the factory loading is consistent. (Jonsson and Svensson, 2016)

4.1.2 Active- and Passive Waiting Time

The second category that causes a potential difference in lead time relates to waiting time of semi-finished products that still require further processing before they can be considered as final products. The waiting time can be distinguished between active- and passive waiting time. Active in this context means physically located at the operational step and passive is waiting to be activated. See figure 9 for a schematic diagram and both will be described respectively underneath.

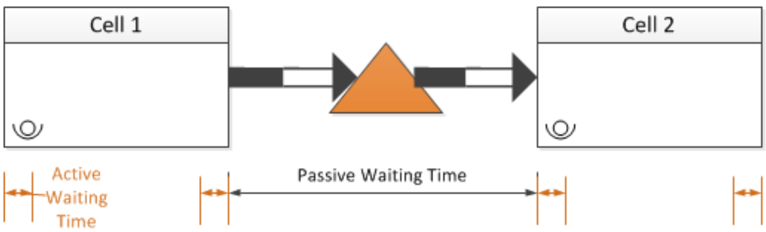


Fig. 9 Active- and passive waiting time

Johnson (2003) defines the production batch size as the number of similar parts that are processed before a workstation is transformed to process different parts, i.e. one production routing. An ordinary batch in the automotive industry contains multiple parts of the same product that require an identical production step, however often cannot be processed simultaneously due to equipment restrictions. Therefore, products have to wait before being processed, i.e. wait-in-batch time, and wait until the entire batch has been processed before the batch can be transferred to the next station, i.e. wait-to-batch (Hopp and Spearman, 2008). This captures the relationship between the size of the batch and the active waiting time per part at the operational step. Lean principles strive for a single-piece production, however, as mentioned before, this is not always applicable. It indicates an adjusted goal to strive for a batch size as low as possible (Kilpatrick, 2003). A trade-off exists between the desire to process many similar products at the same operational step to have a shorter cycle time per product, but causes an increased WIP, and decreasing batch sizes to reduce unnecessary waiting times and create more flexibility.

The latter waiting time includes buffers. Buffers are not active in the current production process, however become essential when operational malfunctions (e.g. breakdowns) or fluctuating capacity occurs. It can deliver products to the ongoing process when the predicted process is lacking, so operational steps will not experience unplanned stops, i.e. starvation (Petersson et al., 2010). Unfortunately, when not needed, these products remain passive and push inventory costs and quality risks (Burns et al., 1985).

4.1.3 Preparation for Processing

This preparation category contains the movement of materials and changeover of machinery. The movement includes any transportation of raw materials and (semi-)finished products from and towards machinery, inventories and expedition (Gevers Deynoot et al., 2015). The needed components are prepared and brought to the workstations. Increasing distances and activities will directly increase move time and, therefore, affect the total lead time (Johnson, 2003). Childerhouse and Towill (2003) have analysed 32 industrial case studies to study value chain optimisation that would increase effectiveness and efficiency of operating practices. It proves that there is a constant underlying principle that remains the basis to achieve the highest results. This principle refers to the simplicity of material flow. It holds the key to decreasing the movements of materials (ibid.)

The changeover is defined by Anupindi et al. (1999) as the cleaning, resetting, or retooling of equipment in order to be able to process a specific product. The higher the lot size, the lower the total unit load and thus the higher the capacity. This means that the lower the lot size, the lower the inventory and, using Little's law, the lower the flow time (ibid.). The previously described changeover activities could be performed either whilst the machine is still running or being shut down. Preferably all changeover activities for the next operational step will completed without an inactive machine. This reduces the time that a machine is not operating during the changeover, thus decreasing the changeover time and cost. The goal is to externalise as much of the changeover activities as possible and perform these tasks in parallel with uptime machine operations, i.e. strive for methods such as SMED (Single-Minute-Exchange-of-Dies) (Hopp and Spearman, 2008; Cakmakci, 2009).

Enhancing move- and changeover time could also be done by restructuring manufacturing systems, so operations become more adjustable to required rapid changing situations. Redesigning machinery in such a way that it becomes more flexible or even reconfigurable. Figure 10 presents a simplistic engineering example of a dedicated-, flexible- and reconfigurable manufacturing system. Changing dedicated systems into flexible manufacturing systems will result in the ability to manufacture a higher variety of products, however still with the certain existing product restrictions (Koren and Shpitalni, 2010). A reconfigurable manufacturing system allows for an even more rapid change in its structure in order to quickly adjust production capacity and functionality in response to changing market requirements (Mehrabi et al., 2000; ElMaraghy, 2005)

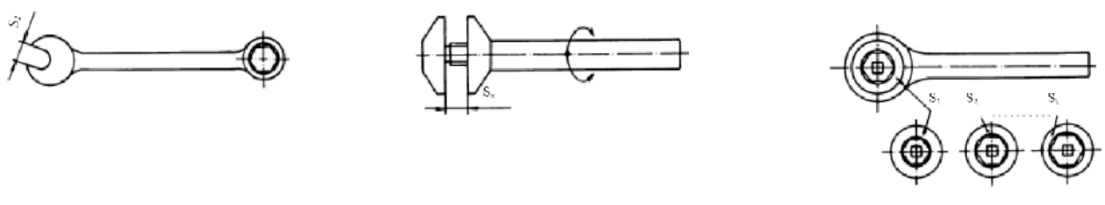


Fig. 10 a. Dedicated- b. Flexible- c. Reconfigurable system (Sirca, 2008)

4.1.4 Discrepancy

A part of an organisation's competitiveness originates from the ability to be flexible to meet and exceed customer expectations (Grigore, 2007). Striving for a customer-focused production, this flexibility can be categorised into four segments (Calantone and Dröge, 1999). The first two segments are more internal aspects and concern the mix- and volume variation (Salvador et al., 2007). It defines the ability to customise the order in perspective of the product, process and quantity. The latter two segments cover the external aspects; flexibility towards distribution/access and responsiveness to target market (ibid.). Respectively, these aspects describe the distribution network abilities and a more general ability to meet the customer's need (Stevenson and Spring, 2007).

The internal variation disturbs the desired synced process and consists of controllable- and random variation (Hopp and Spearman, 2008). Controllable variation refers to process-specific parameters that have been consciously decided on, due to prioritisation- or preferences reasons. Variation in routing times, batch sizes or transportation are set, so certain production paths become more synced. However, this directly translates into other paths being unbalanced. Parts wait for other parts to be assembled together, which increases the inventory and passive waiting time, i.e. wait-to-match time (ibis.)

Unfortunately, events also occur beyond control and prediction, i.e. internal deviation. These random alterations include e.g. unplanned downtime of machinery, human errors and material handling issues. They are difficult to predict, however could be prevented or minimised by periodic controls (Chang, 2014; Hopp and Spearman, 2008). In case of material handling issues, this could be classified as a tangible disturbance and, therefore, has the probability to be either reduced or even eliminated in future practise. Reoccurring problems form the basis for standardised solutions in the purchasing department and enhance upcoming transitions (Bellgran & Aresu, 2003).

4.1.5 Utilisation

Law (2016) defines the last category as the ratio between the output of an operating system versus its capacity. Variability and utilisation are closely related, as variability has a lesser impact on the waiting time if the utilisation of a workstation is low. A low utilisation of a machine means idle time and access capacity, thus when a batch has a high variability the machine is likely to have the capacity to intercept this. On the contrary, if the utilisation of a cell of machine is high, it is unlikely to have idle time or overcapacity. When a batch arrives at this station, it will have to wait until there is capacity for it to be processed. This relationship increases the overall waiting time, resulting in a longer queuing time and the average lead time per part (Johnson, 2003).

The utilisation also depends on the production uncertainty. According to Galbraith (1973) uncertainty is the difference between the required information to perform a task and the information that is already in possession. Ho (1989) then states that within production processes there are two groups of uncertainty; environmental- and system uncertainty. Environmental uncertainty includes e.g. supply- and demand uncertainty, and any other uncertainty that is beyond the production process. System uncertainty is everything related to the production process, e.g. operation yield-, production lead time-, quality- and failure of systems uncertainty (Ho, 1989; Aytug et al., 2005). This is also called "process uncertainty" and affects the utilisation of the process, where the uncertainty upstream is called "supply uncertainty" and downstrain "demand uncertainty" (Angkiriwang et al., 2014).

Kingman's formula describes the relationship between variability (V), utilisation (U), time (t) and their effect upon the expected waiting time in queues (CTq) that work for exponential- and normal distribution (Hopp and Spearman, 2008). Kendall's notation is a classification of a single-station, single-job-class queueing system, where its notation is often used to describe the sort of distribution used in the Kingman's formula. Production systems are often non-exponential and have many process time distributions, requiring a normal distribution. The formula below is based on normal distributed interarrival times, process times and with a single machine at the station.

$$CT_q = V \times U \times t$$
$$\approx \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u}{1-u}\right) t_e$$

Eq. 1 The expected waiting time (Hopp and Spearman, 2008)

Ca is the arrival coefficient of variation and Ce the coefficient of variation of the production time. If the variability is less than one the congestion for a normal distribution will be smaller than the one for an exponential distribution, and thus the queuing time smaller.

The relationship can also be described graphically (see figure 11). Te is defined as the mean effective production time, which is the minimum cycle time needed independent of the variability. When the variability of the arrival rate is high, utilisation of the machines should be lower to prevent long queueing times. When variability is low, and the process is thus more predictable, the utilisation rate can be higher without causing more congestion. To keep the cycle time close to the mean production time, the variability and the utilisation and their relationship should be considered.

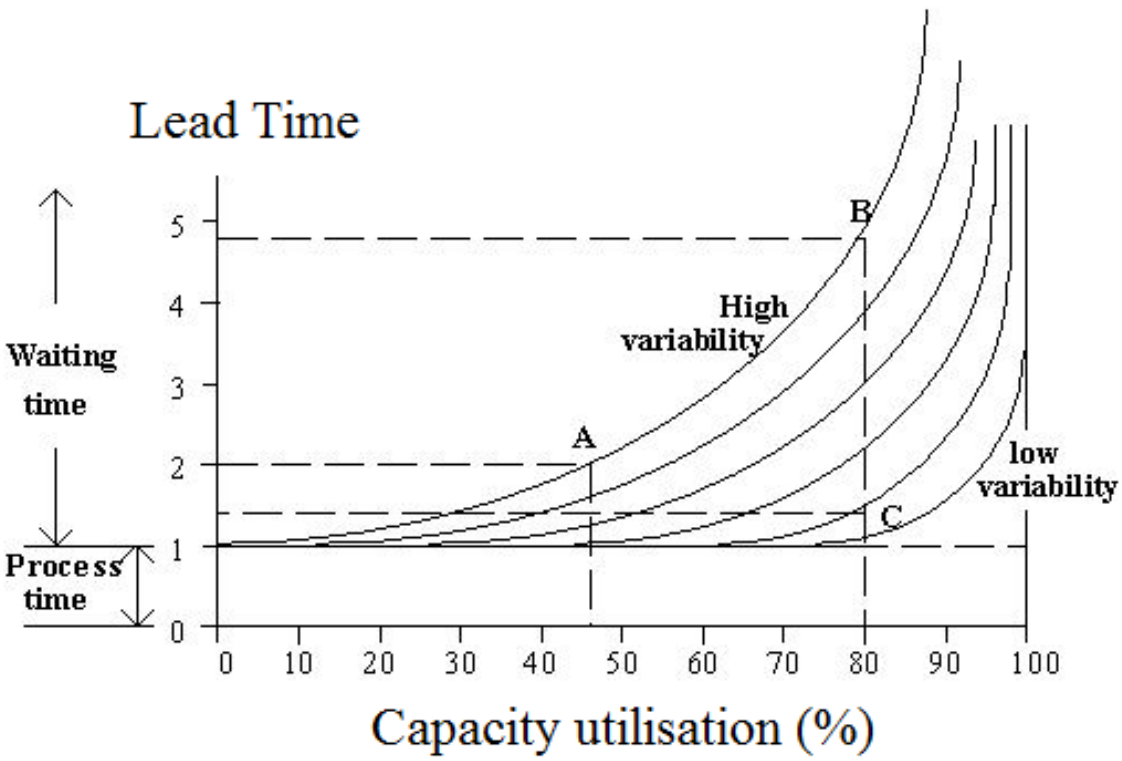


Fig. 11 The relationship between cycle time and utilisation in different variability contexts

4.2 Time Compression Paradigm

Time compression is the elimination, compression, integration and concurrency of activities (Towill, 1996). The four different tactics are defined in table 1 below, taken from the same article:

Tactics adopted	Engineering procedure
Elimination	Remove a process
Compression	Remove time within a process
Integration	Re-engineering interfaces between successive processes
Concurrency	Operate processes in parallel

Table 1 Tactics for time compression (Towill, 1996)

The elimination of activities is often discussed as a means of reducing lead time, with a focus on value adding- and non-value adding activities. The latter consists of necessary- and unnecessary activities, where the unnecessary should be eliminated or minimised where possible. The value adding- and necessary non-value adding activities ask for thorough research, so reduction does not harm the current state. In the table above, this is referred to as compression, i.e. removing of time within a process. (Bergman and Klefsjö, 2010)

Less often discussed is the integration of activities to reduce lead time. Through integration, the value added production time of both activities remain, whilst any steps in between are merged. To understand which processes can be integrated, VSMs (see section 4.6.2) have to be drawn and agreed upon by all stakeholders. The stream charts have to be a realistic representation of what actually happens throughout the process (Womack and Jones, 1994). Within a process, there are often hidden elements that could be important candidates for elimination. These are often overseen and thus often non-value adding (Thomas, 1990). Very few managers have a complete picture on all supply chain processes until thorough research, e.g. flow charts or VSMs, has been executed (Towill, 1996).

Integration often leads to both elimination and compression, as two or more operations are merged into one. This means that supporting processes also only have to be done once (e.g. material handling, transport and picking). Any time in between the two processes (e.g. waiting time) is completely eliminated. Companies often refer to the overarching concept *Business Process Re-engineering* (BPR) and have shown remarkable improvements, where a cascade of operations experience a re-sequencing to postpone variety (Evans et al., 1995).

The time compression tactics can be categorised into industrial-, production-, information- and operation engineering improvements, as can be seen in table 2. Each category has different techniques of achieving the time optimisation, where the integration and sequencing of processes both belong to production improvements.

Strategy	Technique	Example
Industrial engineering improvements	Set-up time reduction	Single minute exchange of dies
	Handling methods	Container design and conveyor use
	Product design	Design for manufacture
Production engineering improvements	Integration of processes	Combine two processes into one
	Sequencing of processes	Resequencing to postpone variety
Information technology improvements	Quicker and more accurate data capture	Barcoding on order paperwork and/or materials packaging
	Electronic data interchange	Orders, funds transfer or engineering designs transferred instantly
Operations engineering improvements	Kanban	Production controlled via actual orders
	JIT supplies	Greater frequency and smaller quantities
	Shared call off information	Improved service levels through lower forecast errors

Table 2 Practical ways to achieve time compression (Mason-Jones and Towill, 1999)

By reducing the total lead time through compression, the supply chain will gain reliability and stability. The noise and its negative effects will decrease due to a shorter time horizon, which then allows the company to reduce its (safety)stocks, buffers and WIP. Subsequently the flexibility of the production process also increases as e.g. more capacity opens up, cycle times become shorter and waste is eliminated. However, the decrease of uncertainty is more a secondary effect of the time compression. Increase market competition and globalisation demands a short TTM where time compression can be a very effective manner of achieving this. (Mason-Jones and Towill, 1999)

4.3 Cause-Effect Diagram

All the above factors are aspects that have a direct influence upon the lead time; either as a category, a primary- or secondary cause. An Ishikawa diagram shows the relationship between cause and effect, where its purpose is to identify the different causes to the identified problem. After grouping and levelling of the above-mentioned causes, they should be clarified and discussed. (Law, 2016)

The different categories discussed are utilisation, preparation, production time, discrepancy and waiting time, each with its own causes. E.g. a reduction in waiting time will also lead to a reduction in lead time, where the waiting time is the cause and the lead time is the effect. The time compression paradigm is a part of the production time cause, since it has a direct influence on this matter.

The Ishikawa diagram below shows the relationships for this specific research case as found important during literature studies. It covers the most relevant causes, but might not be all-embracing for other situations.

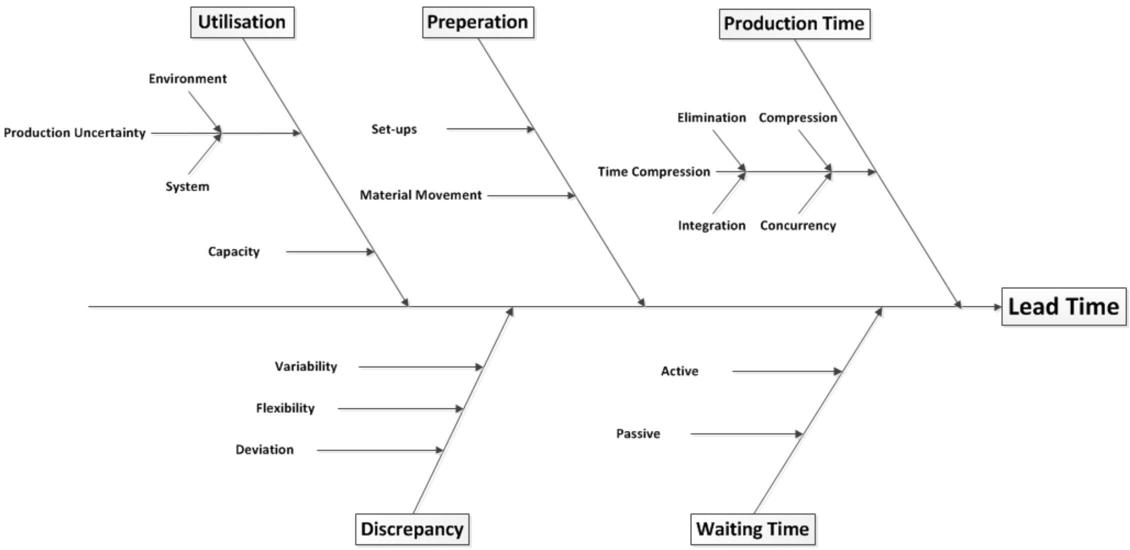


Fig. 12 Cause-Effect diagram for lead time

4.4 Production Planning and Control

Organisation experience discrepancies between a production system and its accompanying control system. The frequent improvements on the production system enable the organisation to answer to rapid changing needs, however in course of time, the production- and control system are not showing any similarities and have to be adjusted (Verweij and Zwegers, 1998).

After any decisions have been made regarding the production system, production process or product design, the PPC can be initiated. PPC looks at a production line, its efficiency and the economic health, and strives for high effectiveness and efficiency. (Shethna, 2017) There are different PPC models used in literature, but a division is always found between production planning and production control (see figure 13). In section 4.5 more specific planning methodologies affection the MPS will be discussed, including ways of planning (push vs. pull). Below the main functions of the model are discussed, where several different views upon the models are combined to one.

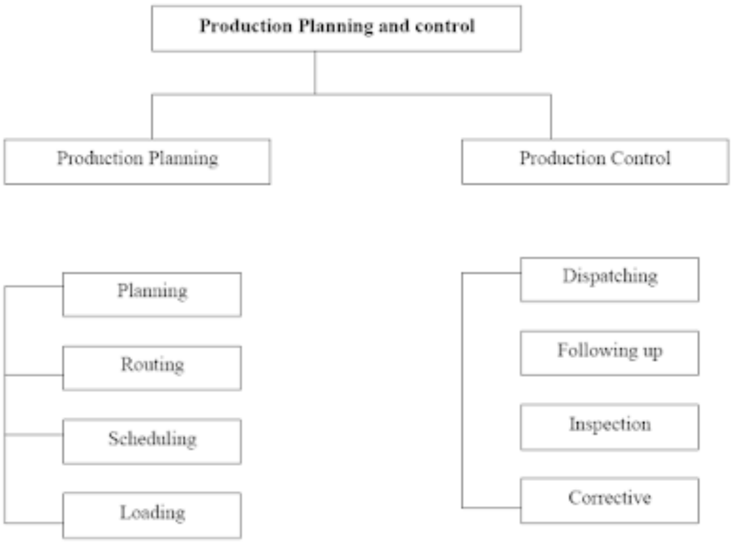


Fig. 13 PPC model (eSupplyChain, 2008)

4.4.1 Production Planning

The production of a product is often the most challenging phase, which essense an effortless production planning process. The production planning puts the entire production process into motion and includes performing the right tasks at the right time under the right circumstances in the right environment. Utilising the correct decision tree is vital as one needs to have a strategy for what to prioritise. These decisions also depend on the type of production system, often divided into unit-, continuous- and intermittent production. The production planning includes the routing-, scheduling- and loading of products. The long-term view should include objectives, such as the availability of materials at the right time in the right quantity, and complete utilisation of resources whilst continuously comparing to and updating the forecast. (Vaishnavi, 2011; Shethna, 2017)

4.4.1.1 Routing

The first step in planning is scheduling products or materials throughout the production line. This includes the layed down path and order of the various operations that will be done. Operational steps, the arrangement of operations in their sequence, material handling, transportation, storage and deterioration are all part of the planning (Shethna, 2017). In a detailed routing plan, the required quality, production system, amount and quantity involved, specific workstations and manpower are displayed. A generalised routing is established based on building or department numbers (Vaishnavi, 2011).

The purpose of routing, besides planning, for the project managers is to find the most feasible and economical solution, whilst keeping in mind a high utilisation of both physical and human resources. This always has to happen in collaboration with quality management to ensure the achievement of the set standards (Guide et al., 1999). When the routing comes close to the realistic production, it can be used as a basis for a higher-level planning system to elongate the scheduling forecast, e.g. a Material Requirement Planning (MRP) or Master Production Schedule (MPS).

4.4.1.2 Scheduling

This is the next step under routing, where the different times of the processes, machines and resources are calculated. The sum of these times is needed for the entire chain of steps from raw material to finished product. It enables, together with availability of the resources, a planner to plan the production of a certain product (Guide, 2000). Scheduling this determines when operational steps are being performed, or when a product needs to be completed (Vaishnavi, 2011). A planner must be flexible and able to prioritise flows and patterns to yield, since capacity is limited. Uncertainties such as rush orders, machine breakdowns and absence of operations need to be adaptable (Sipper and Bulfin, 1997).

4.4.1.3 Loading

Scheduling and routing merge and are executed in the loading step. It is the total of work assigned to the machines and operators, considering the numbers of parts that need to be processed in the given cycle time (Georgiadis et al., 2006). The load of each routing point and the scheduling of an activity are checked for resources and support. This is also where the assignment of individual operations takes place and where the efficiency of the process is trailed. This efficiency is then compared to the ideal scenario and possible simulated situations, where the pace of the process and the capacity can be set (Vlachos et al., 2007)

4.4.2 Production Control

The controlling part ensures that there is a level of monitoring over the production, its accompanying workflow and the necessary resources. Any adjustments upon those could be done during the controlling phase. Companies aim to regulate inventory, achieve the highest utilisation of resources and carefully schedule and follow the production plan. Through this aim, a company can achieve cost-effectiveness, minimise waste, maintain its high quality and smoothen the production process. (Shethna, 2017)

4.4.2.1 Dispatching

Vaishnavi (2011) defines dispatching as starting the production activities, through e.g. the release of production orders, instructions guided by routing cards, operational sheets and loading schedules. The releases act as the fuel for the progression of the production line. For each activity and task, the effort, time and cost are recorded and added to the routings before moving towards the next step (ibid.). Dispatching requires high levels of communication and coordination between all departments, thus a high level of production control is needed (Framinan et al., 200). When there is a change in situation, e.g. a rush order, the production can be loaded with a higher capacity and last-minute changes. The original schedule might be changed to start operations immediately in order to prioritise the rush order and satisfy the client's needs.

4.4.2.2 Follow-up

Follow-up ensures that the planned production is achieved as it follows orders and ensures that these are up to standard containing the right paperwork. This process includes the preparation of the tools and materials on time, and the determination for possible and visible bottlenecks that prevent smooth flow. Any deviation from the planned production is reported, which should then be analysed and communicated back to prevent from happening again. (Vaishnavi, 2011; Shethna, 2017)

4.4.2.3 Inspection
Duri et al. (2000) states that performance has to be evaluated through inspection. Where follow-up is mostly corrective, inspection is more of a preventive measure of production control. It includes periodic audits and inspections as a means towards maintaining the right quality of the product.

4.4.2.4 Corrective
Corrective includes all the deviations found in the previous control steps. During the corrective action, action plans are written and reported outliers are discussed. A correction can include the adjustment of the routing, the rescheduling of operations, the priority of certain orders or tasks or individual performances. Tools, machines, methods and techniques are reviewed and updated or adjusted if necessary. Possible investment might need to be needed to update the process, e.g. new machines or training for the personnel. (Vaishnavi, 2011; Shethna, 2017)

4.5 Enhancing the MPS

A MPS is a predefined plan that establishes the quantity and planning of materials to support production forecasting, i.e. it drives the execution of the MRP (Lu et al., 2012). It does not necessarily have to be applied to the entire product portfolio and the fixed character enhances chain stability. The challenge lies in environments with scheduling uncertainties, since MPS relies on the plan. The quality of a MPS could be improved by freezing it or adopting a hybrid manufacturing strategy (Tang and Grubbström, 2002)

4.5.1 Freezing the MPS

The policy of MPS freezing means that no changes in the production planning can occur for a certain time frame (Zhao and Lee, 1993). This includes the freezing of production for the same time period, thus for this period i.e. the products, capacity and operators are set. It contradicts the desire to be responsive to changing customer needs, however continuously adjusting the MPS develops unstable and uncontrollable schedules, ending up in increased manufacturing-, reliability- and inventory costs (Sridharan and Berry, 1990). The stochastic demand of the aftermarket and freezing the MPS are diametrically opposed.

4.5.2 A Hybrid Manufacturing System

To fully understand the adoption of a hybrid manufacturing strategy the core underlying concepts need to be understood (see figure 14). In a pure push manufacturing strategy, the production- and information flow behave in the same upstream direction. Production orders are initiated by a signal that is driven by the horizon projection of customer demand (Hopp and Spearman, 2008). Meanwhile, a pure pull- and CONWIP (Constant Work in Progress) manufacturing strategy is based on the demand of a customer (Spearman et al., 1990). Therefore, the information flow behaves downstream to signal the upstream production flow. Either the production flow is triggered by its successive upstream operation (i.e. pure pull) or by a signal that triggers the first operation (i.e. CONWIP). The choice between the latter two strategies depends on the nature of the planning structure (ibid.).

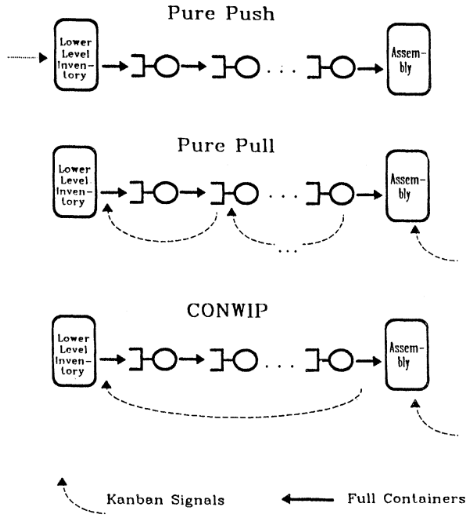


Fig 14 Push-, pull- and CONWIP strategy (Spearman and Zazanis, 1992)

Industries adopt a pure pull or CONWIP manufacturing strategy to allow for a production frequency that is based on the demand of the customer, which will be beneficial for e.g. waste reductions, unnecessary WIP and quality risks (Renna et al., 2013; Anupindi et al., 1999). In the context of spare parts, this order is based on desire and not on necessity. Resulting in a customer demand with a higher order flexibility, even though time to delivery remains (barely) untouched (Krupp, 1993). To respond on these challenges, a hybrid manufacturing can be conducted. Two integrated push-pull manufacturing strategies provide the needed agility; bottleneck focused and BOM (Bill-of-Material) controlled.

4.5.2.1 Bottleneck Focused

The overall production pace is as fast as the slowest production step, i.e. the bottleneck dictates the throughput per time frame (Li et al., 2009). This implies that the integration of a push- and pull system lies at this point and should be therefore always be producing. This implies that all operational steps prior to the bottleneck follow a push strategy, whereas the remaining operational steps follow a pull strategy (Olhager and Östlund, 1990).

4.5.2.2 BOM Controlled

The BOM could contain a complex structure, where multiple branches are attached to the critical production path of the product (Kashkoush and ElMaraghy, 2016). Figure 15 shows that the red path is defined as the critical path, indicating that the point of integration between push and pull is located on the intersections at the buffer before operational step six. The critical path determines the longest lead time, so should be pushed (Olhager and Östlund, 1990).

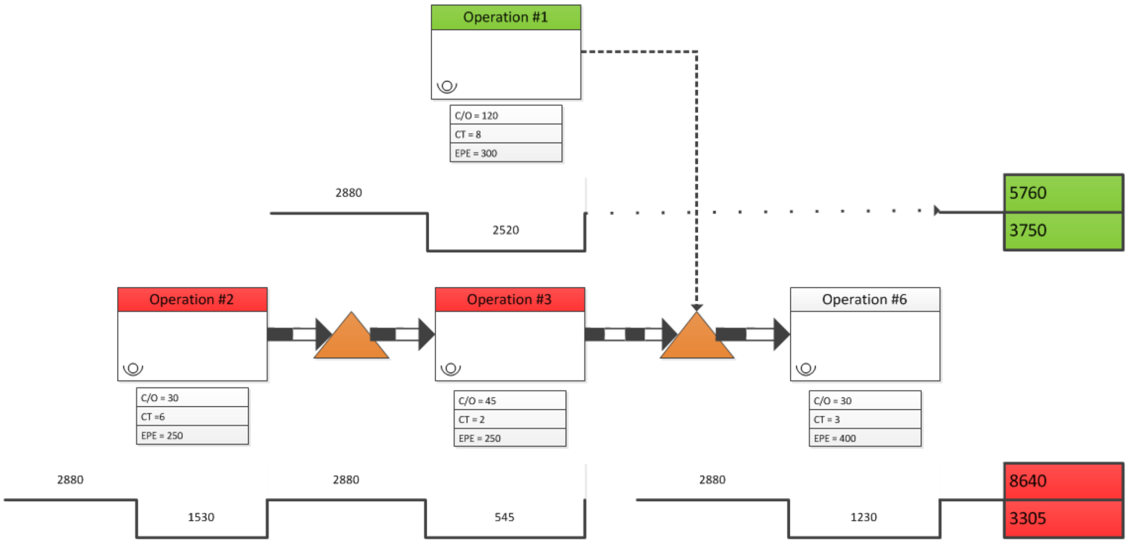


Fig. 15 Integrated push and pull strategy based on structure

Applying an integrated push- and pull system does cause a dynamic manufacturing system, where different production paths require different production rules. The push-part still creates buffers and is sensitive to forecast errors, which could lead to over-capacity of operational steps if not acknowledged. Meanwhile, this same part outperforms the pull-part in terms of time to delivery and could be restricted by the low buffer level. Therefore, careful planning is crucial (Masuchun et al., 2004)

4.6 Facility Layouts and VSMs

Determining the movement network of materials will increase the understanding of processes and possibilities for improvements. The behaviour of a network depends on the product portfolio and current strategy of a company. Mapping the movements will reveal the production layout and identify value adding and non-value adding activities.

4.6.1 Functional- and Flow Layout

In a functional layout the different operations are clusters according to similar processes, e.g. milling-, drilling- and welding clusters. Therefore, this layout is also known as process layout (Nicholas, 1998). Material moves from one function to another, where (almost all) operations in a specific function are able to perform identical handling to create planning flexibility, prevent stoppage of production and strengthen supervision (Anupindi et al., 1999). Unfortunately, the flexibility does have a disadvantage that causes wastes and complexity, e.g. the five milling operations in figure 16 are able to perform the same job. This means 5! = 120 planning possibilities (Nicholas, 1998). The functional layout illustrated below shows the production of a product that follows an irregular path across four functions. This weaving pattern can be identified in a spaghetti diagram and implicates the material movement flexibility, however complexity as well (Liker, 2004)

Another facility layout can be characterised as flow layout. Operations are physically located in a such a sequence that material movements are organised and predicted (see figure 16). When processes indicate repetition and continuity flows of similar products can be arranged based on the required operations of the products, i.e. product layout (Nicholas, 1998). Each flow has the ability to produce a certain group of products, since the cells are configured specifically for those. This immediately points out the benefits of a flow layout. Due to a smoother material movement, the WIP will be lower and utilisation of machinery can be optimised (Liker, 2004). Dedicating a layout to a select product group does mean that planning flexibility decreases and output capacity is restricted in the short term, since layout is designed and balanced on the current state (Nicholas, 1998)

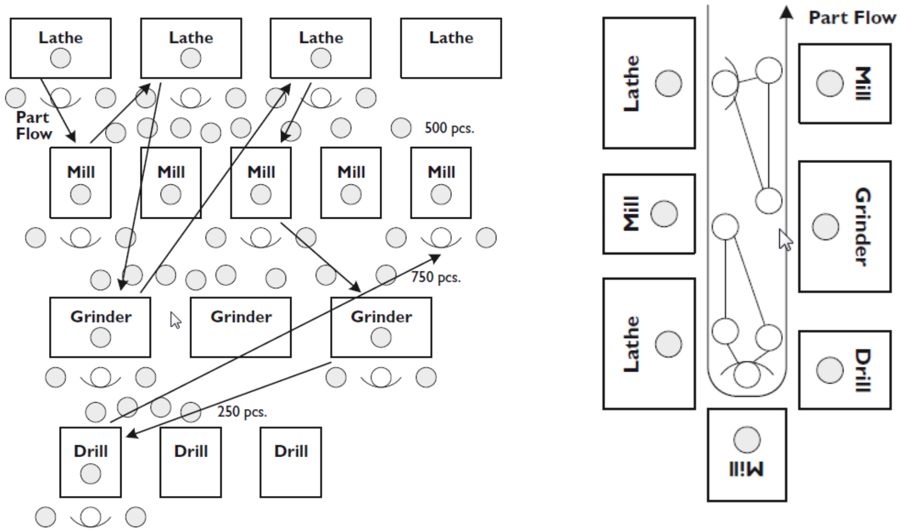


Fig. 16 Functional- (left) and flow (right) layout (Liker, 2004)

There are many different ways of supplying the cells with necessary parts, depending on the layout of the floor some are more suitable than others. In figure 17 the main ways of supply are covered. One way to supply a flow layout is by utilisation of decentralised in-house logistics, called supermarkets. Tow trains with parts successively drive past the cells according to schedule, to JIT (Just-In-Time) replace the empty bins with full ones. Both the layout and the warehousing methods influence the means of transportation, though also restricted by the products.

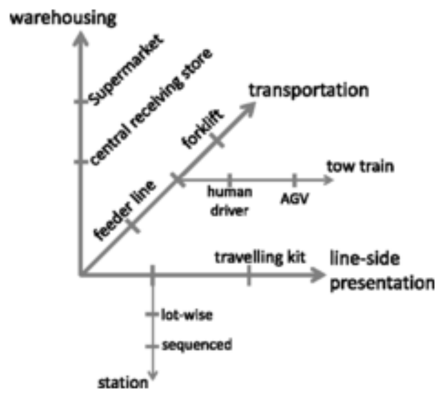


Fig. 17 Different ways of supplying cells (Battini et al., 2012)

4.6.2 Value Stream Mapping

As indicated previously in the time compression paradigm section, VSM is a tool utilised to exactly identify all value adding- and non-value adding activities of a productive process (Rother and Shook, 2003). It enables the possibility to not only visualise material flows, but information flows as well to really understand both tangible- and intangible streams (Martin and Osterling, 2014). A VSM can visualise which material movements are occurring and how processed are signalled.

VSM is a preferred tool that could support optimisation projects, since it contains a step-by-step procedure with a relatively low complexity (Braglia et al., 2006). Mapping the process in such a matter allows for thorough inspection and focus on waste, i.e. muda (Rother and Shook, 2003). The procedure starts with a fact-based visualisation of the current state (an example of this can be seen in figure 18), followed by a dream state to establish an overarching vision and ending with a future state that will highlight sources of waste (Braglia et al., 2006). The tool provides a common language for a high understanding among participants and enhanced communication towards stakeholders, so improvements can be endorsed by all (Ramesh et al., 2008).

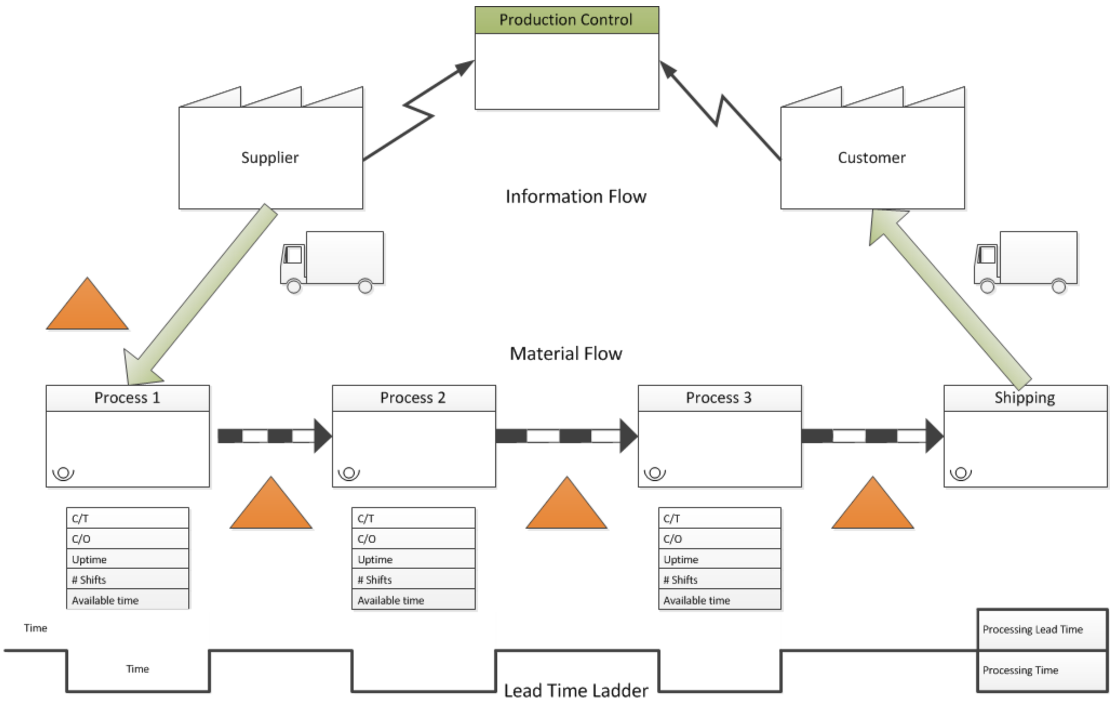


Fig. 18 Example of ordinary VSM

5 Case Description

The case description is meant to give a basic understanding of the ways of working of the case company, the current state and first observations. This chapter aims to answer RQ2.

Approximately one third of the output of voestalpine is meant to serve the aftermarket of the automotive industry and is characterised by multiple car brands, model types and different service contracts. This means that their product mix is large and constantly changing, but it also means that they have many customers with different demands. This requires a high level of flexibility in production, whilst staying competitive. Their customers are well-known players on the market, which reflects into high customer demands and little influence in product engineering. voestalpine delivers the spare parts towards the distribution centers of these customers, thus the supplier of tools can be the same as the customer of the products.

5.1 Lead Times

To produce the forty complex, high volume spare parts that are in the focus for this thesis, currently forty different cells are used in many combinations and routings. Every one of these cells is unique even though some of the main capabilities overlap. The commonality is that all the forty products within the scope are said to have a long lead time in the assembly, where the assembly also makes up the largest part of the total lead time to begin with. An example of the three products with a high lead time can be seen in table 3. The lead time of assembly (in working days) is depicted in purple, whereas the lead time including the press and the EC is green (both in production days and in calendar days, including weekends). Unfortunately, the required calendar days to produce the products is around twenty days longer than the WBZ (Wiederbeschaffungszeit). The WBZ indicates a X days order freezing period before delivery, so required quantity to produce is known. The number of days depends on the agreement with the customer and differs between customers and products. As the current lead times are estimated based on experience, more realistic lead times of all forty products are needed.

Finished Product	Description	LT Assy	Total	Total (Cal. Days)	WBZ (Cal. Days)
718446S00AK	DAG ZB RUECKWANDTUER MOPF X204	30	62	86,8	58,8
718028S00AK	VW ZB HECKKLAPPE GOLF PLUS	30	62	86,8	60
717124S00AK	AUDI ZB HECKKLAPPE B8	27	59	82,6	60

Table 3 Assembly- and total lead time

Multiple visits to production and first interviews with stakeholders indicate a remarkable observation of long lead times in between the assembly steps. These buffers push the WIP-level, however the preliminary investigation has not shown any explanations. To understand the origin of these long intermediate steps the processes will require a more thorough analysis.

5.2 Layout of Assembly

The production of serial parts is often transferred from the customer to voestalpine, where voestalpine tries to fit the product into the current production processes without having too many dedicated operating cells. With this thought, investments were done in universal hemming-, welding- and clinching cells. Cells within assembly can be recognised by their first two numbers (54xxx), whereas e.g. the press shop always starts with 51xxx. In the past, voestalpine would take over entire production lines rather than trying to integrate the new product into the existing production lines. This means that the layout has evolved over the years depending on available space, instead of a strategic idea or optimal long-term solution in terms of flow or design.

In figure 19 the current layout of the assembly is displayed, where the different colours represent working areas, each with their own operating managers and operators. Some clusters can be found (e.g. the manual machines are yellow), however the majority has been randomly distributed, which creates a spaghetti of material movements. The colours do not necessarily represent functional groups, but more the location of a cell or machine. Next to this, due to the size and the construction of the machines, it can be difficult to impossible to relocate cells and machines.

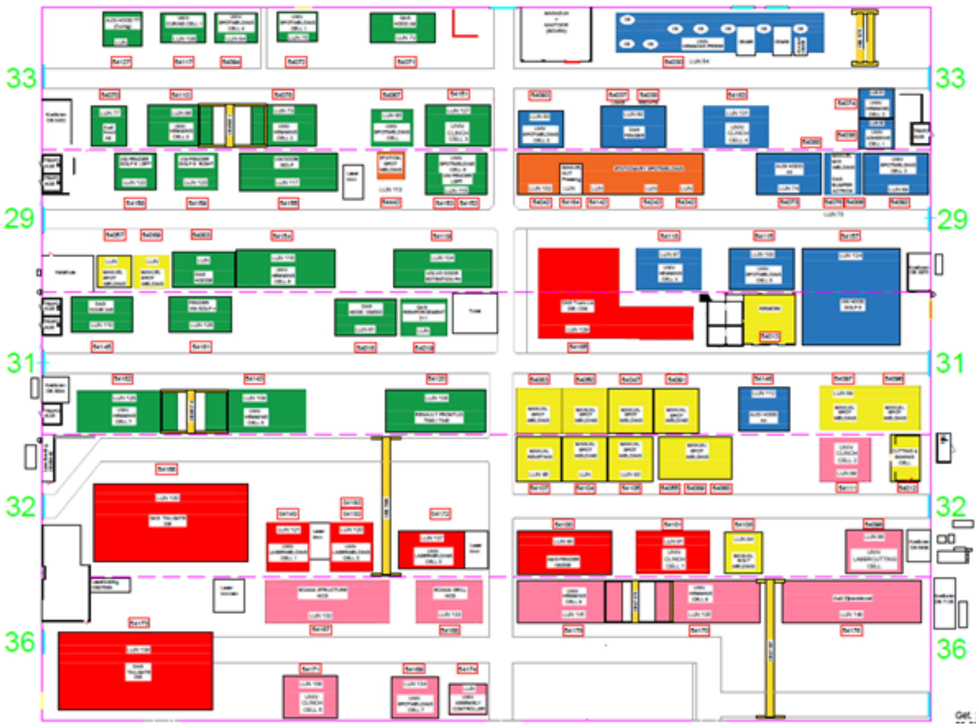


Fig. 19 Floor plan of assembly

5.3 Ways of Planning

The planning of production is based on customer delivery date communicated by the Sales Order department, but the needed production time is calculated with some time allowances and room for errors. This means that products are prioritised upon the earliest date of delivery, pushing the first part of production until the delivery date comes so close that priority to the product is given. After this the required batch sizes are produced according to a traditional pull system, which shows changing batch sizes throughout assembly. Routings are automatically updated in the system, where the successive step will present itself after a previous operation is done. A single routing step is always set to five days, no matter which product, batch size or operational step. MRP is used for the routings of products and for the requesting of materials needed to do operational steps. With dispatching of production orders, and thus materials, the warehouse is triggered with demand for parts at specific cell locations. Every morning, the schedule is updated by the production planner and communicated back to the shift manager and operating managers on the production floor. They give a follow-up of the production output of the previous shift with the purpose that all parties know what has been produced versus what should have been produced. Throughout the day, any major differences or changes are constantly looped between production and its planner, giving a high level of control. It enables follow-up and corrective actions.

For the past months, however, the company has been in backlog with the production causing some problems. The ERP (Enterprise Resource Planning) system does not show the delay, so often the planning is based on experience and intuition. But even if backlog would not be an issue, voestalpine its production strategy is customer demand focused using pull strategies for planning the different operational steps.

Within the five-day routing, SAP has the ability to be filled with other preferences to support planners with programmed suggestions, recommendations and regulations, e.g. adding a customised safety time for operations with a high uncertainty, so SAP helps planning production horizons. Figure 20 presents the entire SAP architecture of a product routing, where a few elements require further explanation. The five days are constructed as follows: two days are allocated for preparation of production (e.g. planning, material handling, changeover scheduling), one day is allocated to the production activities (see lower green bar in figure 20) and the last two days are allocated to possible production delays and material movement. The former and latter two days (called Z22 in SAP) are standard for each production step, no matter the batch size or the cycle time (see planning- and safety time in figure 20). The time in between Z22, i.e. the time allocated to production time (lower green bar), is adjustable, but has been put on a standard x days. Most of the time this comes down to one or two days. The adjustability allows for customised and optimised production routings according to each specific situation. However, in the current SAP environment, all these preferences have been disabled, resulting in a planning based on the intuition of the planner.

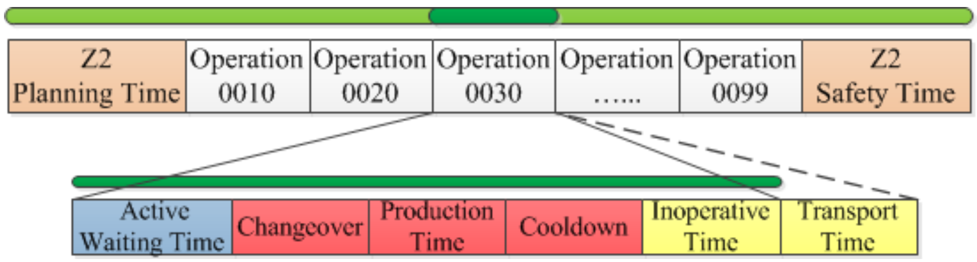


Fig. 20 SAP routing architecture

Freezing the planning for 48 hours has been implemented recently to make sure that the production planning is more reliable. This policy ensures that prior production steps are done before the successive step is planned, meaning that lesser rescheduling will be done and a higher visibility is created throughout the assembly hall. The effect upon production is that after every production step the semi-finished products are brought back to storage until they appear back on the planning. A downside to this is that products are forced to spend more time in inventory. Exceptions exist when multiple operational steps are done on the same BOM level (i.e. WIP-operations), where the semi-finished product is placed temporarily on the PVB (Produktionsversorgungsbereich) before moving to the next cell, but this is limited as much as possible.

Chapter 6 will discuss the product that will be used as an example throughout the thesis, to ensure clarity and visualisation of any improvements and examples. Chapter 7 will discuss and further analysis the current processes to get a better understanding. This information will be used as a foundation to base any research towards possible improvements on, which is then covered in chapter 8. The analysis and suggested improvements will intersect in the concluding discussion of chapter 9.

6 Product Description

One product will be used as common theme and described in detail. It allows for an enhanced understanding of chosen current state analyses, future potential improvements and accompanying discussion and conclusion in the upcoming chapters. The VW Golf Plus backdoor consists of a majority of influential factors mentioned in the Cause & Effect Diagram (section 4.3) and is, therefore, a suitable product to combine findings with a tangible example. Its part number is 718028S00AK. The extension, S00AK, indicates a finished product. If this extension is replaced with HxxAR, the product is not finished yet and can be seen as a semi-finished product within assembly.

The VW backdoor Golf Plus contains three BOM branches, which intersect with the critical path at two different points (Figure 21). The longest branch [54174 - 54151 - 54160 - 54149] is dedicated to the production of the outer part of the backdoor, i.e. the visible side of the door. The remaining production steps of the BOM belong to the production of the inner part. The other two individual branches (two times 54042) on this chain are identical and simple production steps, where two small reinforcements are installed on the inner frame.

Based on production time, the 54169 is the bottleneck cell. Literature states that a bottleneck analysis should be determined by calculating the cycle times (de Bruin et al., 2005). However, since current standard production parameters show different batch sizes spread out over the chain plus one-piece flow is non-occurring, the production time is leading and determines the bottleneck.

The cells 54150 and 54055 are placed in sequence, due to their characteristics. A sequence allows a planner to overrule the 48-hour freeze and plan successive operations straight after the previous operation. In this case, the batch does not return to warehouse until the 54055 is finished. After completing an order on the [54150 - 54055] a planner must follow regulations resulting in a 48-hour freeze before the 54143 may be planned.

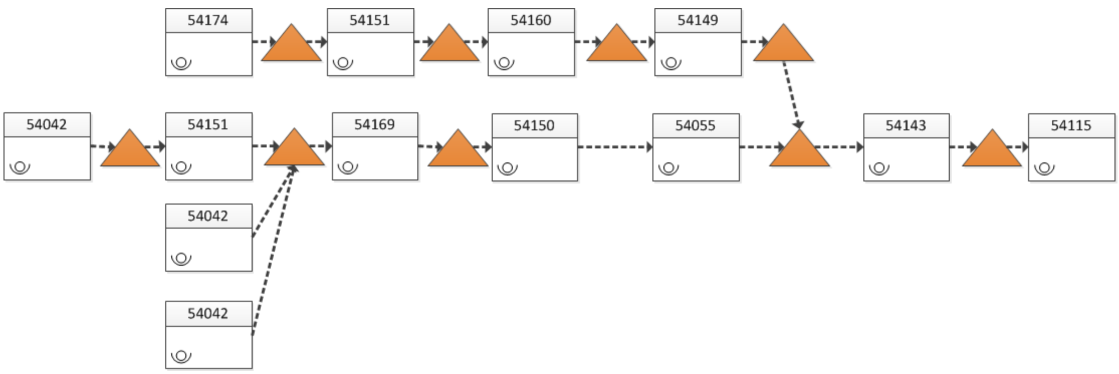


Fig. 21 Production roadmap VW backdoor Golf Plus

7 Current Process Analysis

To be able to reflect on several models to support the aim of the research, the dynamic behaviour of constituent parts needs to be properly understood. Only then a customised overarching solution can be provided that could support the desire to reduce lead times in the assembly department of voestalpine. The following sections will be used to gain a deeper understanding into answering RQ2 and will be used as building blocks for possible improvements.

The data presented in the following chapter will be utilised in successive chapters. It will proceed by analysing these data from different perspectives to give support to the next chapter. The aim here is to define potential major improvements and knowledge gaps to ensure a focused future state analysis. Different elements of the interactive AIM workshop session were further investigated in sections and subsections of 7.3 and 7.5.

7.1 Demarcation of Products and Cells

The current process analysis has been based on the set project scope and could not be executed before thoroughly reviewing and determining the relevant products, cells and accompanying parameters.

Due to the scope of the project, a demarcation has been done over the entire product portfolio of assembly. When including the set research limitations, a product group of forty final products were found with a given estimated lead time of anywhere between 59 and 87 days (see appendix F). Within these forty products, two major clusters of brands were found; Daimler and Volkswagen. Volkswagen covers sixteen of the forty products with some of the highest lead times. Daimler has eighteen products, but are found lower on the list of highest lead times.

As mentioned before, the WBZ is the time communicated towards the customers, meaning that customers need to freeze their order x days before delivery. The given estimated lead time was compared to the accompanying WBZ, where almost all products exceeded it with 1-28 days. To determine the validation of those results, the given estimated lead time needed to be investigated. This lead time was recently based on predictions of the company. The realistic lead times of the forty products required further research and will be explained in section 7.3.2.

The selected product group utilises forty cells (see appendix G), e.g. welding, hemming and clinching. The complexity of the machine park partly originates from the capabilities of the cells, since not all cells are dedicated to one operational handling. A welding cell cannot be seen as ordinary welding, however could either contain solder-, laser-, spot welding or a combination of those three.

7.2 Time Analysis

To better understand the current processes, more realistic lead times needed to be found rather than the estimated ones. A brainstorm session was organised with multiple disciplines to gain more insight into areas of concern in assembly. The found areas were then investigated and contribution towards a long lead time marked.

7.2.1 Critical Path Determination

The average time required to perform each operational step for the production of the final part, i.e. cycle time, is recorded in SAP (Systems, Applications and Products) and was utilised to calculate the critical path of an assembled product. Each BOM has been crosslinked with SAP to determine theoretical- and realistic production time. The longest operational path is equivalent to the fastest operational time and defines the product's highest added value time.

In table 4 the critical path of 718028S00AK has been calculated. Some semi-finished parts are produced in sequence, hence the identical product number (HxxAR). The BOM-branch 718028H11AR has a shorter cycle time than 718028H13AR, since 718028H13AR is the summation of both 718028H13AR and 718028H10AR production steps. Therefore, the latter contributes to the critical path. Including the higher-level results in the total critical path of 1951 seconds per final product (see table 5)

718028S00AK				
Semi-Finished Products	Cell nr.	ICT Time (sec/prod)	Prod. Time (sec/prod)	Critical Steps
718028H01AR	54115	207	240	1
718028H22AR	54143	230	267	1
718028H07AR	54150	160	200	1
718028H07AR	54055	114	144	1
718028H33AR	54149	130	150	0
718028H08AR	54169	255	300	1
718028H44AR	54160	155	189	0
718028H11AR	54042	50	72	0
718028H12AR	54042	50	72	0
718028H13AR	54151	49	58	1
718028H55AR	54151	65	103	0
718028H10AR	54042	31	36	1
718028H66AR	54174	105	120	0

Table 4 Cycle time per BOM-level

ICT Time (sec/prod)	Prod. Time (sec/prod)
1601	1951

Table 5 Total ICT- and real critical path

The theoretical cycle times per operational step support the production planning, however, are barely a precise reflection of realistic production. Production processes can be interrupted or disturbed by several influencers and cause delay. Comparing the theoretical and realistic production times provides an insight in potential system waste during the production process, but will not be investigated during this research.

7.2.2 Lead Times Analysis

For the first demarcation of products, a given list with estimated lead times was used. However, voestalpine does not keep track of its lead times of products. The estimated lead time thus only gives an indication based on experience. When trying to calculate the lead times, difficulty occurs in the varying batch sizes, where the press shop often uses a minimum batch size of 1000 and the assembly assembles in batch sizes of multiples of hundreds. The second difficulty is found in inconsistency of batch sizes throughout assembly, as some semi-finished parts are used for multiple parent parts. Even though a FIFO (first-in-first-out) plan system is aspired, currently only applicable to serial production.

A well-known method for calculating lead times is Little's Law, where the lead time (TH) is found based upon cycle time (CT) and Work in Process (WIP). TH represents how long it takes for one product to exit the chain, i.e. output per seconds per product. The mentioned difficulties in the previous paragraph still influence the calculation, possibly disturbing the outcome of the TH data.

When further investigating the cycle time and the WIP within the company, it is noted that the cycle time does not include the time that parts spend waiting in the buffer before production. The WIP however, does include both the products in the buffer and the productions in the operational step and, therefore, a comparison between the two cannot be made. The assembly chain is characterised by production accompanying fluctuating batch sizes and adds complexity to the determination of lead times. These obstacles summoned means that another method had to be found to make a fair comparison.

To determine more realistic lead times, the new calculation was based on the transfer dates from the warehouse to cells, where the first date was the start of production and the last date the final operation. By following the successive operational steps on date, and verifying these in terms of batch size, the lead times were calculated and can be found in appendix I. With an average of ten batches per product, only five out of the forty products are produced with the WBZ where the average product takes 21 days more than allowed. Fourteen of the forty products fall within the estimated lead times, but on average products take twelve days longer than calculated. This translates into 32.5% and 17.4% respectively.

7.3 Production Time

In literature, a division was made between lead time, production time and cycle time. voestalpine keeps track of its scheduled production in SFDC (Shop Floor Data Collection), where the realistic production hours are measured next to any other variables. The division of uptime was calculated for production year 2017.

As can be seen in figure 22, the production time is close to 50%. Unfortunately, this section is not a pure representation of the uptime production time. As mentioned above, the SFDC keeps track of all activities. However, any breakdown or pause below the five minutes will not trigger the system, indicating a higher inaccurate production time. The utilisation rate of the machines is not included and it only covers the effective hours and not the efficiency of the production.

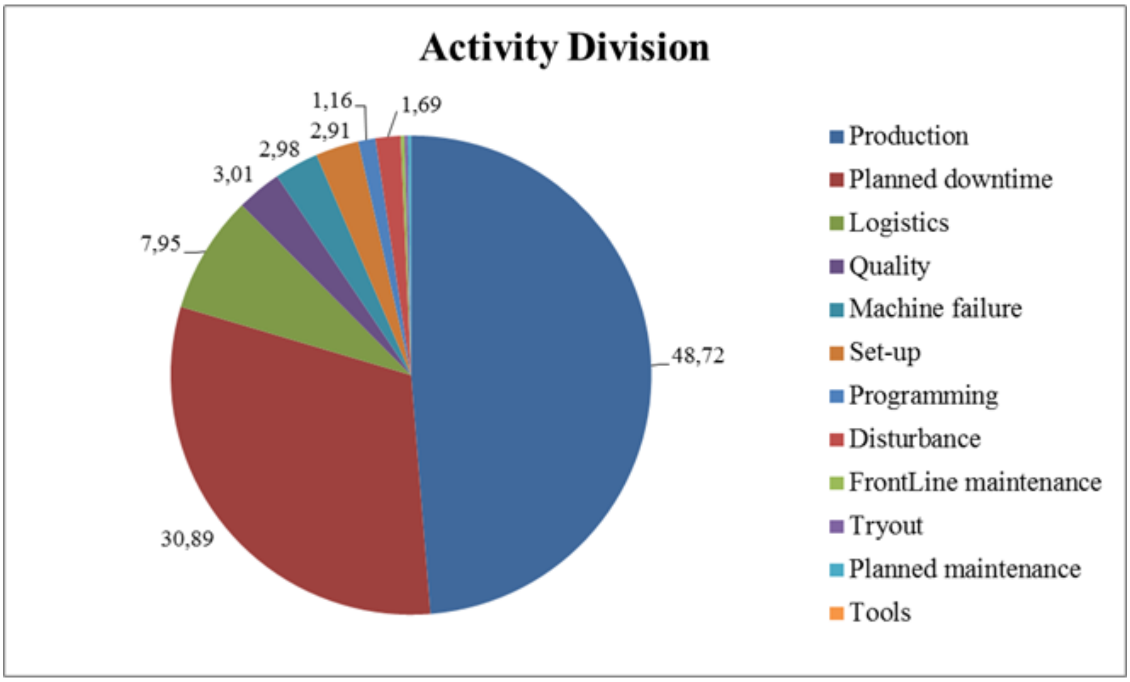


Fig. 22 Pie-chart of cell activities

The efficiency of the different cells was calculated by taking the programmed total order time to produce versus the time that it actually took to produce that same number. This has been done for both machine- and man hours. Respectively, the overall efficiency for 2017 was 80,23% and 67,87%. This brings the total efficiency to 74,05%. A list of the individual efficiencies per cell can be found in Appendix J.

Appendix K presents two sides of the utilisation rate; total utilisation rate per cell and the stake of complex, high volume, spare parts compared to all operations on a cell.

7.3.1 Planned Downtime

The planned downtime presented in figure 22 accounts for more than a third of the entire cell activities. This seems remarkable, however is caused by three major aspects. The first is due to machine uncertainty. The planners plan an extra five to seven operations one or two shifts in advance, so operators have the possibility to switch operation during machine breakdown and maintain a high employee utilisation rate. When the initial operation is up again, the operator can switch back, which again results in planned downtime for the backup operation. The second activity is defined by the time a cell is not planned at all, i.e. no operations are allocated to a cell. Declaring the tracked time as planned downtime can only be done with the authority of an operating manager. The last activity that is incorporated in the planned downtime are breaks, e.g. lunch and coffee breaks, which are 15 hours a week.

7.3.2 Logistics

In the assembly hall, many movements of people, forklifts, materials et cetera have been observed and requires further investigation. These movements are partly caused by the aforementioned layout of the assembly, but can also be directed to the 48-hour freeze as this requires a warehouse step in between every operational step. All the movements from and to warehouse are organised by the W&D (Warehouse & Distribution) department, since it concerns great distances and heavy loadings. The W&D is triggered by a call-off system based on the fabrication numbers of the products. It tells the driver where to pick something up, how big the order is and where to bring it to. If two operations are sequenced, assembly takes care of the movement of products by utilising a smaller manual forklift. To complete an operation, racks and materials are needed at the cells, other racks with different measurements are needed after the production and empty racks need to go back to the warehouse.

Figure 23 displays all the cells in the assembly hall, where the colour represents the investigated number of logistical movements per day, as can be seen in the legend. The cells most often used, according to the forty cells demarcation of this research scope, are 54115, 54169, 54042, 54172 and 54174. The majority of these cells, logically, also have a lot of movement around them during the day with some exceptions. An example of this is the 54115 (an universal spot welding cell), which has up to 23 movements per day. The remaining frequent material movement cell, e.g. 54100 and 54166, are dedicated cells that do not belong to the research.

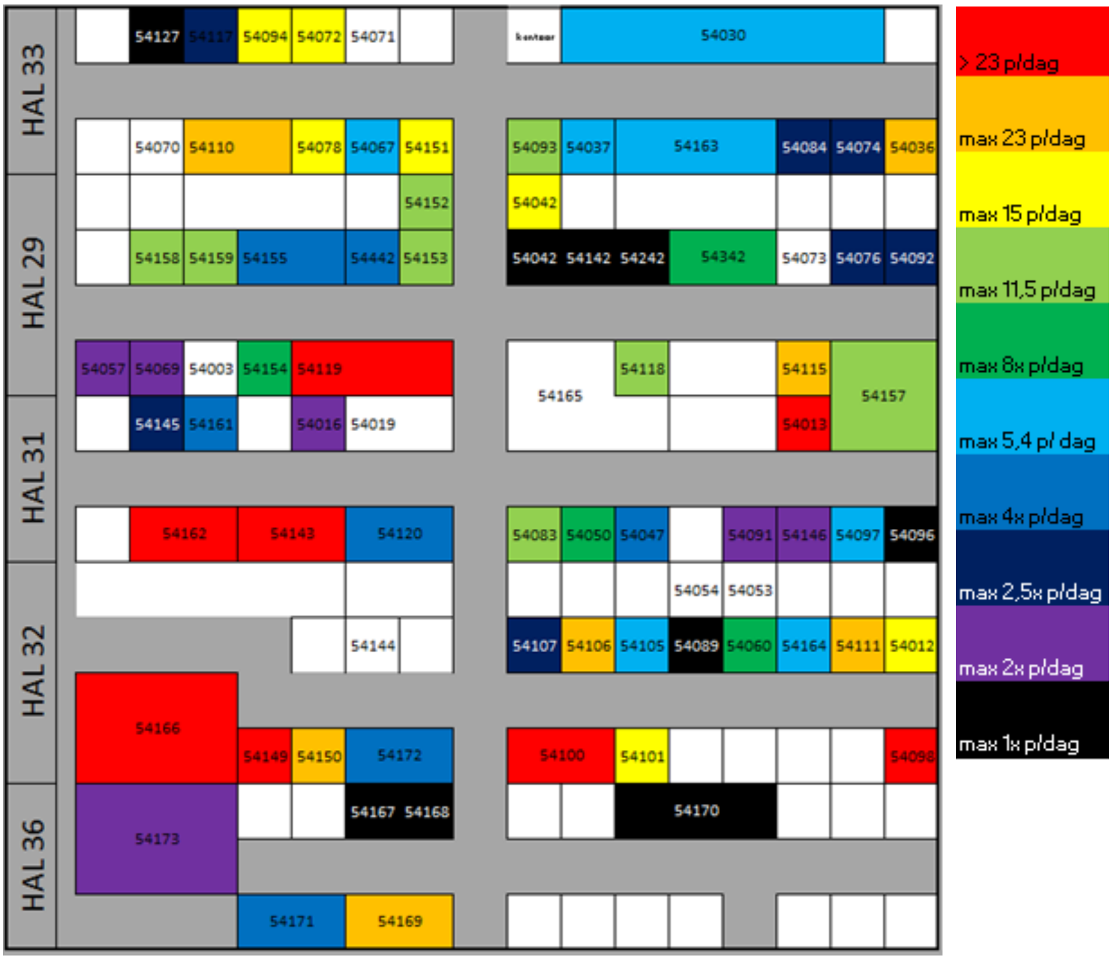


Fig. 23 Movements from and towards cells as calculated in 2015

7.3.3 Changeover Time and Changeover Activities

Prior to production operating cells undergo a changeover. The operating manager initiates the changeover by ordering the required materials for the first two hours of production and their accompanying jig(s). The equipment coordinator delivers the required jig at the operating cell, however does not install it. The scheduled operator needs to pick-up a master sample to verify the quality of the produced batches. When the operator arrives at the cell the jig has been put into place and the start-up materials are present. After installing the jig and programming the cell the operator must first produce a destructive test and batch sample, so further produced parts meet the required quality standards.

The analysis of all cells' activities (figure 22) dictates that only 2,91% of the overall time a cell is dedicated to changeover activities. Time set in SAP for changeovers are self-reliant, meaning that batch sizes do not have any influence on time reserved for changeovers. The theoretical- and realistic SAP time required to perform the changeover activities have been determined, resulting in a margin of error within SAP (appendix O). The theoretical time is extracted from SAP, whereas the realistic time is an average of the last four months. Since the average is based on multiple months the value is reliable and a good representation of the changeover time.

The results do show potential improvements, however insignificant compared to the entire process and the aim of the research. The 2,91% and margin of error in SAP provide the evidence to be able to neglect the changeover influencer from the research, since improvements will have a minor impact on the aim of this project.

7.3.4 Quality Issues

All internal- and customer quality issues concerning the complex, high volume spare parts since 2016 have been investigated and can be found in Appendix L. All thirteen issues are unique apart from the 717140H01AR and 718446S00AK. These two parts show repetition, however with no major impact on the assembly process. The 718143S00AK and 713933S00AK did affect the assembly once by five and seven days respectively. The others were solved within 24 hours.

Taking in consideration the above analysis and the 3,01% coverage of the overall cell activities (see figure 22) quality issues can be excluded from the research, since it has a minor impact on the lead time of complex, high volume parts in the assembly. No further research will be dedicated to this influencer and, therefore, will be terminated from the potential improvements.

7.4 Current SAP Routing

As discussed in the case description, currently each routing (no matter the WIP-sequence) is five working days long. Placing these routings over time creates the planning. The current Z22 + x production time SAP parameters create two problems. The first problem concerns the time frame scheduled for a WIP operation. WIP operations are performed immediately after each other and should be considered as one operations, i.e. SAP parameters will indicate a two times five days planning flexibility even though a Z22 + 2 production days would suffice in most cases. The second problem is more an overarching SAP problem, since it reflects the inaccuracy of the current SAP settings. These settings have been set years ago and barely have been updated since. These two problems cause imprecise planning parameters, which affect multiple stakeholders, e.g. financial department and material handling.

The purpose of the Z22 + x production time (rounded up to days) is to provide the planners with room for anticipating on the production planning and allow for flexibility, however practise shows that this time frame is generous. Routing settings could be more adjusted towards reality, so planners actually start planning based on the set dates in SAP instead of planning on intuition. This current unnecessary space results in less planning urgency and higher non-value added time.

Due to research scope reasons, this investigation and improvement will not be further discussed in the following chapter. However, the analysis does need to be pointed out, because it has a secondary support on the aim of this research. Since the SAP settings concern all products of voestalpine, this analysis will include the all departments, all products and supplier logistics.

In a new proposed situation, the time horizon of the planning should be closer to reality and with lesser safety buffers in terms of time. By uncovering the realistic time and reducing the safety, problems will be detected sooner. Not having the flexibility that is available today requires the planners to follow production more tightly, as they have to anticipate sooner. The proposition is as following (figure 24):

1. To update the production preparation time (T1) towards a more realistic number and differentiate for production groups.
2. To make the time allowed for production (T2) dependent on batch size and cycle times.
3. To minimise the time allowed for delays and material movement (T3).

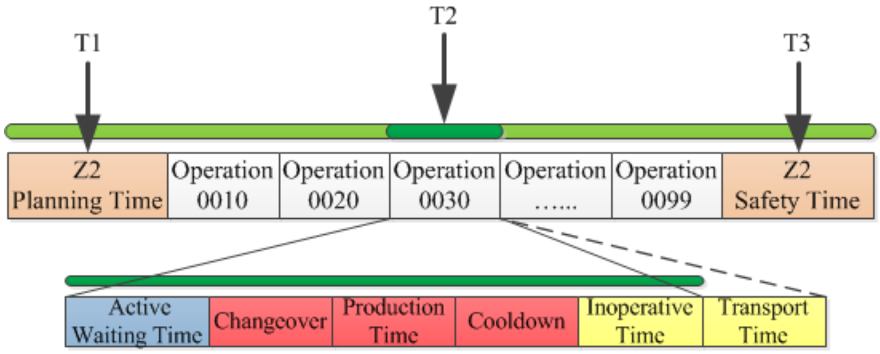


Fig. 24 Proposition new horizon

Preparation time might not be necessary for all the departments and for the product groups where it is needed, the norm of two days is not always the right one. Some operations in the EC do not need preparation time, whereas other steps in the Press Shop need more than two days. A more realistic picture of the lead times has to be created, which will allow for an enhanced planning.

The current time for production is always set to one day, which cannot be realistic when looking at the different cycle times and batch sizes. The second proposal is to make the time allowed for production more realistic by calculating the sum of the cycle time and the batch size. This means that a large batch size might go over the one day currently allowed, but it will be a more realistic way of working. This solution might not cause a reduction in lead time, but will give more insight and transparency into the planning.

The third adjustment is to minimise the time allowed for the movement of materials and possible delays. If production goes according to plan, movement of materials will not be necessary as this is done continuously. Changeover time is taken into account when calculating the new time allowed for production, and the production time is more realistic due to the changes in proposal two. These extra days were more of a safety day in case of machine breakdown or production delays, covering up any planning bottlenecks rather than unveiling them. The elimination will create more insight and earlier detection into the problems.

All the above changes should bring the planned lead time closer to reality, even though this works both ways e.g. some ERP lead times will get longer while other will become shorter. However, with a more realistic lead time planning ERP will also become more efficient as the understanding of the working of the system will improve.

7.5 Current Bottleneck Analysis

Gaining insight into the bottleneck of the current process is essential as it determines the pace of production and possible solutions will give the highest impact when focusing on the bottleneck. Furthermore, the process infrastructure should be adjusted accordingly. For example, a bottleneck process should never undergo starvation as it is the most expensive process within the production and its time is most valuable. Within this research, a bottleneck analysis has been performed on the forty products. The bottleneck and its production can be limited by certain factors, e.g. batch sizes and racks.

voestalpine has determined its batch sizes depending on e.g. costs and production efficiency, which is called the calculated batch sizes. However, this batch size strategy is not applicable for all products. Some products have a set batch size that planners should not adjust unless absolutely necessary (FX), whereas other products have an upper- and lower limit (EX). Planners have in the latter scenario the choice to adjust batch sizes anywhere in between, where this set batch size by the planner is called the MRP. The organisation strives to create variability in the chosen batch size in the near future. Therefore, this research took the fixed batch sizes (FX) into account for the entire product scope.

Furthermore, transportation of the batches differs from operation to operation, i.e. a BOM can consist of multiple racks, where some racks can facilitate multiple BOMs. The number of racks is restricted by the customer and could limit and disturb the current WIP pace. External influencers, such as the delivery of components, have been disregarded as potential bottleneck as this is not within the scope.

Within SAP, calculated cycle times (ICT time) and realistic cycle times (e.g. including breakdowns, efficiency and breaks) were found. To determine the bottleneck in the current process, the realistic cycle times were taken and multiplied with the MRP batch sizes of 2017. Appendix M shows the bottleneck cells for all the forty products, including the production time of this cell for the specific products. This overview shows that some cells re-occur more often than others, which often also have a higher utilisation rate. The 54169 cell is the bottleneck for the VW Golf Plus backdoor. This operating cell is an universal spot welding cell with a high utilisation (see appendix K) and is frequently marked as bottleneck.

7.6 Current State Value Stream Mapping

To visualise the current state, and later map any possible improvements, all the above-named factors were taken into account to determine the current state. These current state diagrams show the distinction between value added- and non-value added activities. The principles of "Learning to See" (Rother and Shook, 1999) were used to map the production lead time and the production time, together with the information- and the material flow. This visible representation of the production shows the buffers, cycle times and any other things happening throughout the chain. Mapping the current state stimulated the potentials for an improved future state. By comparing the current state and future state VSMs, one could easily detect the gains that have been made by implementing different improvements. The current state VSM of the VW Golf Plus backdoor can be seen in figure 25.

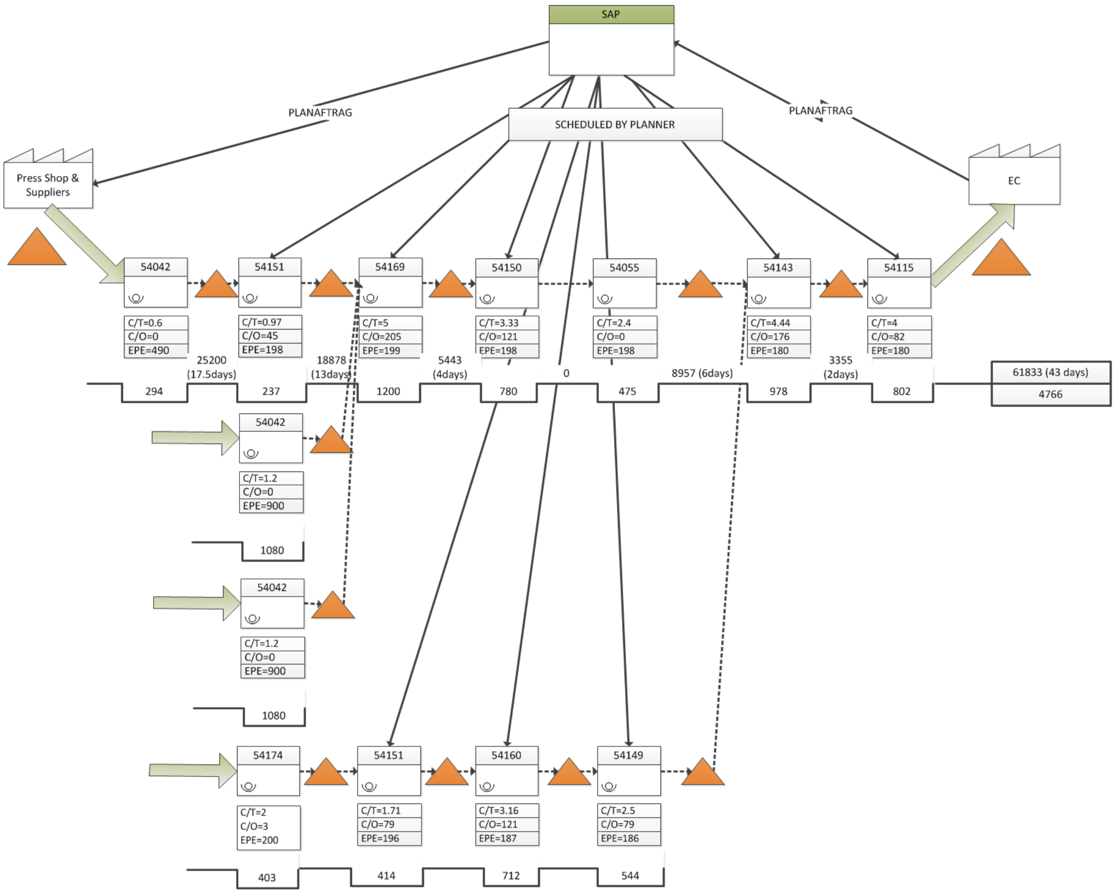


Fig. 25 VSM of the VW Golf Plus backdoor

SAP signals the planners when an order is needed, from which they start planning the production. The scope of this project disregards the press shop and EC. Therefore, these are considered supplier and customer. When an order is planned, a manual signal triggers the start of production. Below all the processes, a table of data is found stating the cycle time per product (C/T), the changeover times (C/O) and the batch sizes (EPE) in minutes and pieces respectively. This data is used to calculate the value added time, which can be seen directly below. The 48-hour freeze creates a buffer between each operational step, with only a few exceptions, i.e. WIP-labels. The average time spent in buffers was calculated over 2017 taking all batches, and then visualised in non-value added time. The total (non-) value added time is 43 days and can be found at the end of the timeline, after which the products are send to EC.

8 New Way of Planning

The following chapter will discuss possible improvements and their implications within the case company. This will be the main framework used to answer RQ3 and RQ4, where four main possible improvements are researched. Due to a limited time frame, not all possible solutions will be investigated, rather placed in further recommendations.

8.1 Selection of Suggested Improvements

Whilst doing the current state analysis, two major possible directions came up for a future solution. In the lead time analysis (see section 7.3.2) it showed that the time between the sequential production steps can go over 100 days, meaning that after one operational step the semi-finished products wait at least three months before undergoing the next operational step. Furthermore, when the VSMs were created, they showed a large discrepancy between the value added time and the non-value added time. The first possible direction is thus the improvement of buffer/ passive waiting time between operational steps and decreasing the lead time by minimising this non-value added time.

When looking into the non-value added time a lot of material movement, unbalanced operations and illogical flows can be seen. The current layout of the factory grew towards its state over the years, as demand increased and more and more capacity was needed. A new hall was built, new machines were added and universal cells were created rather than dedicated cells. This, however, resulted in the current spaghetti state of assembly. Strategy and vision are lacking in the placement of cells, and there is no strong relation between flow and layout. This insight led to the second direction; a future factory design.

To prioritise between the two options the pros and cons of both were considered. A future factory design allowed for creativity and, when done correctly, will always give an improvement in terms of lead times compared to the current state. The downside is that when designing a new layout, it should not be limited to the scope of this project as this view would twist reality. A new factory design has to cover all of production, e.g. spares, but also serial. When diving into the non-value added time between operational steps, there is no improved result at first hand making it more difficult. However, any application of improvements found in this area are more realistic to be implemented and could, therefore, set in action. Figure 26 shows the focus areas for potential improvements, where the grey areas will be focused in this chapter. The other three potential improvements will be further discussed in chapter 10.

The focus of this research has been set on the suggested improvements of reducing the non-added value time between operational steps. This gives the organisation a higher result on the short term, which supports the urgency to meet the WBZ as soon as possible. The knowledge that has been gained from the current state analysis was partly used on a side project, where multiple stakeholders investigate a future factory design for the assembly.

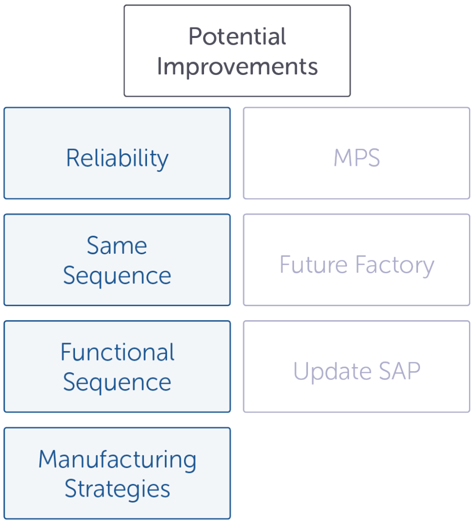


Fig. 26 Overview suggested improvements

8.2 Sequencing

In order to reduce the lead time, where the longest time can be found as non-value added waiting time in between operational steps, the 48-hour freeze will have to be opposed. The sequencing of operational steps will be introduced through routing decisions and operational rules. Sequencing of two operational steps entails the completely finishing of one batch within the first operational step, before moving the entire batch to the next. A waiting period of maximum twelve hours is allowed to ensure that the second cell can finish its current operational step. In this time, the products will wait at a dedicated floor space only allowed to be used by sequenced steps. This allows the team managers to keep track of the bigger picture, as these dedicated spaces will be bookable for sequenced inventory only. It then also quickly indicated when products are stored longer than twelve hours, meaning that there is some sort of malfunction at the sequenced machine.

A dedicated floor space is needed as the regulations for this buffer are different than for other semi-finished goods inventory. The twelve-hour limitation is one, but also the requirement that the products placed in this space are directly the next in line for production on the sequential cell. After the production of the first cell, the entire batch is moved here and will wait to be picked up when the next cell changed over. As the warehouse between operational steps in then eliminated, lesser logistical movements from and to the warehouse are required. A shorter movement from the cell to the dedicated buffer space is necessary, but the searching for and order picking of the batch is no longer needed. The movement to and from the warehouse are then replaced by the movement to the buffer area, thus lowering the costs of logistics.

By allowing operational steps to be sequencing, the waiting time between the steps is minimised to twelve hours tops. This instead of week and months that are seen now for product buffers between operations. It minimises the non-added value and will results into a lower inventory overall as products are forced to go through the assembly at a quicker pace. In the sections below, different ways of sequencing will be investigated and applied to the product mix. These ways of sequencing have led to the generic model of lead time reduction, namely the decision tree.

8.2.1 Reliable Cells and Products

Collected from SAP-data and interviews with planners, operators and operating managers, reliable cells have been determined (table 6). The company strives for all operations to be reliable. A reliable cell is characterised by a machine that guarantees a 100% output when 1% of the concerning operation has been produced. Allowing to direct sequence successive operations in combination with one of these reliable cells. Translating this sequence into SAP will automate planning of operations from the last operations of the sequence until the first one. Resulting in the elimination of intermediate warehouse steps and potential passive waiting time. Furthermore, the planner will not experience any human errors, e.g. overseen batches in warehouse. Any batch size changes due to quality issues will automatically adjust the quantity order of the next operation, which results in no overproduction or starvation. The 48-hour freeze in between operations adds unnecessary time to those who are labelled as reliable production steps and can, therefore, be neglected in a reliable cascade. Identifying the reliability of operations is essential for the decision to sequence operations or add SAP-preferences to the plan system. Furthermore, guarding the cell reliabilities and continuously developing unreliable operations will result in an increasing possibility to ensure production certainties.

Reliable Cells	Cell Description
54042	Stationary Spot Welding
54071	DAG Hood A8
54094	Univ. Spot Welding Cell 4
54110	Univ. Hemming Cell 3
54115	Univ. Spot Welding Cell 5
54116	Univ. Spot Welding Cell 5
54143	Univ. Hemming Cell 5
54151	Univ. Clinch Cell 3
54170	Univ. Hemming Cell 8
54174	Univ. Assembly Controller
54342	Stationary Spot Welding

Table 6 Reliable cells

Concerning the individual operations in the 718028S00AK BOM, reliable cells are the 54042, 54151, 54174, 54143 and 54115. Meaning that operations after these steps can be planned tight, since machine breakdowns are almost non-existing. The profits gained from this improvement will be further highlighted in section 8.7.

Besides restructuring production patterns based on reliable cells, the planning behaviour should also take in account reliable products (table 7). Products that show low abnormalities and high-performance predictions over a longer period of time should be produced according a tighter schedule. Reducing safety times without losing ensurement of production, e.g. arrival of purchased components.

Reliable Product	Description
717428S00AK	VW ZB TUER VORNE GOLF VI LI -9K9
717429S00AK	VW ZB TUER VORNE GOLF VI RE -9K9
717430S00AK	VW ZB TUER HINTEN GOLF VI LI -9K9
717431S00AK	VW ZB TUER HINTEN GOLF VI RE -9K9
720110S00AK	VW TUER HI LI TOURAN -9K9
720111S00AK	VW TUER HI RE TOURAN -9K9
720112S00AK	VW TUER VO LI TOURAN -9K9
720113S00AK	VW TUER VO RE TOURAN -9K9
724630S00AK	VW ZB TUER HINTEN LI PASSAT B6 KD -9K9
724631S00AK	VW ZB TUER HINTEN RE PASSAT B6 KD -9K9
724632S00AK	VW ZB TUER HINTEN LI PASSAT B7 KD -9K9
724633S00AK	VW ZB TUER HINTEN RE PASSAT B7 KD -9K9

Table 7 Reliable product groups

Taken from the forty products three products groups, containing twelve individual parts, have been labelled as products with a stable production.

8.2.2 Same Sequence Cells

One of the limitation of cell-sequencing is that a cell has to be reliable, as explained above. This because of the planning execution of the second cell, and possible distortion when the first cell fails. Another option for planning consecutive cells without a warehouse step was found when closely investigation the forty different products and their routings. Seven of these products have same-cell routing steps on different levels, e.g. a 54115 step which is followed up by a 54115 step. The same-cell routings are found for the 54115, 54116 and 54174 cells which also happen to be reliable cells. Other same routing is found in cells that operate with two operational steps parallel within one cell, where both operational step have a different number (54150-54160, 54115-54116, 54172-54182). Even if not all cells would be reliable, failure to finish an operational step would then only affect the same machine and elongate its process, pushing back the sequential step but thus not affecting anything else. This means that in the future, same-cell routings can also be sequenced if the cells are not reliable, saving inventory time in the warehouse. An example can be seen in table 8 below, where three operational steps can be found on the 54115 in sequence.

Finished Product	BOM Level	Semi-Finished Product	Description2	Cell Nr.	Description3
717431S00AK	2	717431H01AR	VW ZB TUER HINTEN GOLF VI RE	54143	Univ. Hemming Cell 5
717431S00AK	3	717431H02AR	VW ZB TUER HI GOLF VI RE MIG 2	54115	Univ. Spot Welding Cell 5
717431S00AK	4	717431H21AR	VW ZB TUER HI GOLF VI RE PNT	54115	Univ. Spot Welding Cell 5
717431S00AK	5	717431H22AR	VW ZB TUER HI GOLF VI RE MIG 2	54115	Univ. Spot Welding Cell 5
717431S00AK	6	717431H03AR	VW ZB TUER HI GOLF VI RE AFL	54150	Univ. Laser Welding Cell 2
717431S00AK	7	717431H32AR	VW ZB TUER HI GOLF VI RE LOETEN 1	54160	Univ. Laser Welding Cell 2
717431S00AK	8	717431H05AR	VW ZB TUER INNEN HINTEN GOLF VI RE	54151	Univ. Clinch Cell 3
717431S00AK	7	717431H04AR	VW ZB RAHMENTEIL HI RE GOLF	54055	Manual Spot Welding

Table 8 Current BOM routing

Rather than planning these on their own, having to wait for availability of the machine, the ERP-system should call-off all three steps at the same time. Regarding the planning, it will only affect the cell itself and thus not disturb the system as a whole if any disruptions happen to occur. The 48-hour freeze here can be disregarded as the cells for these forty products are all reliable. The new BOM structure is displayed in table 9. All three 54115 operations have been places in the same BOM-level, as well as the 54150 and 54160 that are produced in parallel on the same machine. This new way of planning directly reduces the non-added value as it cuts into the inventory waiting time. For this product, it results in a lead time reduction of a bit over seven days on a lead time of 38 days, which translates into a 18% lead time reduction.

Finished Product	BOM Level	Semi-Finished Product	Description2	Cell Nr.	Description3
717431S00AK	2	717431H01AR	VW ZB TUER HINTEN GOLF VI RE -9R9	54143	Univ. Hemming Cell 5
717431S00AK	3	717431H02AR	VW ZB TUER HI GOLF VI RE MIG 2 -9R9	54115	Univ. Spot Welding Cell 5
717431S00AK	3	717431H21AR	VW ZB TUER HI GOLF VI RE PNT -9R9	54115	Univ. Spot Welding Cell 5
717431S00AK	3	717431H22AR	VW ZB TUER HI GOLF VI RE MIG 2 -9R9	54115	Univ. Spot Welding Cell 5
717431S00AK	4	717431H03AR	VW ZB TUER HI GOLF VI RE AFL -9R9	54160	Univ. Laser Welding Cell 2
717431S00AK	4	717431H32AR	VW ZB TUER HI GOLF VI RE LOETEN 1 -9R	54160	Univ. Laser Welding Cell 2
717431S00AK	5	717431H05AR	W ZB TUER INNEN HINTEN GOLF VI RE -9F	54151	Univ. Clinch Cell 3
717431S00AK	5	717431H04AR	VW ZB RAHMENTEIL HI RE GOLF -9R9	54055	Manual Spot Welding

Table 9 New BOM routing

8.2.3 Functional Follow-up

Besides reliable cells and same cell sequences, there are also cells than need to be operated in parallel due to their processes, defined as a functional follow-up. An example of this is that sometimes, the curing process has to be done directly after the hemming process in order for products to harden in the right manner. This can be seen in the [54030 - 54117] follow-up.

Even though the 54030 cell is an unreliable cell with a high changeover time and requires a high number of operators, the doors that are produced at this cell need to move to cell 54117 right away. This is also one of the few processes where products are moved before the entire batch is produced, as the hardening has to be done within a time limit.

These existing functional follow-ups have been checked throughout all the routings of the forty products. If routings are sequenced in one product, it should also be possible to apply the same routing for another product. In the current product mix, these follow-ups have been found to be consistent throughout and thus no lead time improvement was found in this process. Even though these routings are very specific, meaning that the 54030 cannot be followed-up with any other cell than 54117 as the cell itself is very unreliable, when new products are introduced into the production mix they should be checked for these specific follow-ups. As the current way of production is conservative and relies on many built-in safeties, new products can benefit from more follow-up routings to reduce inventory, and tighter scheduling to limit lead times.

8.2.4 Bottleneck Hybrid Manufacturing Strategy

The determination of the bottleneck per product allows for adjusting the current push and pull manufacturing strategy to a bottleneck hybrid manufacturing strategy. As mentioned in literature and the current state process analysis, the bottleneck decides the fastest throughput of products, since it requires the longest production time, and should therefore never experience starvation. To avoid starvation all operations prior to the bottleneck should be sequenced. So far, the planners did not utilise a bottleneck analysis for the prioritisation of routings, however this knowledge supports the suggested way of planning. All operational steps before the bottleneck should be pulled to adapt all previous operations to the pace of the bottleneck cell. The remaining cells after the bottleneck can follow a push strategy, because the required production pace is lower than the bottleneck operation. The hybrid manufacturing strategy standardizes the initial, most utilised, part of the process and provides the planner with the preferred flexibility at the end. Pulling the process until the bottleneck will decrease passive waiting times, reduce stock levels and, therefore, shortens overall lead times.

In case of the VW Golf Plus backdoor, the bottleneck is sequenced in the initial steps of production [54042 - 54151 - 54169] and the routing is part of the critical path (see figure 27). The current BOM shows buffers, whereas the future state contains no buffers and neglects the feeding cell 54042. Planning the bottleneck in a future planning environment would directly result in a shorter lead time of approximately thirteen days. These thirteen days profit are found in the long-term average between the 54151- and 54169 cell. All previous operational steps before the bottleneck are automatically planned in sequence supporting the planning behaviour of the planner.

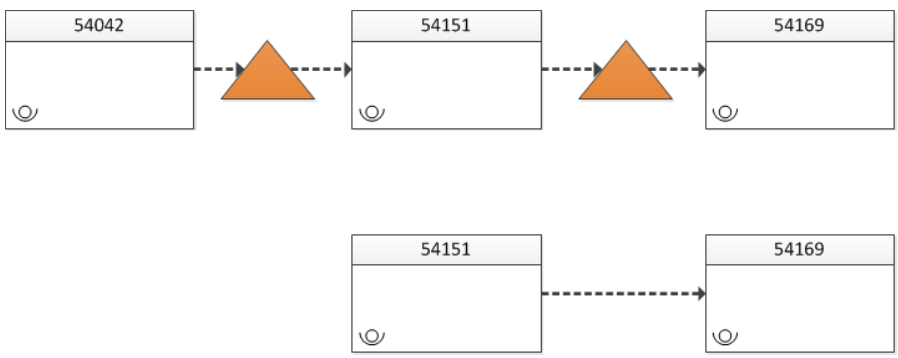


Fig. 27 Comparison VW Golf Plus push vs. hybrid manufacturing strategy

8.3 Improved Bill-of-Materials

Restructuring BOMs according to aforementioned sequencing improvements will require a new analysis on the application of batch sizes and bottleneck. It will ensure and enhance the already found adjustments. Therefore, section 8.3.1 and 8.3.2 are dedicated to required successive steps after having executed the decision tree.

8.3.1 Adjustments of Batch Sizes

The ERP-system keeps track of two different batch sizes, namely the calculated batch size and the MRP batch size that fluctuates depending on the planner. As the MRP batch size is the actual batch size produced, rather than the optimal calculated one, this number is taken as baseline for the adjustments. The average MRP batch size over an entire production year was taken, and its deviation was also calculated to gain insight into its variation. Over the forty different products it could then be seen that there was not one batch size ran through the entire production chain. Often big batches were fabricated in the first operational step, whereas the final operational step often does not edit more than 200 pieces at the time. This causes long lead times as some parts produced in the first step will then go into warehouse waiting to undergo the next operational step. An example of this can be seen in table 10 below, showing the original batch sizes of the VW Golf Plus.

BOM Level	Semi-finished Product	Product Description	Cell Nr.	Cell Description	Calc. Batch Size	MRP	P.T. (hours)
2	718028H01AR	VW ZB HECKKLAPPE GOLF PLUS	54115	Univ. Spot Welding Cell 5	200	180	12
3	718028H22AR	VW ZB HECKKLAPPE INN AUS GOLF PLUS	54143	Univ. Hemming Cell 5	200	180	13
4	718028H07AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54055	Manual Spot Welding	200	198	8
4	718028H07AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54150	Univ. Laser Welding Cell 2	200	198	11
5	718028H08AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54169	Univ. Spot Welding Cell 7	200	199	17
6	718028H13AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54151	Univ. Clinch Cell 3	200	198	3
7	718028H10AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54042	Stationary Spot Welding	200	490	5
6	718028H11AR	VW ZB SCHARNIERVERSTAERKUNG LI	54042	Stationary Spot Welding	200	900	18
6	718028H12AR	VW ZB SCHARNIERVERSTAERKUNG RE	54042	Stationary Spot Welding	200	900	18
4	718028H33AR	VW ZB HECKKLAPPE AUS GOLF PLUS	54149	Univ. Laser Welding Cell 1	200	186	8
5	718028H44AR	VW ZB HECKKLAPPE AUS GOLF PLUS	54160	Univ. Laser Welding Cell 2	200	187	10
6	718028H55AR	VW ZB HECKKLAPPE AUS MITTE GOLF PLUS	54151	Univ. Clinch Cell 3	200	196	6
7	718028H66AR	VW ZB HECKKLAPPE MITTE GOLF PLUS	54174	Univ. Assembly Controller	200	200	7

Table 10 Original batch sizes

As one of the lead time improvements is the sequential production of operational steps, it only makes sense that these steps have the same batch sizes. This because right after finishing the first operational step, the entire batch is moved to the next cell which has already been set up and is ready to produce the next step. One of the first improvements in terms of batch sizes was to equalise these throughout the new sequential operations. This limits the movement of the warehouse between cells and between the semi-finished goods inventory. For some customers, quantity tests have to be done at the beginning of the batch resulting into the loss of a few products.

When the process of changing batch sizes was starting, many influential factors had to be considered, costs being one of them. Using a tool provided by cost engineering, both the costs for lower batch sizes as the benefits for higher batch sizes could be calculated. These results will be compared to the profit in terms on lead time days later on in chapter eight.

Specific cells [54042 - 54151 - 54164 - 54171 - 54342] only manufacture small parts and are rarely found in the critical path. These parts are stored by large quantities stacked on top of each other in wooden or metal boxes. The production of these parts can be done in large quantities, but no consistency was found of doing so in the past. However, because sometimes the batch sizes were the similar to press batch sizes, it would lead to long lead times within the production as quantities would be taken in hundreds rather than a thousand, meaning that the last part of the batch would lay in warehouse for a very long time (up to six months). To create consistency and give more insight into the lead times, so called “feeding-cells” were introduced. These cells will always manufacture in large quantities so that the acquiring of these parts can never delay the production as they are always on stock. The ERP-system will give notice when the stock is running low, so that a new production order will appear in the planning tables of the production planners. The products delivered by feeding cells will not be included in the lead time analysis, as they will be regarded as purchase parts. It will rather be a definition change of how to handle this production as these products can never be a limiting factor, and will not be included in the critical path. This definition change will, however, only be done for products that are not limited by their rack, e.g. products can be stacked and more than fifty products fit in a rack or wooden box.

Producing in larger batch sizes will also affect the available storage space in the warehouses. To limit this, the different racks and quantities were investigated and compared to the maximum stacking height within the warehouse. As the internal regulations do not allow stacking higher than eight meters, but also not more than seven racks, the optimal number of racks was calculated using the same tool received from cost engineering. For example, if a rack is two meters high, the warehouse space will most optimally be used if four racks are stacked on top of each other. Producing large quantities is more economical and saves changes overs, so a balance here between space and quantities was found.

The feasibility of any changes in batch size based upon the above-named reasons was tested by calculating the utilisation rate of each of the cells. When lowering batch sizes, it is important that the utilisation is low enough as more changeovers will be needed, thus costing more time. As the complete machine park at the moment is not stable, utilisation rates should allow for flexibility and unplanned events within production. But even with higher batch sizes, and thus reducing the number of changeover, utilisation rates were calculated as it means that cells will be producing for a longer period of time consecutively. This gives planners lesser flexibility during that specific period of time. In figure 28 the utilisation rate of all the forty different cells can be seen, as calculated with the operations done in 2017. For all the different cells where the batch size was changed goes that the utilisation rate was 60% or below, allowing for enough room for the planning of other products or any adjustments.

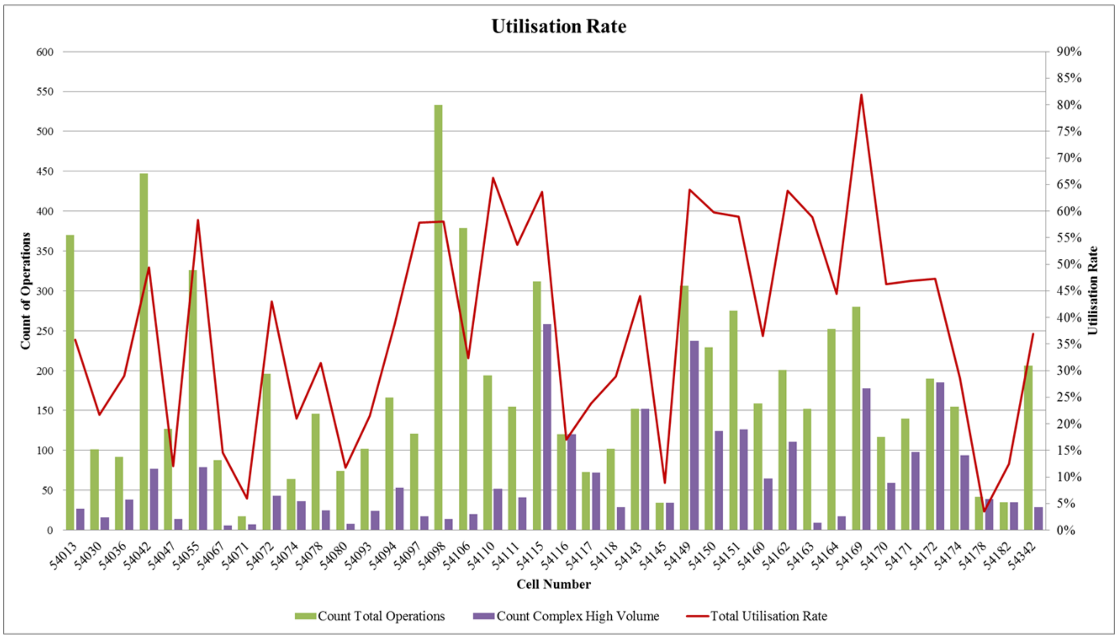


Fig. 28 Utilisation rate of all cells

All these changes were then implemented for all the forty products and their impacts were calculated. Impacts both in terms of costs and benefits, but also in terms on days as many products will have lesser time spent in the warehouse. The VW Golf Plus is again used as an example for the new batch sizes, and can be seen in table 11. The batch sizes of the operational steps that will sequenced are made equal and the batch sizes of the feeding cells are increased.

BOM Level	Semi-finished Product	Product Description	Cell Nr.	Cell Description	Calc. Batch Size	MRP	P.T. (hours)
2	718028H01AR	VW ZB HECKKLAPPE GOLF PLUS	54115	Univ. Spot Welding Cell 5	200	180	12,0
2	718028H22AR	VW ZB HECKKLAPPE INN AUS GOLF PLUS	54143	Univ. Hemming Cell 5	200	180	13,4
4	718028H07AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54055	Manual Spot Welding	200	198	7,9
4	718028H07AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54150	Univ. Laser Welding Cell 2	200	198	11,0
5	718028H08AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54169	Univ. Spot Welding Cell 7	200	199	16,6
5	718028H13AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54151	Univ. Clinch Cell 3	200	205	3,3
5	718028H10AR	VW ZB HECKKLAPPE INNEN GOLF PLUS	54042	Stationary Spot Welding	1000	1000	10,0
6	718028H11AR	VW ZB SCHARNIERVERSTAERKUNG LI	54042	Stationary Spot Welding	1000	1000	20,0
6	718028H12AR	VW ZB SCHARNIERVERSTAERKUNG RE	54042	Stationary Spot Welding	1000	1000	20,0
4	718028H33AR	VW ZB HECKKLAPPE AUS GOLF PLUS	54149	Univ. Laser Welding Cell 1	200	186	7,7
5	718028H44AR	VW ZB HECKKLAPPE AUS GOLF PLUS	54160	Univ. Laser Welding Cell 2	200	200	10,5
5	718028H55AR	VW ZB HECKKLAPPE AUS MITTE GOLF PLUS	54151	Univ. Clinch Cell 3	200	200	5,7
5	718028H66AR	VW ZB HECKKLAPPE MITTE GOLF PLUS	54174	Univ. Assembly Controller	200	200	6,7

Table 11 New batch sizes

8.3.2 Future State Bottleneck Analysis

Performing a future bottleneck analysis and comparing it to the current state bottleneck analysis will indicate potential shifts in bottleneck cells, change in utilisation and supports the improvement on the way of planning. The results from previous section will have a direct influence on the character of the bottleneck. The relationship between cell loading and bottleneck is evident and requires a new analysis.

The analysis was again done by multiplying the batch size with the cycle time of the individual operation that resulted in the production time per operation per product. The cycle time have not changed between the current- and future state of this research, so the batch size was the only influencer. The new analysis can be found in appendix N, however table 12 highlights the differences between the current- and future state. The results show three options of change, either change of bottleneck cell, difference in required production time or a combination of both. Since the feeding cells have been neglected from the future state analysis (see section 8.2), the 720110S00AK, 720110S00AK and 720113S00AK show a change in bottleneck cell accompanying a lower production time threshold.

COMPARED BOTTLENECK ANALYSIS						
Finished Product	Current State Semi-Finished Product	Future State Semi-Finished Product	Current State Cell nr.	Future State Cell nr.	Current State Production Time (hours)	Future State Production Time (hours)
717116S00AK	717116H02AR	717116H02AR	54094	54094	16	18
717427S00AK	717427H05AR	717427H02AR	54093	54143	45	54
717429S00AK	717429H03AR	717429H03AR	54182	54182	17	16
720110S00AK	720110H06AR	720110H05AR	54171	54169	24	13
720111S00AK	720111H06AR	720111H05AR	54171	54169	25	17
720113S00AK	720113H06AR	720113H08AR	54171	54169	29	22

Table 12 Comparison of current- and future state bottleneck analysis

The results of the entire future state bottleneck analysis were utilised in the suggested future way of planning, but also in the suggested future SAP settings (see section 7.5 and 8.5). These SAP preferences will facilitate an enhanced estimation of the realistic production time to improve the time in between Z22.

8.4 Decision Tree for Sequencing

The enumeration of the above-named improvements has led to a generic model for routing adjustments, leading to an improved lead time within the assembly. Even though this model has been developed with a control group of high volume, complex spare parts, it can be implemented for any product that has the priority for lead time reduction. Restriction are found in the form of dedicated warehouse space, utilisation rates of cells and a maximum time allowance on the production floor of sequenced cells. For these, and any other future products, the decision tree is to be followed from top to bottom (see figure 29). Each process requires one of more action, either to give insight or needed to later analysis. Four different decision moments are found, possibly leading to further action e.g. changing is routing and sequencing. The detailed descriptions and possible changes can be found in the earlier paragraphs mentioned in the figure, whereas the tree forces a more optimal way of planning. It is of most importance that the new owner of the decision tree follows through step by step when creating the routing for new products, provided that the product fits in the scope.

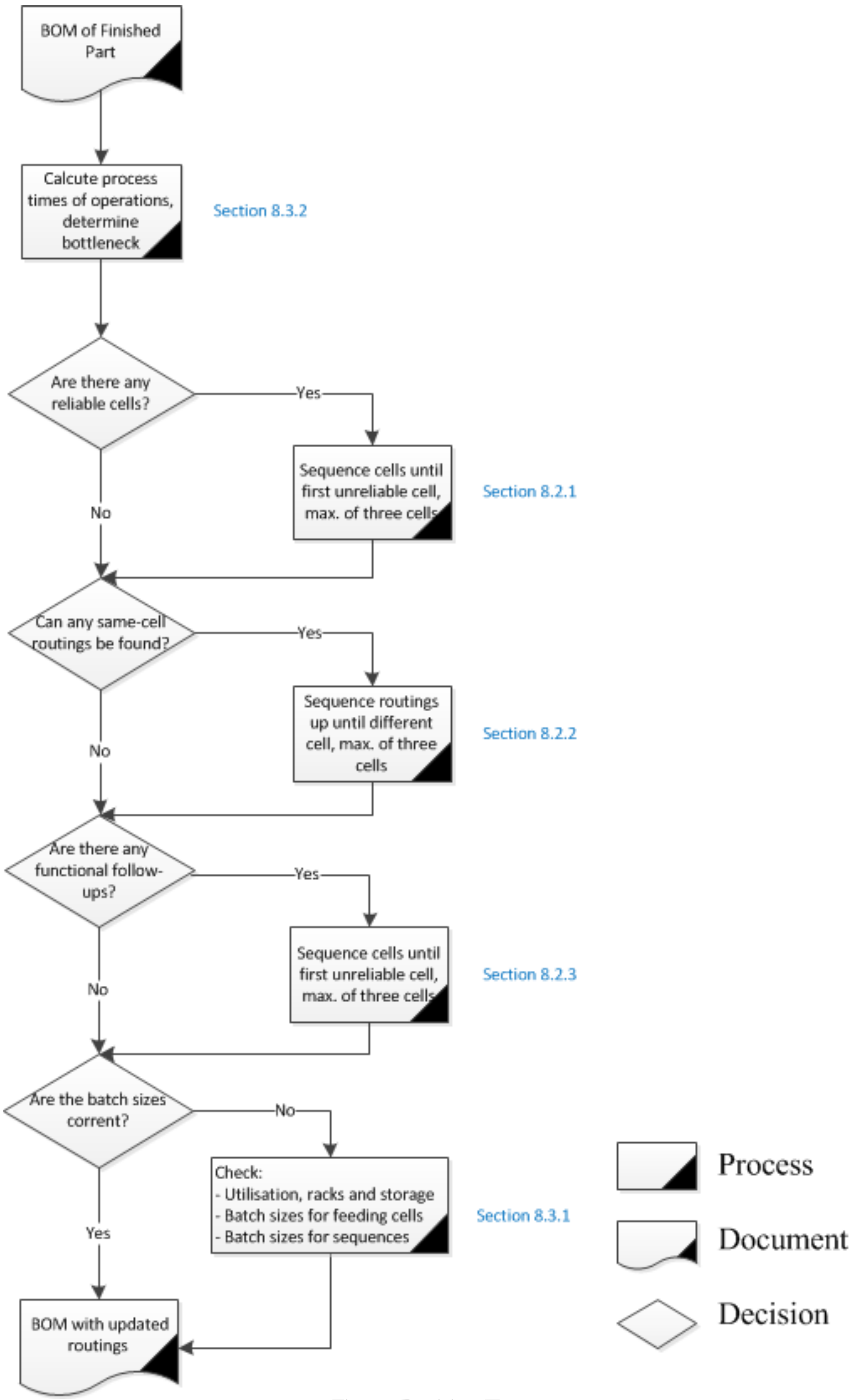


Fig. 29 Decision Tree

8.5 Decision Tree Results

The decision tree is a generic model that can be applied to any product with any number of routing steps over any of the cells found in production, now but also in the future. It facilitates the elimination of non-added value between operational steps, however to maximise the profits voestalpine also need to involve strategic changes, e.g. manufacturing strategies (section 8.2.4). To see the overall results of implementing this decision tree and making the changes in both the routings and the BOM structures, the lead time benefits were calculated for the theoretical approach and modelled in SAP to have a simulation as comparison.

8.5.1 Lead Time Improvements

All the routings within the BOMs of the high complex, spare parts have been put into the decision tree and recommended changes have been followed up upon. The definition change of feeding cells is also considered in the new state, but not seen as a direct improvement upon the production lead time within assembly. The new times include any of the benefits gained from the previously explained steps (e.g. batch sizes, the different sequencing), which are then summed together into lead time reduction. The overview of this can be seen in table 13 below, which summarises the overall improvements for all forty products.

Finished Product	Current LT (days)	New LT (days)	Profit (days)	Profit (%)	Def. Change (days)	Final LT (days)
713931S00AK	47,38	22,17	25,21	53%		22,17
713933S00AK	30,6	20,2	10,4	34%		20,2
714769S00AK	45,8	45,8	0	0%	40	5,83
714770S00AK	54,4	54,4	0	0%	40	14,4
715007S00AK	22,75	17,3	5,5	24%		17,25
715012S00AK	21,57	15,0	6,57	30%		15
715029S00AK	34,75	14,94	19,81	57%		14,94
717116S00AK	42,33	18,33	24	57%		18,33
717124S00AK	81,82	81,82	0	0%		81,82
717140S00AK	36	27,4	8,6	24%		27,4
717141S00AK	26	15,2	10,8	42%		15,2
717427S00AK	47,53	29,63	17,9	38%	10,8	18,83
717428S00AK	39	28,62	10,38	27%		28,62
717429S00AK	33,73	31	2,73	8%		31
717430S00AK	50,36	46	4,36	9%		46
717431S00AK	37,89	34,41	3,48	9%		34,41
718028S00AK	40,86	27,46	13,4	33%	17,5	9,96
718135S00AK	35,79	35,65	0,14	0%	20,23	15,42
718136S00AK	49,09	48,91	0,18	0%	38,18	10,73
718137S00AK	18	15,7	2,3	13%	7,63	8,07
718138S00AK	30,93	30,53	0,4	1%	18,33	12,2
718143S00AK	49,64	21,93	27,71	56%		21,93
718446S00AK	45,33	21	24,33	54%		21
718550S00AK	180,17	180,17	0	0%	146,5	33,67
719995S00AK	70,5	70,5	0	0%		70,5
719996S00AK	67,83	67,83	0	0%		67,83
720110S00AK	21,63	15,83	5,8	27%		15,83
720111S00AK	23,89	16,99	6,9	29%		16,99
720112S00AK	28,36	19,76	8,6	30%		19,76
720113S00AK	47,14	25,81	21,33	45%		25,81
720207S00AK	10	10	0	0%		10
720208S00AK	9,25	9,25	0	0%		9,25
720209S00AK	19,6	19,6	0	0%		19,6
720210S00AK	23,4	23,4	0	0%		23,4
724630S00AK	22	17,23	4,77	22%		17,23
724631S00AK	26,2	18,2	8	31%		18,2
724632S00AK	24,2	19,4	4,8	20%		19,4
724633S00AK	48,33	40,33	8	17%		40,33
724636S00AK	47,25	38,58	8,67	18%		38,58
724637S00AK	119,5	101,4	18,1	15%		101,4

Table 13 Decision Tree Results

The table shows that, when applying the decision tree, most products show significant improvement in terms of lead time, where the new lead time of five products is less than half of the current lead time. However, twelve of the forty parts do not show any improvement when applying the changes found in the generic model. Of these twelve however, five undergo a significant improvement throughout the definition change of the feeding cell, giving more insight in the realistic production lead time. The overall improvement of the forty cells gives an average of a 20,5% shorter lead time.

The example that has been used in this thesis is the VW Golf Plus door, which can also be found the table. The improvements result in 13,4 days shorter lead time that translates into a 33% decrease. The definition change for its feeding cell allows for a new production lead time of a little under 10 days, compared to the original 41 days.

8.5.2 Secondary Profits

Major benefits from lead time reduction are evident. It stimulates operation stability, reduces overhead costs and enhanced the overall productivity. However, a shorter lead time comes with more advantages, which are more indirect and secondary compared to the aforementioned.

The automotive market is changing and tenants need to be won to survive the competition. The ability to produce quicker allows for flexibility when environments change. Currently a buffer is made when adjustments are planned to overcome the downtime of machinery. Reducing lead times will enable voestalpine to postpone temporary overproduction and, therefore, decrease back-up buffers. The time profit that is made can increase order fulfilments from existing and new tenants, which directly influences the cash flow.

Furthermore, the number of logistical movements will become more comprehensible as the sequences of operational steps will lead to fewer transports. Instead of having to move semi-finished products to and from to inventory after every operational step, buffers can be moved directly to the next operation. As the buffer sizes have been equalised throughout the operational steps, even lesser movements are required as there is no splitting up of batch sizes anymore. One barriers, however, is that currently movement of batches is done by the warehouse whereas movement of buffers is done by operators. High level agreements and communication will have to be set in place to ensure the logistic movements of sequenced buffers.

Producing products with a higher pace without increasing risk leads to an enhanced and trustworthy WBZ rate to the customer and earlier release of production racks to start new production routings. Secondly, planners will not need to plan for both productions but will plan the sequence once saving time for a higher level of control over the production planning and execution. The opportunity to outpace competitors with a faster and more reliable output will facilitate the consistency of meeting the WBZ.

8.6 Introduced SAP Routing Parameters

The ability to set SAP routing parameters according to realistic production time, production performances and characteristics has been disabled so far. To meet a more realistic production planning and improve lead times throughout production, SAP routings (Z22 + x production days) should be adjusted and SAP preferences added.

For the former SAP suggested improvements, twenty-five different product groups were established, e.g. serial- vs. spare parts. Multiple sessions were held to better understand SAP's way of working, which resulted in the splitting of T3 (see section 7.5). For the current state of production, one day will always be necessary after the operation as it covers any delays, i.e. Z21 instead of Z22. The production is not reliable enough yet to allow a truck to be loaded right after manufacturing, and the company cannot afford an average of eighty trucks per day to wait until production is ready. Furthermore, planners will have to anticipate faster when production is influenced in any way, and have less room for error whilst creating the production schedule. Finance will be affected as their calculations towards the customers have to be updates, but these as well will be closer to reality.

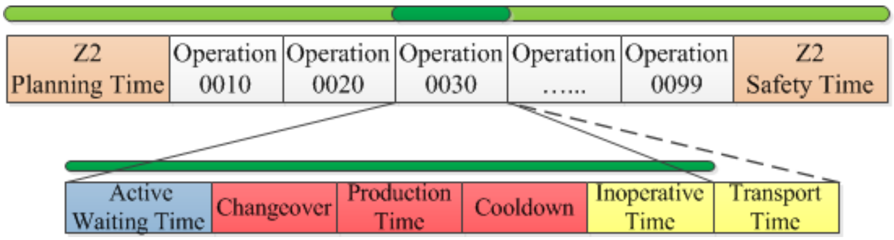


Fig. 30 SAP routing architecture

The latter SAP suggested improvements concerned the addition of SAP preferences according to production performances and sequence characteristics. By providing the system with more information about the production path, safety times will be reduced, buffers will decrease and lead time will be shorter. This is also applicable to the planning time of routings (i.e. Z2), which can be eliminated since the output of the first operation are the input of the successive one. The lower bar in figure 30 should be adjusted to meet a more realistic planning of routings.

The VW Golf Plus backdoor sequence [54042 - 54151 - 54169] shows a major gain in lead time reduction without increasing risk. A current state planning would result in 15 working days (3 x 5 routings days) lead time, whereas the combination of both SAP improvements above would conclude in a 7 working days lead time (Z21 + 3 production days + 1 safety day). Due to the fact that the 54169 is not a reliable cell, SAP preferences would suggest a single safety day addition. Furthermore, all purchased components of all three operations could be assigned to the first operation to ensure availability for the entire routing. This would go against all JIT-principles, however this would pale into insignificance compared with the days gained from this improvements.

8.7 Improved VW Golf Plus Backdoor

So far, all the improvements has been done on a theoretical basis, meaning that improved BOM structures have not been crosslinked with realistic dynamic customer demands and the presence of other products. To meet a more realistic estimation, the improved version of the VW Golf Plus backdoor (728999S00AK) has been created in SAP, so an estimated planning pilot could be run against recent disturbers.

Both call-off sheets have been planned individually and the results match the hypothesis. The tables below seem to show duplicates in the individual tables, e.g. twice the call-off row of the 718028H13AR, however the positive row indicates the creation of the product and the negative row is the demand of the higher level (in this case the demand from 718028H08AR). The colours in both tables below highlight the fabrication numbers that have been merged in the improved state. The first four rows do not take place in assembly, however are required to present the customer call-off. The lead time based on the critical path of both VW Golf Plus doors have been calculated, since the critical path still determines the shortest production pace throughout assembly. Table 14 shows a final call-off of the lowest level (718028H02AP) on 05-07-2018.

Finished Product	Description	Date	Disposition element	Quantity
718028S00AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	31-8-2018	SD-LiefPl	-42
718028S00AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	31-8-2018	Planauftr.	200
718028H91AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	13-8-2018	Sek-Bedarf	-200
718028H91AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	13-8-2018	Planauftr.	200
718028H01AR	VW ZB HECKKLAPPE GOLF PLUS -9R9	10-8-2018	Sek-Bedarf	-200
718028H01AR	VW ZB HECKKLAPPE GOLF PLUS -9R9	10-8-2018	Planauftr.	200
718028H22AR	VW ZB HECKKLAPPE INN AUS GOLF PLUS -9R9	4-8-2018	Sek-Bedarf	-200
718028H22AR	VW ZB HECKKLAPPE INN AUS GOLF PLUS -9R9	4-8-2018	Planauftr.	200
718028H07AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	29-7-2018	Sek-Bedarf	-200
718028H07AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	29-7-2018	Planauftr.	200
718028H08AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	22-7-2018	Sek-Bedarf	-200
718028H08AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	22-7-2018	Planauftr.	200
718028H13AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	16-7-2018	Sek-Bedarf	-200
718028H13AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	16-7-2018	Planauftr.	200
718028H10AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	10-7-2018	Sek-Bedarf	-200
718028H10AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	10-7-2018	Planauftr.	490
718028H02AP	VW INNENTEIL HECKKLAPPE -9P9	5-7-2018	Sek-Bedarf	-490

Table 14 Call-off sheet 718028S00AK

This identical product can be found in table 15, however in this improved state this product will be called-off on 26-07-2018. The comparison between both tables presents that the improved version of the 718028S00AK is able to start 21 days later than its current version with the final delivery date (31-08-2018) the same.

Finished Product	Description	Date	Disposition element	Quantity
728999S00AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	31-8-2018	SD-LiefPl	-42
728999S00AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	31-8-2018	Planauftr.	200
728999H91AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	13-8-2018	Sek-Bedarf	-200
728999H91AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	13-8-2018	Planauftr.	200
728999H01AR	VW ZB HECKKLAPPE GOLF PLUS -9R9	10-8-2018	Sek-Bedarf	-200
728999H01AR	VW ZB HECKKLAPPE GOLF PLUS -9R9	10-8-2018	Planauftr.	200
728999H07AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	6-8-2018	Sek-Bedarf	-200
728999H07AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	6-8-2018	Planauftr.	200
728999H99AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	30-7-2018	Sek-Bedarf	-200
728999H99AR	VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9	30-7-2018	Planauftr.	200
718028H02AP	VW INNENTEIL HECKKLAPPE -9P9	26-7-2018	Sek-Bedarf	-200

Table 15 Call-off sheet 728999S00AK

These 21 days provide planners with an immediate catch-up of the backlog, ability to reprogram cells or catch-up with other products. The new VSM for the VW Golf Plus backdoor can be seen in figure 31 and has resulted in a significant decrease in buffers. The current state contains eleven buffers and the improved state only four, because three operating cells have been redefined to feeding cells and buffers were eliminated due to sequencing. Leading to a lower risk of longer unnecessary waiting time. The green buffers indicate the feeding cells and can be neglected from the count (see section 8.2)

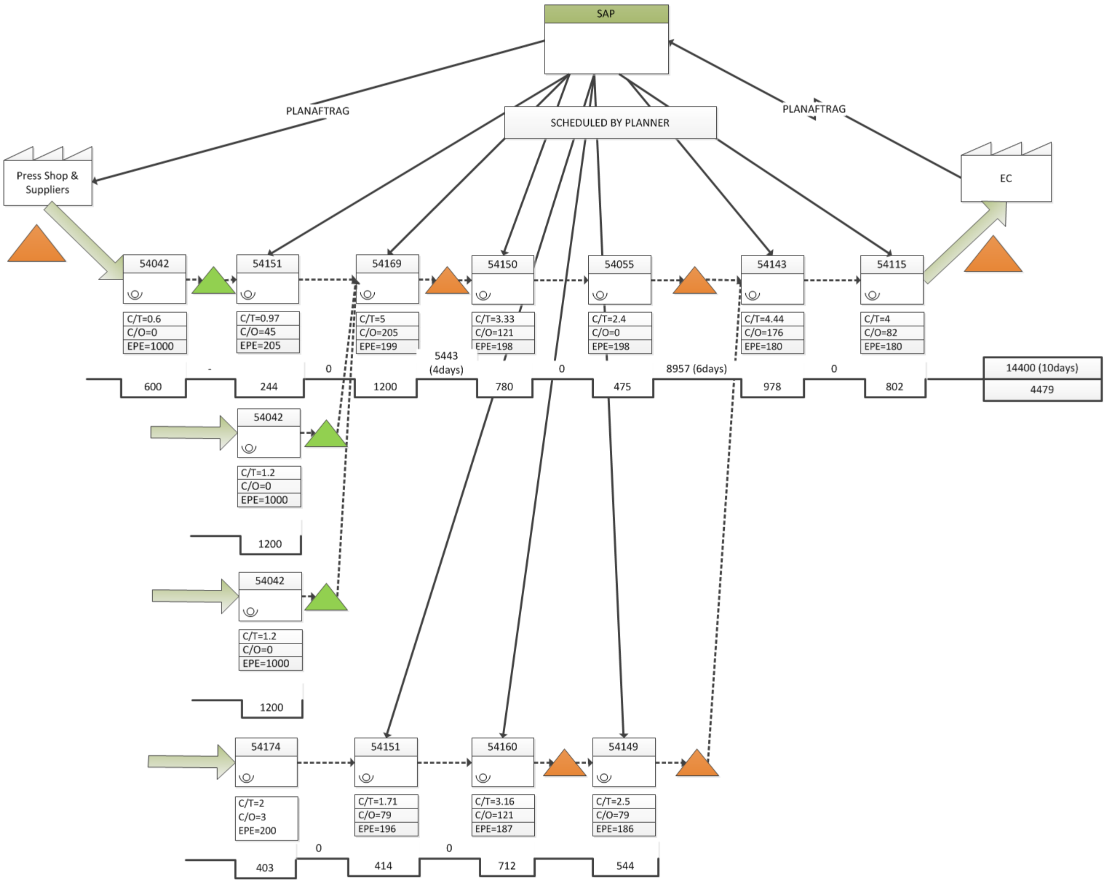


Fig. 31 VSM of the 728999S00AK

9 Concluding Discussion

Producing complex, high volume, spare parts efficiently and effectively is crucial to stay competitive in the automotive industry. Reducing the lead time of these parts could be very profitable, especially when customer delivery demands are not met. Forty products have been defined as complex and high volume in this research where the purpose was to analyse their current performance and to investigate potential improvements. Throughout the thesis, it has been aimed to fulfil the objective and answer the four research questions formed in chapter 2. The questions have been a guideline for the structure of the research that has led to a decision tree and relating suggested improvements to reduce lead time of complex, high volume, spare parts.

It has been shown that voestalpine currently lacks precision and transparency in its lead time and production of complex, high volume, spare parts. This has led to a demarcation based on estimated numbers and intuition. A new calculation method has been introduced in order to find the new lead times, giving between 10 and 180 days with little consistency between the lead times and batch sizes. This was compared to the given estimated lead of 59 to 78 days resulting in a higher variation than expected, thus with lead times of months but also lead times within the customer order lead time. As the demarcation of products was set by the case company based on the estimated lead time, it might be possible that products should have been in the scope that were not, whereas the products where the found lead time was short could have been excluded. The new calculation method is more realistic, but has its limitations as following batch sizes throughout the assembly is difficult due to the changing sizes. Batches do not have an individual travel history and pieces of the same product experience a variety of duration throughout the factory. Therefore, the current lead time analysis has been based on the complete call-offs of 2017. Taken in account the fluctuating batch sizes per operation, the product pace is not entirely guaranteed. The warehouse and planners have not applied any FIFO-system, which increases the probability of planning. These combinations were made in the 2017 call-off data based a FIFO-philosophy, however the reality could show an inequality. Thus, as the actual production data was used for the calculated lead times, they ought to be more realistic than the estimated ones, but can still have some little inconsistencies.

The occurrence and influence of lead time disturbers were more deeply explored in assembly, excluding changeover and quality issues as potential lead time influencers. The largest influencer was found in the buffer time between the operational steps rather than in breakdowns, logistics or other disturbances. This indicates an inefficient planning partially caused by disturbances or utilisation rates, but mostly by planning behaviour and unutilised SAP-parameters. Improving planning methodology and the SAP parameters has led to a focus on the non-value added time between consecutive operational steps. To minimise this time, analyses have been performed on sequence routing steps and bottleneck analyses have been performed on sequence routing steps and bottleneck. These two factors are the basis of a newly constructed decision tree.

Sequencing cells resulted into a maximum time of twelve hours in between the two cells, since SAP suggests prioritisation of this routing in the planning. Eleven out of forty cells were proven to be reliable, allowing for cascading these cells and the operational steps after. The reliability ensures that the successive step always will be produced, and no anomalies in the planning will occur. Sequencing identical cells, whether reliable or not, will never disturb the overall planning realisation besides the realisation of this specific cell. Functional cells previously had to be operated in sequence, and even though currently this does not give an improvement, it is important for any future products as it affects the product quality.

A potential problem with sequencing is that currently there is no dedicated floor space for the twelve-hour-buffers before the next operational step. For three consecutive weeks pictures have been made of the assembly floor to find potential area, however, it is expected that team managers will prefer buffers in inventory rather than on the floor. Understanding of the benefits of sequencings needs to be prioritised in order to create understanding for buffers on the production floor.

Determining each bottleneck per product both gave insight into the way of production and stimulated an improved way of planning. Applying a manufacturing pull strategy until the bottleneck, and pushing after, lead times decreased and planning was more efficiently adjusted to customer demand. If there is the possibility to sequence the step before the bottleneck, then its utilisation will stay high and starvation on the bottleneck will be prevented. The difficulty here lays in variety of bottleneck per product, meaning that some cells will be sequenced for one product, but not for the other.

The above-named principles have led to the decision tree for lead time reduction, where actions resulting from the decision tree will lead to lead time reduction. Two successive steps will need to be taken after following the tree, namely the levelling of batch sizes and changing the manufacturing strategy to bottleneck focused. The application of this decision tree to the forty products has led to an average decrease of 20,5% in term of days. In this generic model some products will be affected more than others. The highest reduction found was 57% meaning that the new lead time is less than half. However, seven products are not affected by the tree at all. Changing the way of planning by the introduction of feeding cells has led to an average decrease in lead time of 38 days.

This new way of planning has been tested in the ERP-system to verify the results in the planning environment. After changing the routing, and different parameters in SAP had been adjusted, the simulation of the chosen product resulted in a 21 days lead time reduction. The solutions have not been tested in reality, because implementing the new BOM structures, new way of working and adjusted inputs per sequence would require a preparation- test- and roll-out phase, including a secure and proven control plan. All stakeholders will need to be involved, which would not be feasible in this research period. This results in profits and potential pitfalls, which could differ from the actual profits and pitfalls. All improvements, however, have been theoretically tested, simulated and verified by multiple stakeholders decreasing the risk of inaccuracy and increasing credibility.

For execution of the suggested decision tree and its accompanying successive steps, voestalpine needs to take project ownership. The improvements made in this research require further endorsement of all stakeholders before actual implementations can be put into action. Strengths and weaknesses need to be inventoried and short-/long-terms need to be mapped.

With the suggested implementations in place, voestalpine will approach its customer demands and enhance production flexibility, leading to increased customer satisfaction.

10 Further Recommended Research

Over the course of the project, interesting topics and potential gaps came across, however have not been further investigated due to relevance, importance rate or without of reach of the scope. The following chapter does briefly touch each topic to avoid loss of knowledge and to state the essence of the individual subjects. The figure below shows improvement areas found throughout the thesis, that were not focused on but could, in the future, be improvements towards a better flowing system. voestalpine should consider these topics for further discussion and research.

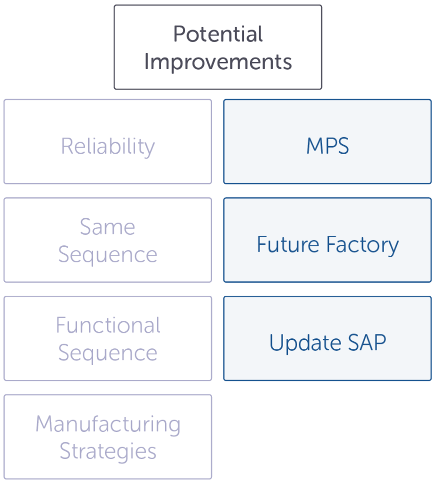


Fig. 32 Overview further recommendations

10.1 MPS Based Planning

Serving the aftermarket of the automotive industry means that profits increase when the demand for maintenance or repairs increases. This shows in the customer demand of the different customers of voestalpine, as the requested products increase in correlation to bad weather. The general trend that has been seen over the last years is that the demand in the winter is higher than in the summer, even though this does not always correspond to the customer's long-term forecast horizon. voestalpine has shown to have a better long term forecast than its customers, but does not take initiative to be proactive with this knowledge as this would mean intentionally buffering, which is at odds with current policies. However, it often means that, due to inaccurate customer forecasting, in the winter production has to run overtime to meet the demands. Utilising a MPS will support to level the demand and create more stability and levelled production throughout the year (see figure 33). The effect of this will be an increased delivery performance towards the customer. Even though the recommendation is for voestalpine to implement a MPS for its yearly production, the implementation of this in not within the scope of this project as there is no direct gain towards the lead time in assembly.

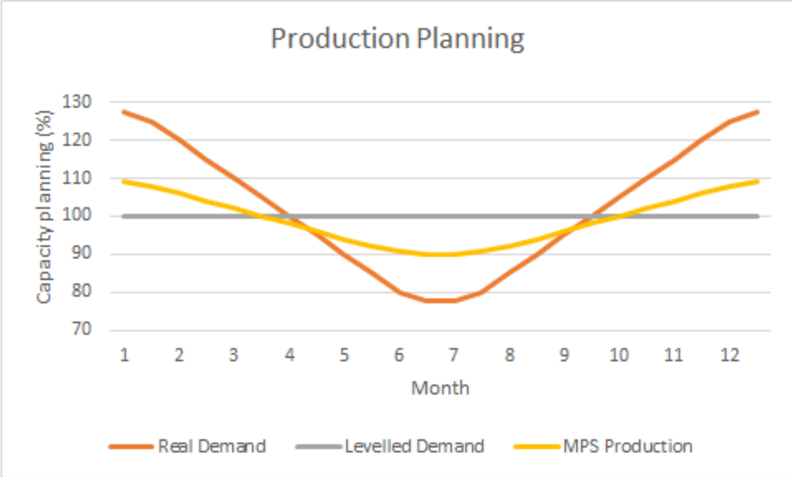


Fig. 33 Production planning

10.2 Future Factory Design

Currently no long-term strategy has been established to prepare the assembly layout for future challenges of the automotive industry. New operating cells are installed on the floor based on a short-term vision, which could hurt future executions. Section 11.2.1 - 11.2.4 elaborate on the findings that have not been further investigated, but are labelled as high potentials.

10.2.1 Re-engineering of cells

In the analytical framework two topics concerning re-engineering of cells have been discussed to be able to analyse the possibility of integrating two or multiple sequencing functions into one. Integrating potential successive processes could either be executed to enhance the flexibility or reconfigurability of an operating cell. The expected outcome would enable voestalpine to decrease material handling, increase reactability towards product changes and simply planning complexities.

From the analysis, it can be concluded that this potential improvement will not be further researched within this thesis. Functions cannot be simply merged, since a deeper understanding of the different functions have led to the realisation that identical functions are not so identical at all, i.e. a spot welding cell does not necessarily have to be identical to another spot welding cell. Furthermore, this potential improvement would require a highly technical investigation with a good understanding of robotics and accompanying knowledge. Focusing the research on this topic would certainly be appreciated and profitable. However, a single integration would cover at least the entire research period and would not decrease the lead time of all selected complex, high volume, spare parts.

10.2.2 Cell Clustering

An analysis was done for all the BOMs on all levels, where the operational cells were counted on how often they are needed during the production of these forty products. To see any clusters, one has to look at the sequence of the cells. First the cells were clusters in pairs, meaning that operational steps a-b-c-d resulted in a-b, b-c and c-d. These clusters of cell numbers were then counted over the total of BOMs, where the highest cluster appears eight times over the different products. Interestingly, there is only one cell cluster found in two different brands of cars, whereas other clusters are more often found within the same brand but a different model. Most clusters are uniquely found in the same model but a different version, or e.g. in both the left and the right door. Sequencing or integrating the cells that are found to have a high count could highly influence the lead time, but these options together with the increasing of reliability of these cells would need to be investigated.

In the assembly hall, the cell numbers are very specific. However, many cells have similar functions (e.g. spot welding, laser welding, hemming) and therefore it can be interesting to look at cell clustering on a higher level than just on cell number. For the clusters of two cell functions, higher counts were found and more clusters that cover multiple brands. Cell clustering on function could become very interesting when designing a new factory layout.

10.2.3 Uniqueness of Patterns

Another possibility for a new floor layout is to have dedicated storage space before each cell, limiting the production of the supplier cell on whether the bin is full or not. By integrating the warehouse and the assembly in this manner, bottlenecks directly show as the production of a cell must be stopped when the bin before the next cell is full. The routings of different cells, and the cells before and after were analysed to investigate possibilities for this future concept, as can be seen in appendix O. This concept, however, requires similar takt times throughout the assembly and with the current way of working this option is not realistic in the near future.

10.2.4 Functional- vs. Flow Layout

From above input a side project has been run to facilitate and argue future factory designs and its accompanying long-term strategy. Two well-known layouts (functional- and flow layout) have been put into context to predict challenges, restrictions and applicability (see figure 34 and 35).

Fig. 34 Potential Functional Layout

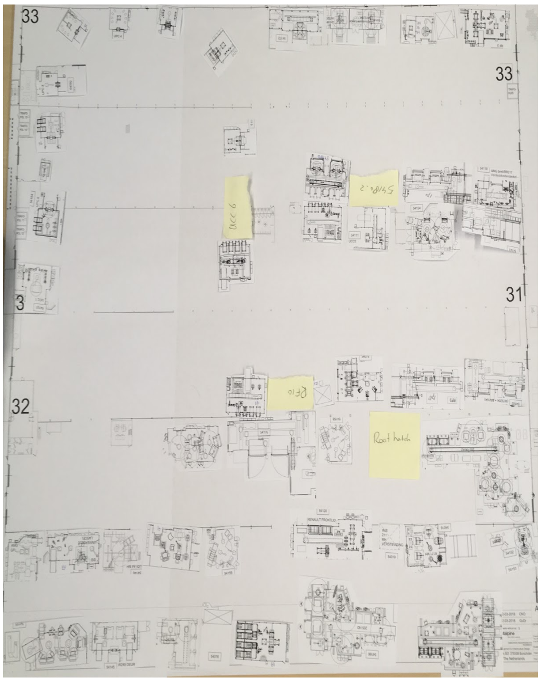


Fig. 35 Potential Flow Layout

10.3 Synchronise SAP

Every department in voestalpine utilises SAP data for cost calculations and time estimations. The finance department determines the total charged cost per product, based on e.g. movement- and utility costs, to establish the required price for customers to pay to achieve a certain profit. However, the SAP system is outdated and lacks accuracy when it comes down to recent input. The batch sizes used in reality do not match its accompanying calculated batch size (see table 16 for call-off sheet of 718028S00AK), resulting in either higher or lower charged costs for the customer. Also calculated cycle times and changeover times show significant differences in comparison to reality (section 7.3.1 & appendix P). Besides the consequences on cost calculations, this also influences the way of planning. Planners will need to correct automated planning schedules based on their intuition, meaning the risk of human errors and the presence of non-added value increases.

Semi-Finished Product	Calculated Batch Size	Reality Call-Off
718028H01AR	200	212
718028H22AR	200	223
718028H07AR	200	238
718028H07AR	200	238
718028H08AR	200	237
718028H11AR	200	673
718028H12AR	200	837
718028H13AR	200	281
718028H10AR	200	451
718028H33AR	200	217
718028H44AR	200	168
718028H55AR	200	291
718028H66AR	200	438

Table 16 Differences in batch size call-off 718028S00AK

References

Alänge, S. (2009). The Affinity-Interrelationship Method AIM [Class handout]. Technology Management and Economics, Chalmers University of Technology, Gothenburg

Angkiriwang, R., Pujawan, N.I. and Budi Santosa, B. (2014) Managing uncertainty through supply chain flexibility: reactive vs. proactive approaches, *Production & Manufacturing Research*, 2(1), pp. 50-70

Anupindi, R., Chopra, S., Deshmukh, S. D., Van Mieghem, J. A., & Zemel, E. (1999). *Managing business process flows.* Vol. 400. Upper Saddle River, NJ: Prentice Hall.

Aytug, H. Lawley, M.A., McKay, K. Mohan, S. and Uzsoy, R. (2005), Executing production schedule sin the face of uncertainties: A review and some future directions. *European Journal of Operational Research*. Elsevier. Pp. 86-110

Battini, D., Boyson, N. and Emde, S.J. (2013), Just-in-Time supermarkets for part supply in the automobile industry, *Journal of Management Control,* Vol. 24, No. 2, pp. 209-217

Belasco, J.A. (1988), Managing Bottlenecks, *Leadership Excellence*, Vol. 5 No. 3, pp. 15-16

Bellgran, M., & Aresu, E. (2003). Handling disturbances in small volume production. *Robotics and Computer-Integrated Manufacturing*, *19*(1-2), pp. 123-134.

Bellgran, M., Gullander, P., & Harlin, U. (2002). Towards improvement of production efficiency and effectiveness from a life-cycle perspective. *In Proc. of 33rd Int. Symposium on Robotics*.

Bergman, B., & Klefsjö, B. (2010). Quality from customer needs to customer satisfaction. Studentlitteratur AB.

Borrego, M., Douglas, E.P., and Amelink, C.T. (2009), Quantitative, Qualitative and Mixed Research Methods in Engineering Education, *Journal of Engineering Education*, Vol. 98, Iss. 1 (Jan 2009), pp. 53-66

Boysen, N., Fliedner, M. and Scholl, A., (2007). A classification of assembly line balancing problems. *European journal of operational research*, 183(2), pp.674-693.

Braglia, M., Carmignani, G., & Zammori, F. (2006). A new value stream mapping approach for complex production systems. *International journal of production research*, 44(18-19), 3929-3952.

Bryman, A. and Bell, E., (2015). Business research methods. Oxford University Press, USA.

Burns, L. D., Hall, R. W., Blumenfeld, D. E., & Daganzo, C. F. (1985). Distribution strategies that minimize transportation and inventory costs. *Operations Research*, 33(3), pp. 469-490.

Cakmakci, M. (2009). Process improvement: performance analysis of the setup time reduction-SMED in the automobile industry. *The International Journal of Advanced Manufacturing Technology*, 41(1-2), pp. 168-179.

Calantone, R., & Dröge, C. (1999). Supply chain flexibility: an empirical study. *Journal of Supply Chain Management*, *35*(2), pp. 16-24.

Chang, C. C. (2014). Optimum preventive maintenance policies for systems subject to random working times, replacement, and minimal repair. *Computers & Industrial Engineering*, *67*, pp. 185-194.

Chadwick, B., Gill, P., Stewart, K. & Treasure, E. (2008), Methods of data collection in qualitative research: interviews and focus groups, *BDJ*, vol. 204, no. 6, pp. 291-295.

Childerhouse, P., & Towill, D. R. (2003). Simplified material flow holds the key to supply chain integration. *Omega*, 31(1), 17-27.

Dubois, A. and Gadde, L.E., (2002). Systematic combining: an abductive approach to case research. *Journal of business research*, 55(7), pp.553-560.

Duri, C., Frein, Y., and Lee, H. S. (2000b). Performance evaluation and design of a CONWIP system with inspections. *International Journal of Production Economics*, Vol. 64, pp. 219–229.

de Bruin, A.M., Visser, G.M. and Koole, M.C. (2005), Bottleneck analysis of emergency cardiac in-patient flow in a university setting: an application of queuing theory. *Clinical and Investigative Medicine*, Vol. 28 No. 6, pp. 316-317.

Eisenhardt, K.M. and Graebner, M.E., (2007), Theory building from cases: Opportunities and challenges. *Academy of management journal*, 50(1), pp.25-32.

ElMaraghy, H. A. (2005). Flexible and reconfigurable manufacturing systems paradigms. *International journal of flexible manufacturing systems*, 17(4), pp. 261-276.

eSupplyChain (2008), "Production Planning and Control" Retrieved from
http://www.esupplychain.eu/en/info/viewart/608,Production_planning_and_control
[Accessed 14-03-2018]

Framinan, J. M., Ruiz-Usano, R., and Leisten, R. (2000). Input control and dispatching rules in a dynamic CONWIP flow-shop. *International Journal of Production Research*, Vol. 38, pp. 4589–4598.

Fitzsimmons, J.A. and Fitzsimmons, M.J. (2008), Service Management. Operations, Strategy, Information Technology, McGraw-Hill International Edition, New York, NY.

Galbraith, J., (1973). Designing Complex Organizations. *AddisonWesley*, Reading, MA.

Georgiadis, P., Vlachos, D., and Tagaras, G., (2006). The impact of product lifecycle on capacity planning of closedloop supply chains with remanufacturing. *Production and Operations Management*, 15 (4), pp. 514–527.

Gevers Deynoot, D., Nugteren, G. and Heijnsbroek, E. (2015). Handreiking intern transport en
logistiek. stichting van de arbeid. Retrieved from
http://www.dearbocatalogus.nl/sites/default/files/stvda/handreikingen/handreiking_intern_trans
Port_en_logistiek.pdf [Accessed 06-03-2018]

Grigore, S. D. (2007). Supply chain flexibility. *Romanian economic and business review,* 2(1), pp. 66.

Guide Jr, V.D.R., (2000). Production planning and control for remanufacturing: industry practice and research needs. *Journal of Operations Management*, Vol. 18, pp. 467–483.

Guide, D.R.V., Jayaraman, V. and Srivastava, R. (1999), Production planning and control for remanufacturing a state-of-the-art survey. *Robotics and Computer-Integrated Manufacturing*. Vol. 15, pp. 221-230

Hill, A.V. (2011). The Encyclopedia of Operations Management – A Field of Glossary and Manual of Operations Management Terms and Concepts, Pearson Education Limited, NJ.

Ho, C., 1989. Evaluating the impact of operating environments on MRP system nervousness. *International Journal of Production Research.* Vol. 27, pp. 1115–1135

Hopp, J.W. and Spearman, M.L. (2008), Factory Physics. Waveland Press, INc. Long Grove, Illinois.

Hwang, R. & Katayama, H. (2009), A multi-decision genetic approach for workload balancing of mixed-model U-shaped assembly line systems, *International Journal of Production Research*, vol. 47, no. 14, pp. 3797-3822.

Ignizio, J., P., (2009). Optimizing Factory Performance: Cost-effective ways to achieve significant and sustainable improvement. McGraw-Hill Companies, Inc.

Johnson, D.J. (2003), A Framework for Reducing manufacturing Throughput Time. *Journal of manufacturing systems*. Vol. 22, No. 4, pp. 283-298

Jonsson, A. and Svensson, V. (2016), Systematic Lead Time Analysis. Chalmers University of Technology. Retreived from http://publications.lib.chalmers.se/records/fulltext/238746/238746.pdf [Accessed 06-03-2018]

Kashkoush, M., & ElMaraghy, H. (2016). Product family formation by matching Bill-of-Materials trees. *CIRP Journal of Manufacturing Science and Technology*, Vol. 12, pp. 1-13

Kilpatrick, J. (2003). Lean principles. *Utah Manufacturing Extension Partnership*, 68, 1-5.

Koren, Y., & Shpitalni, M. (2010). Design of reconfigurable manufacturing systems. *Journal of manufacturing systems*, 29(4), pp. 130-141.

Krupp, J. A. (1993). Forecasting for the automotive aftermarket. *The Journal of Business Forecasting*, 12(4), pp. 8.

Law, J. (Ed.). (2016). A dictionary of business and management. *Oxford University Press*.

Li, L., Chang, Q., Ni, J., and Biller, S. (2009). Real time production improvement through bottleneck control. *International Journal of Production Research*, *47*(21), pp. 6145-6158.

Liker, J. K., AccessEngineering (e-book collection), McGraw-Hill Book Library (e-book collection), & Books24x7, I. (2004). *The Toyota Way: 14 management principles from the world's greatest manufacturer*, New York: McGraw-Hill..

Lu, X. H., Wu, W. Y., Han, P. Z., Li, G. J., and Wei, J. (2013). Study on Master Production Schedule in Manufacturing System for Medium and Small Manufacture Enterprises. In *Applied Mechanics and Materials*. Vol. 252, pp. 349-353. Trans Tech Publications.

MacArthur, E., (2013). Towards the circular economy. *Journal of Industrial Ecology*, pp.23-44.

Martin, K., & Osterling, M. (2014). Value stream mapping. Estados Unidos de América: Shingo Institute.

Martínez Sánchez, A. and Pérez Pérez, M., (2005). Supply chain flexibility and firm performance: a conceptual model and empirical study in the automotive industry. *International Journal of Operations & Production Management*, 25(7), pp.681-700.

Mason-Jones, R. and Towill, D.R. (1999), Total cycle time compression and the agile supply chain. *International Journal of Production Engineering*. Vol. 62, pp. 61-73

Masuchun, W., Davis, S., and Patterson, J. W. (2004). Comparison of push and pull control strategies for supply network management in a make-to-stock environment. I*nternational Journal of Production Research*, 42(20), pp. 4401-4419.

Maxwell, J.A., (2008). Designing a qualitative study. *The SAGE handbook of applied social research methods*, Vol. 2, pp.214-253.

Mehrabi, M. G., Ulsoy, A. G., and Koren, Y. (2000). Reconfigurable manufacturing systems: Key to future manufacturing. *Journal of Intelligent manufacturing*, 11(4), 403-419.

Muffatto, M. and Roveda, M., (2002). Product architecture and platforms: a conceptual framework. *International Journal of Technology Management*, 24(1), pp.1-16.

Nicholas, J. M. (1998). *Competitive manufacturing management: continuous improvement, lean production, customer-focused quality*. McGraw-Hill/Irwin.

Olhager, J., and Östlund, B. (1990). An integrated push-pull manufacturing strategy. *European Journal of Operational Research*, 45(2-3), pp. 135-142.

Petersson, P. (2010). Lean: turn deviations into success!: with examples from manufacturing, administration, services and healthcare. *Part Media.*

Ramesh, V., SREENIVASA, P. K., & Srinivas, T. R. (2008). Implementation of a lean model for carrying out value stream mapping in a manufacturing industry.

Rekiek, B., Dolgui, A., Delchambre, A. & Bratcu, A. (2002), State of art of optimization methods for assembly line design, *Annual Reviews in Control*, vol. 26, no. 2, pp. 163-174.

Renna, P., Magrino, L., and Zaffina, R. (2013). Dynamic card control strategy in pull manufacturing systems. *International Journal of Computer Integrated Manufacturing*, 26(9), pp. 881-894.

Rother, M., & Shook, J. (2003). *Learning to see: value stream mapping to add value and eliminate muda.* Lean Enterprise Institute.

Salvador, F., Rungtusanatham, M., Forza, C., & Trentin, A. (2007). Mix flexibility and volume flexibility in a build-to-order environment: Synergies and trade-offs. *International Journal of Operations & Production Management*, 27(11), 1173-1191. 10.1108/01443570710830584

Scheinberg, S., (2017). Lecture on "Qualitative Research Methods Curiosity and Interviewing"

Shethna, J. (2017). Comprehensive Guide to Production Planning and Control (PPC). Retrieved from https://www.educba.com/production-planning-and-control-ppc/ [Accessed 11-03-2018]

Sipper, D. and Bulfin Jr, R.L., (1997). Production: planning, control, and integration. New York: McGraw-Hill.

Slack, N. and Lewis, M. (2005), The Blackwell Encyclopedia – Operations Management, Blackwell Publishing Ltd, Oxford.

Spearman, M. L., Woodruff, D. L., & Hopp, W. J. (1990). CONWIP: a pull alternative to kanban. *The International Journal of Production Research*, 28(5), 879-894.

Spearman, M. L., & Zazanis, M. A. (1992). Push and pull production systems: issues and comparisons. *Operations research*, 40(3), 521-532.

Sridharan, V., and Berry, W. L. (1990). Freezing the master production schedule under demand uncertainty. *Decision Sciences*, 21(1), pp. 97-120.

Stevenson, M., and Spring, M. (2007). Flexibility from a supply chain perspective: definition and review. *International Journal of Operations & Production Management*, *27*(7), pp. 685-713.

Stevenson, W.J. and Hojati, M., (2007). Operations management, Vol. 8. Boston: McGraw-Hill/Irwin

Suresh, N.C. and Meredith, J.R. (1994). "Coping with the loss of pooling synergy in cellular manufacturing systems." *Mgmt. Science*. Vol. 40, No. 4, pp. 466-483.

Tang, O., and Grubbström, R. W. (2002). Planning and replanning the master production schedule under demand uncertainty. *International journal of production economics*, 78(3), pp. 323-334.

Thomas, P.R., (1990)Competitiveness Through Total Cycle Time, *McGraw-Hill*, New York, NY,

Towill, D.R. (1996) Time compression and supply chain management ; a guided tour. L*ogistics Information Management*. 9(6), pp. 41-53.

Townsend, B., Books24x7 (e-book collection) & Books24x7, I. (2012);, The basics of line balancing and JIT kitting, 1st edn, CRC Press, Boca Raton, FL.

Tu, Q., Vonderembse, M., Ragu-Nathan, T. and Ragu-Nathan, B. (2004). Measuring Modularity-Based Manufacturing Practices and Their Impact on Mass Customization Capability: A Customer-Driven Perspective. *Decision Sciences*, 35(2), pp.147-168.

Upton, D. (1994), The management of manufacturing flexibility, *California Management Review*, Vol. 36 No. 1, pp. 72-89.

Vaishnavi, N. (2011), Essay on Stages of Production Planning and Control. Retrieved from http://www.businessmanagementideas.com/essays/production-essays/essay-on-production-planning-and-control-ppc-top-8-essays/11830 [Accessed 11-03-2018]

Verweij, M. J., and Zwegers, A. J. R. (1998). Analysis and design of production and control structures. In A*dvances in Production Management Systems* (pp. 171-182). Springer, Boston, MA.

Vlachos, D., Georgiadis, P., and Iakovou, E., (2007). A system dynamics model for dynamic capacity planning of remanufacturing in closed-loop supply chains. *Computers and Operations Research*, Vol. 34, pp. 367–394.

Wacker, J. G. (1996). A theoretical model of manufacturing lead times and their relationship to a manufacturing goal hierarchy. *Decision Sciences*, 27(3), 483-517.

Womack, J.M. and Jones, D.T., (1994) From lean production to lean enterprise, *Harvard Business Review,* March/April 1994, pp. 93-103

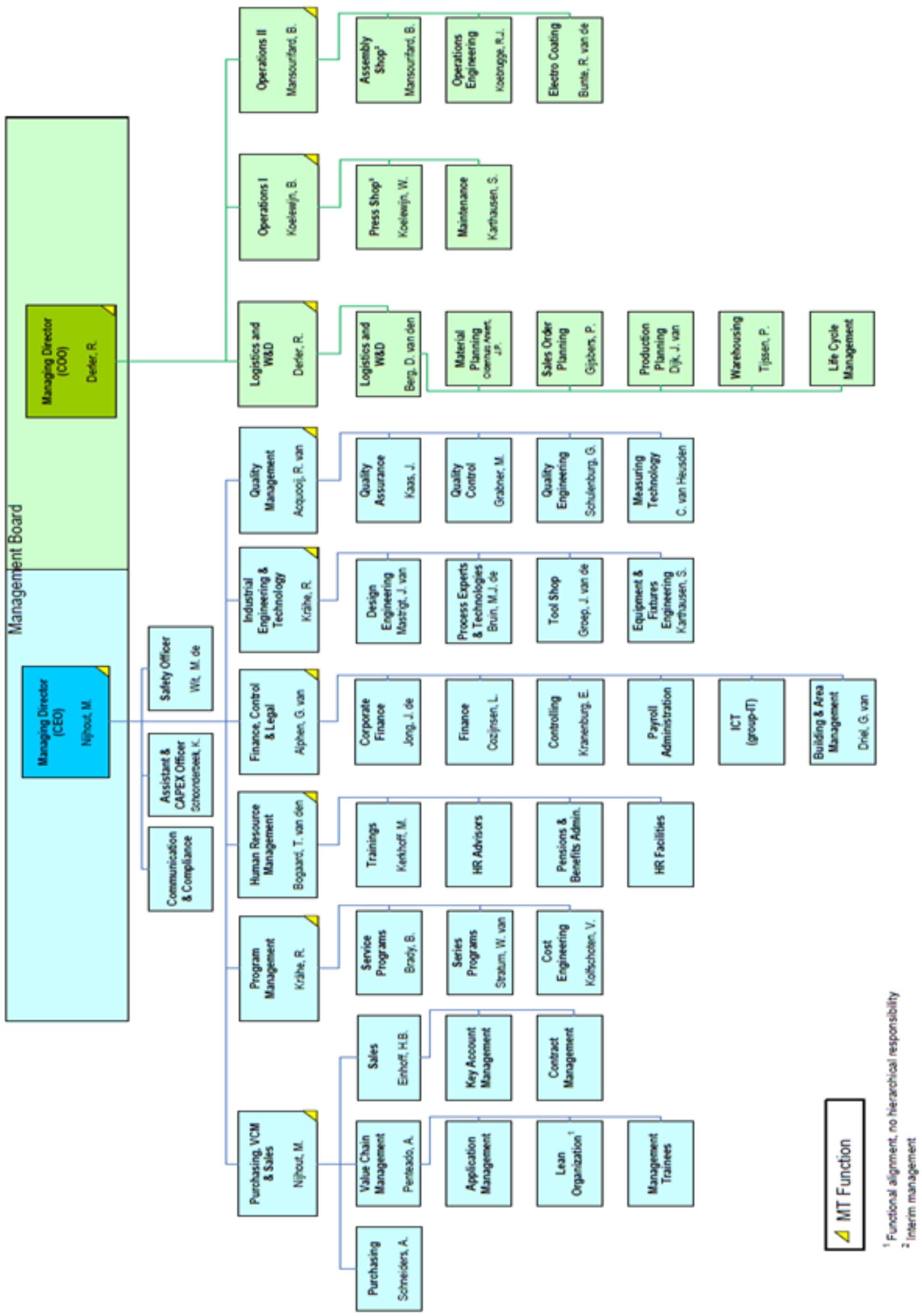
Ylipää, T. (2000). High-reliability manufacturing systems (Doctoral dissertation, Chalmers University of Technology).

Zhao, X., and Lee, T. S. (1993). Freezing the master production schedule for material requirements planning systems under demand uncertainty. *Journal of operations management*, 11(2), 185-205.

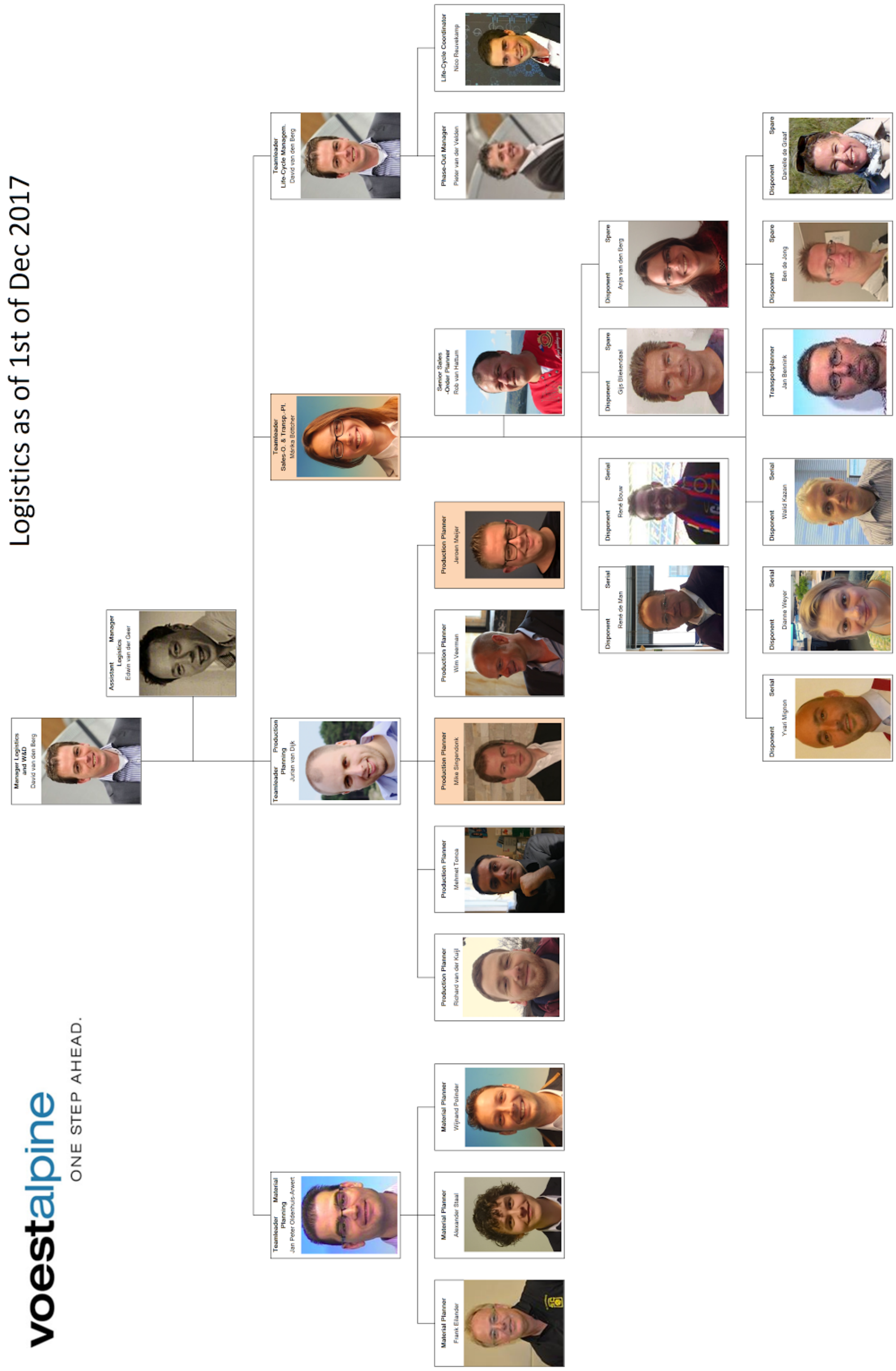
Zhang, C., Okada, N. and Yokomatsu, M. (2007), Bottleneck analysis of disaster risk communication problems based on post-disaster field surveys. Annals of Disaster Prevention Research Institute, Kyoto University, Kyoto. Retrieved from: www.dpri.kyoto-u.ac.jp/web_e/index_e.html [Accessed 05-03-2018].

Appendices

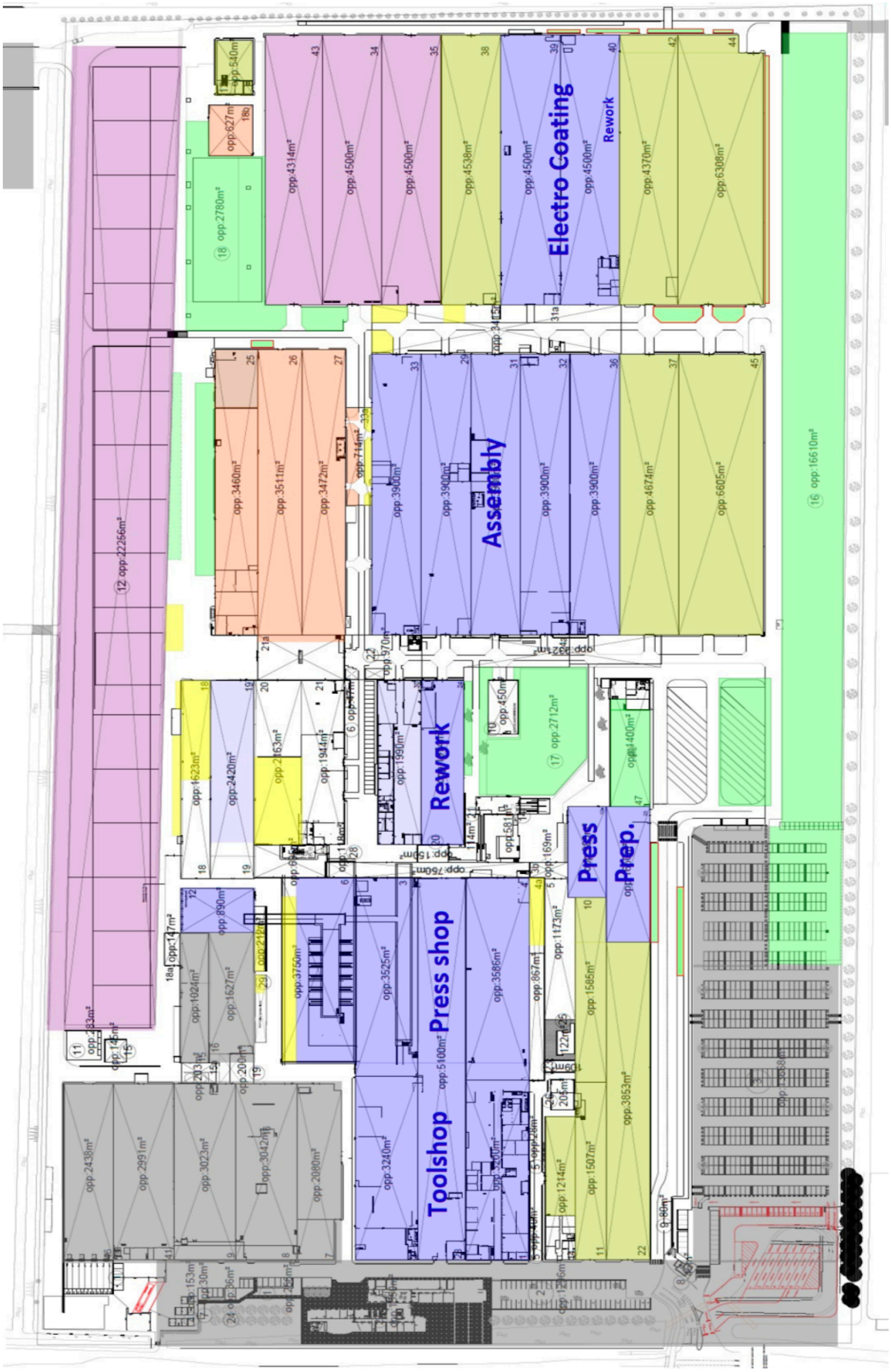
Appendix A: Organisational Structure



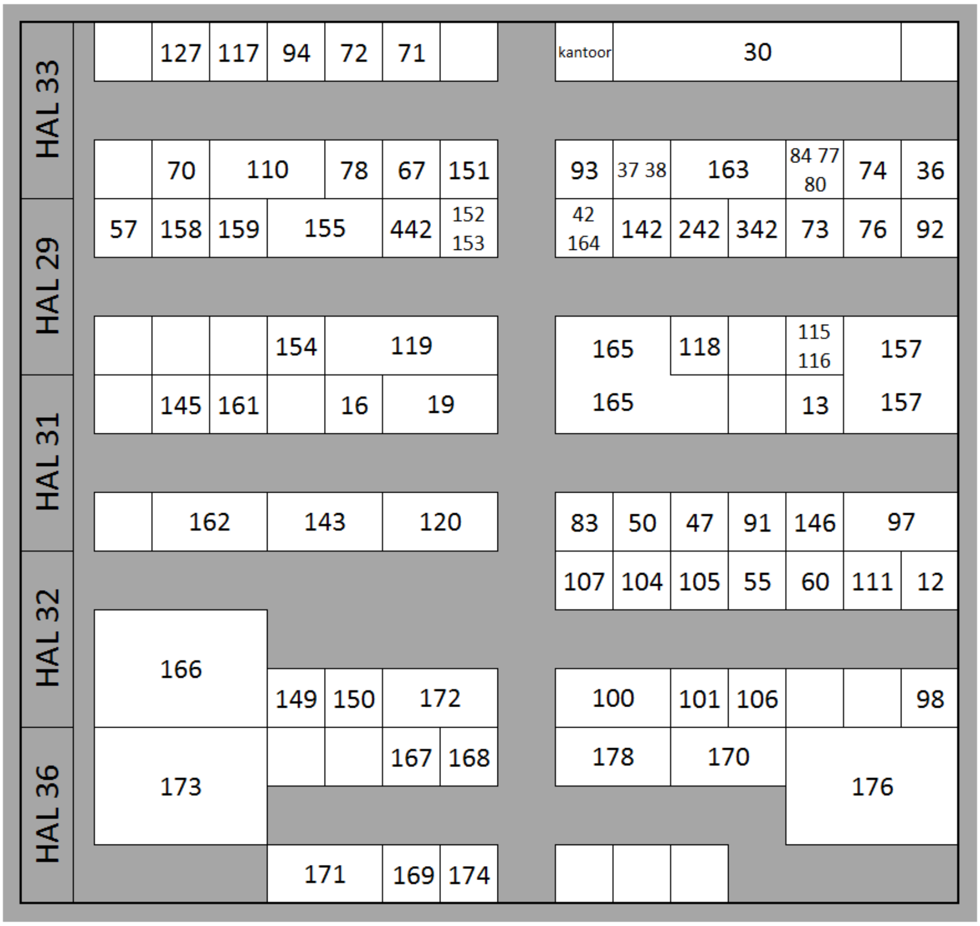
Appendix B: Organisational Chart Logistics, Warehouse and Delivery



Appendix C: Production Plan Layout



Appendix D: Cell Layout of Assembly Hall



Appendix E: BOM 718028S00AK, including purchased parts

<table>
<tr><th>Index</th><th>SAP nr.</th><th>Description</th><th>Process</th><th>Level</th></tr>
<tr><td>1</td><td>718028S00AK</td><td>|-VW ZB HECKKLAPPE GOLF PLUS -9K9</td><td>85147-SEALEN, 85101-EINDVE, 85101-VOORBE</td><td>0</td></tr>
<tr><td>2</td><td>718028H91AK</td><td>|-VW ZB HECKKLAPPE GOLF PLUS -9K9</td><td>85101-OPHANG, 85146-LAKKEN, 85101-AFHALE</td><td>1</td></tr>
<tr><td>3</td><td>000000000000178938</td><td>|-ETIKET VW/AUDI/SKODA/SEAT WK 3822</td><td></td><td>2</td></tr>
<tr><td>4</td><td>718028H01AR</td><td>|-VW ZB HECKKLAPPE GOLF PLUS -9R9</td><td>54115-Lassen</td><td>2</td></tr>
<tr><td>5</td><td>000000000000178274</td><td>|-KUGELBOLZEN</td><td></td><td>3</td></tr>
<tr><td>6</td><td>718028H22AR</td><td>|-VW ZB HECKKLAPPE INN AUS GOLF PLUS -9R9</td><td>54143-Samens</td><td>3</td></tr>
<tr><td>7</td><td>718216S00AP</td><td>|-VW HECKKLP AU SPOILER GOLF PLUS -9P9</td><td>51321-Persen, 51322-Persen, 51323-Persen, 51324-Persen, 51325-Persen, 51326-Persen</td><td>4</td></tr>
<tr><td>8</td><td>718216H01AS</td><td>|-VW VLM-DV-BU ZIE TEKENING * 0.73 -9S9</td><td>33171-Persen</td><td>5</td></tr>
<tr><td>9</td><td>000000000000198060</td><td>|-DC06+ZE50/50 BPO 1477 * 0.73</td><td></td><td>6</td></tr>
<tr><td>10</td><td>000000000000191077</td><td>|-DC06+ZE50/50 BPO 1530 * 0.73</td><td></td><td>7</td></tr>
<tr><td>11</td><td>718028H07AR</td><td>|-VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9</td><td>54150-Laserl, 54055-Aflass</td><td>4</td></tr>
<tr><td>12</td><td>000000000000194221</td><td>|-LASDRAAD A202MS KOPER VAT 200KG</td><td></td><td>5</td></tr>
<tr><td>13</td><td>718028H08AR</td><td>|-VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9</td><td>54169-lassen</td><td>5</td></tr>
<tr><td>14</td><td>000000000000178271</td><td>|-ZSB SCHLOSSVERSTAERKUNG</td><td></td><td>6</td></tr>
<tr><td>15</td><td>000000000000178275</td><td>|-ADAPTERTEIL SBBR-LEUCHTE</td><td></td><td>6</td></tr>
<tr><td>16</td><td>711501S00A</td><td>|-SB Verst ├ñrkung Gasfeder -999</td><td></td><td>6</td></tr>
<tr><td>17</td><td>711502S00A</td><td>|-ZSB Verst ├ñrkung Gasfeder -999</td><td></td><td>6</td></tr>
<tr><td>18</td><td>718217S00AP</td><td>|-VW VERSTAERKUNGSPROFIL HI LI -9PX</td><td></td><td>6</td></tr>
<tr><td>19</td><td>718218S00AP</td><td>|-VW VERSTAERKUNGSPROFIL HI RE -9PX</td><td>51321-Persen, 51322-Persen, 51323-Persen, 51324-Persen, 51325-Persen, 51326-Persen</td><td>6</td></tr>
<tr><td>20</td><td>718217H01AS</td><td>|-VW VLM-DV-BI ZIE TEKENING * 1.02 -9S9</td><td>33121-Persen</td><td>7</td></tr>
<tr><td>21</td><td>000000000000178160</td><td>|-DX53D+Z100MB 902 * 1.00</td><td></td><td>8</td></tr>
<tr><td>22</td><td>718028H11AR</td><td>|-VW ZB SCHARNIERVERSTAERKUNG LI -9R9</td><td>54042-Gewind</td><td>6</td></tr>
<tr><td>23</td><td>000000000000178272</td><td>|-GEWINDEPLATTE</td><td></td><td>7</td></tr>
<tr><td>24</td><td>718028H03AP</td><td>|-VW SCHARNIERVERSTAERKUNG LI -9PX</td><td>51316-Persen, 51315-Persen, 51314-Persen, 51313-Persen, 51312-Persen, 51311-Persen</td><td>7</td></tr>
<tr><td>25</td><td>718028H05AS</td><td>|-VW VLM-DV-BI 882 * 330 * 0.80 -9S9</td><td>33249-Inkort</td><td>8</td></tr>
<tr><td>26</td><td>000000000000179801</td><td>|-DX53D+Z100 MBO 882 * 0.80</td><td></td><td>9</td></tr>
<tr><td>27</td><td>718028H12AR</td><td>|-VW ZB SCHARNIERVERSTAERKUNG RE -9R9</td><td>54042-Gewind</td><td>6</td></tr>
<tr><td>28</td><td>000000000000178272</td><td>|-GEWINDEPLATTE</td><td></td><td>7</td></tr>
<tr><td>29</td><td>718028H04AP</td><td>|-VW SCHARNIERVERSTAERKUNG RE -9PX</td><td></td><td>7</td></tr>
<tr><td>30</td><td>718028H13AR</td><td>|-VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9</td><td>54151-Stanzm</td><td>6</td></tr>
<tr><td>31</td><td>000000000000178273</td><td>|-STANZMUTTER M6-1.3</td><td></td><td>7</td></tr>
<tr><td>32</td><td>718028H10AR</td><td>|-VW ZB HECKKLAPPE INNEN GOLF PLUS -9R9</td><td>54042-Schwei</td><td>7</td></tr>
<tr><td>33</td><td>000000000000177371</td><td>|-EN911166.01 SCHWEISSSCHRAUBE M6X22 8</td><td></td><td>8</td></tr>
<tr><td>34</td><td>718028H02AP</td><td>|-VW INNENTEIL HECKKLAPPE -9P9</td><td>51231-Persen, 51232-Persen, 51233-Persen, 51234-Persen, 51235-Persen, 51236-Persen</td><td>8</td></tr>
<tr><td>35</td><td>718028H06AS</td><td>|-VW VLM-DV-BI ZIE TEKENING * 0.70 -9S9</td><td>33171-Persen</td><td>9</td></tr>
<tr><td>36</td><td>000000000000179885</td><td>|-DX57D+Z100 MBO 1667 * 0.70</td><td></td><td>10</td></tr>
<tr><td>37</td><td>718028H33AR</td><td>|-VW ZB HECKKLAPPE AUS GOLF PLUS -9R9</td><td>54149-Laserl</td><td>4</td></tr>
<tr><td>38</td><td>000000000000178266</td><td>|-EINSATZTEIL</td><td></td><td>5</td></tr>
<tr><td>39</td><td>000000000000178268</td><td>|-EINSATZTEIL</td><td></td><td>5</td></tr>
<tr><td>40</td><td>718028H44AR</td><td>|-VW ZB HECKKLAPPE AUS GOLF PLUS -9R9</td><td>54160-Laserl</td><td>5</td></tr>
<tr><td>41</td><td>000000000000178337</td><td>|-AUSSENTEIL UNTEN EUROPA</td><td></td><td>6</td></tr>
<tr><td>42</td><td>000000000000194221</td><td>|-LASDRAAD A202MS KOPER VAT 200KG</td><td></td><td>6</td></tr>
<tr><td>43</td><td>718028H55AR</td><td>|-VW ZB HECKKLAPPE AUS MITTE GOLF PLUS-9R9</td><td>54151-Gewind</td><td>6</td></tr>
<tr><td>44</td><td>000000000000178265</td><td>|-GEWINDEBOLZEN M6X25</td><td></td><td>7</td></tr>
<tr><td>45</td><td>718028H66AR</td><td>|-VW ZB HECKKLAPPE MITTE GOLF PLUS -9R9</td><td>54174-Snijde</td><td>7</td></tr>
<tr><td>46</td><td>000000000000178333</td><td>|-AUSSENTEIL MITTE</td><td></td><td>8</td></tr>
<tr><td>47</td><td>000000000000178354</td><td>|-ZUSCHNITT WELLPAPPE WK 3438</td><td></td><td>1</td></tr>
<tr><td>48</td><td>000000000000178355</td><td>|-ZUSCHNITT WELLPAPPE WK 3439</td><td></td><td>1</td></tr>
<tr><td>49</td><td>000000000000178356</td><td>|-ZUSCHNITT WELLPAPPE WK 3440</td><td></td><td>1</td></tr>
</table>

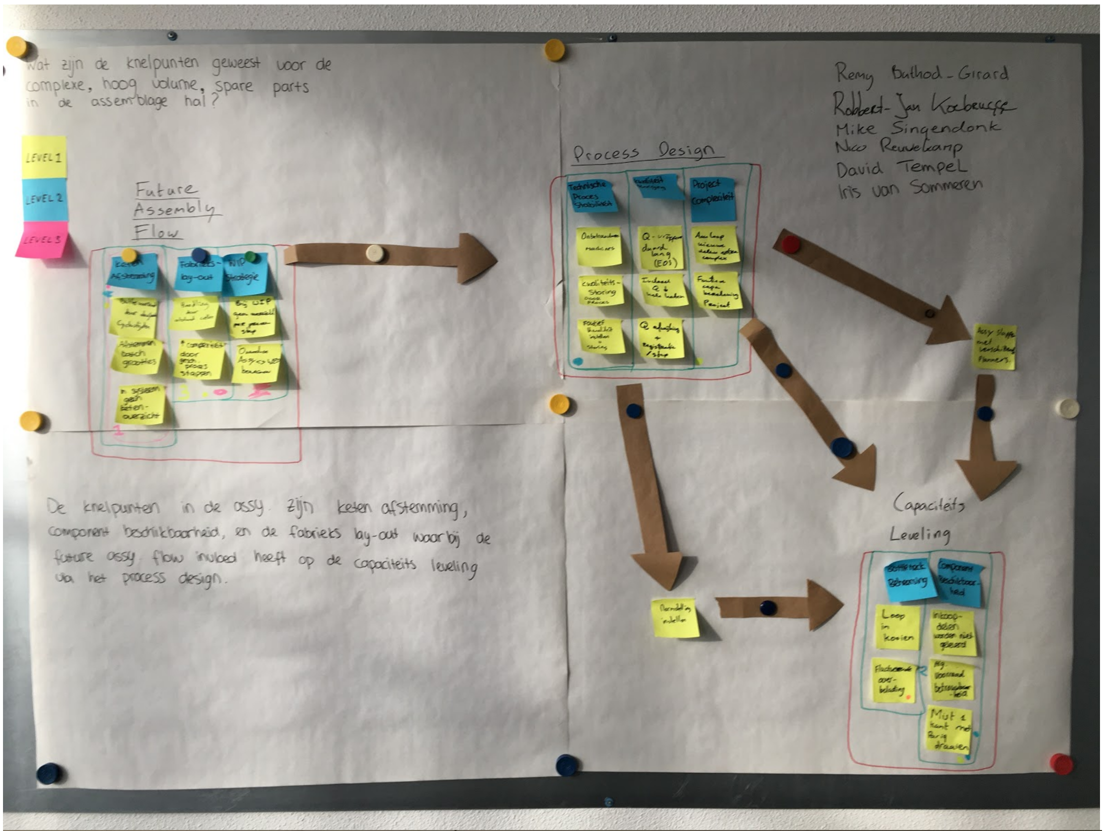
Appendix F: Product Scope

Finished Product	Description	Phase	LT Pur	LT Assy	LT EC	LT Seal	Ship	Total	Total (Cal. Days)	WBZ (Cal. Days)
718446S00AK	DAG ZB RUECKWANDTUER MOPF X204 -9K9	Spare A	20	30	5	5	2	62	86,8	58,8
718028S00AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	Spare A	20	30	5	5	2	62	86,8	60
717124S00AK	AUDI ZB HECKKLAPPE B8 -9K9	Spare A	20	27	5	5	2	59	82,6	60
720112S00AK	VW TUER VO LI TOURAN -9K9	Spare A	20	27	5	5	2	59	82,6	60
720113S00AK	VW TUER VO RE TOURAN -9K9	Spare A	20	27	5	5	2	59	82,6	60
717427S00AK	VW ZB HECKKLAPPE GOLF VI -9K9	Spare A	20	27	5	5	2	59	82,6	60
717430S00AK	VW ZB TUER HINTEN GOLF VI LI -9K9	Spare A	20	27	5	5	2	59	82,6	60
717431S00AK	VW ZB TUER HINTEN GOLF VI RE -9K9	Spare A	20	27	5	5	2	59	82,6	60
724630S00AK	VW ZB TUER HINTEN LI PASSAT B6 KD -9K9	Spare B	20	27	5	5	2	59	82,6	60
724632S00AK	VW ZB TUER HINTEN LI PASSAT B7 KD -9K9	Spare A	20	27	5	5	2	59	82,6	60
724631S00AK	VW ZB TUER HINTEN RE PASSAT B6 KD -9K9	Spare B	20	27	5	5	2	59	82,6	60
724633S00AK	VW ZB TUER HINTEN RE PASSAT B7 KD -9K9	Spare A	20	27	5	5	2	59	82,6	60
717428S00AK	VW ZB TUER VORNE GOLF VI LI -9K9	Spare A	20	27	5	5	2	59	82,6	60
717429S00AK	VW ZB TUER VORNE GOLF VI RE -9K9	Spare A	20	27	5	5	2	59	82,6	60
718550S00AK	DAG HOOD ASSY SWB BR164 -9K9	Spare B	20	21	5	5	2	53	74,2	58,8
713931S00AK	DAG OX ZB MOTORHAUBE W221 -9K9	Spare A	20	21	5	5	2	53	74,2	58,8
715029S00AK	DAG ZB MOTORHAUBE V-MOPF W204 -9K9	Spare A	20	21	5	5	2	53	74,2	58,8
719995S00AK	OPEL DOOR ASM-FRT SI LH C4400 -9K9	Spare A	20	21	5	5	2	53	74,2	56
719996S00AK	OPEL DOOR ASM-FRT SI RH C4400 -9K9	Spare A	20	21	5	5	2	53	74,2	56
720110S00AK	VW TUER HI LI TOURAN -9K9	Spare A	20	21	5	5	2	53	74,2	60
720111S00AK	VW TUER HI RE TOURAN -9K9	Spare A	20	21	5	5	2	53	74,2	60
724636S00AK	VW ZB TUER VORN LI EOS KD -9K9	Spare A	20	21	5	5	2	53	74,2	60
724637S00AK	VW ZB TUER VORN RE EOS KD -9K9	Spare A	20	21	5	5	2	53	74,2	60
717140S00AK	AUDI ZB TUER C6 LIMO L L-9K9	Spare B	20	15	5	5	2	47	65,8	60
717141S00AK	AUDI ZB TUER C6 LIMO R R-9K9	Spare B	20	15	5	5	2	47	65,8	60
717116S00AK	AUDI ZB TUER HINTEN R C6 R-9K9	Spare B	20	15	5	5	2	47	65,8	60
713933S00AK	DAG OX ZB MOTORHAUBE VMOPF W212 -9K9	Spare A	20	15	5	5	2	47	65,8	58,8
720207S00AK	DAG ZB FAHRERTUER LI -9K9	Spare B	20	15	5	5	2	47	65,8	102,8
718135S00AK	DAG ZB FAHRERTUER LI W/S204 -9K9	Spare A	20	15	5	5	2	47	65,8	58,8
720209S00AK	DAG ZB FAHRERTUER RE -9K9	Spare B	20	15	5	5	2	47	65,8	102,8
718136S00AK	DAG ZB FAHRERTUER RE W/S204 -9K9	Spare A	20	15	5	5	2	47	65,8	58,8
720208S00AK	DAG ZB FONDTUER LI -9K9	Spare B	20	15	5	5	2	47	65,8	102,8
718137S00AK	DAG ZB FONDTUER LI W204 -9K9	Spare A	20	15	5	5	2	47	65,8	58,8
720210S00AK	DAG ZB FONDTUER RE -9K9	Spare B	20	15	5	5	2	47	65,8	86,8
718138S00AK	DAG ZB FONDTUER RE W204 -9K9	Spare A	20	15	5	5	2	47	65,8	58,8
718143S00AK	DAG ZB HECKDECKEL W204 -9K9	Spare A	20	15	5	5	2	47	65,8	58,8
714769S00AK	DAG ZB MOTORHAUBE BR245 MOPF ET -9K9	Spare B	20	15	5	5	2	47	65,8	86,8
714770S00AK	DAG ZB MOTORHAUBE BR245 V-MOPF -9K9	Spare B	20	15	5	5	2	47	65,8	86,8
715007S00AK	DAG ZB HINTERKOTFLUEGEL L W204 -9K9	Spare A	20	15	5	0	2	42	58,8	58,8
715012S00AK	DAG ZB HINTERKOTFLUEGEL R W204 -9K9	Spare A	20	15	5	0	2	42	58,8	58,8

Appendix G: Relevant Cells

Cell Nr.	Count	Cell Name
54115	23	Univ. Spot Welding Cell 5
54169	21	Univ. Spot Welding Cell 7
54042	19	Stationary Spot Welding
54174	18	Univ. Assembly Controller
54172	17	Univ. Laser Welding Cell 3
54149	13	Univ. Laser Welding Cell 1
54151	13	Univ. Clinch Cell 3
54171	13	Univ. Clinch Cell 5
54143	10	Univ. Hemming Cell 5
54055	9	Manual Spot Welding
54094	8	Univ. Spot Welding Cell 4
54072	7	Univ. Spot Welding Cell 1
54150	7	Univ. Laser Welding Cell 2
54116	6	Univ. Spot Welding Cell 5
54117	6	Univ. Curing Cell 1
54162	6	Univ. Hemming Cell 7
54170	6	Univ. Hemming Cell 8
54178	6	Universal Hemming Cell no. 9
54342	5	Stationary Spot Welding
54013	4	Finishing
54036	4	Univ. Hemming Cell 1
54047	4	Manual Spot Welding
54074	4	Univ. Adhesive Cell 1
54118	4	Univ. Hemming Cell 4
54145	4	DAG Door 245
54160	4	Univ. Laser Welding Cell 2
54078	3	Univ. Hemming Cell 2
54080	3	Audi Door A3 (Hemming)
54106	3	Manual Bolt Welding
54110	3	Univ. Hemming Cell 3
54164	3	Manual Nut Pressing
54030	2	Univ. Hemming Press
54097	2	Manual Spot Welding
54098	2	Univ. Lasercutting Cell 1
54111	2	Univ. Clinch Cell 2
54163	2	Univ. Clinch Cell 4
54182	2	Univ. Laser Welding Cell 3
54067	1	Univ. Spot Welding Cell
54071	1	DAG Hood A8
54093	1	Univ. Spot Welding Cell 3

Appendix H: Interactive AIM Workshop Results



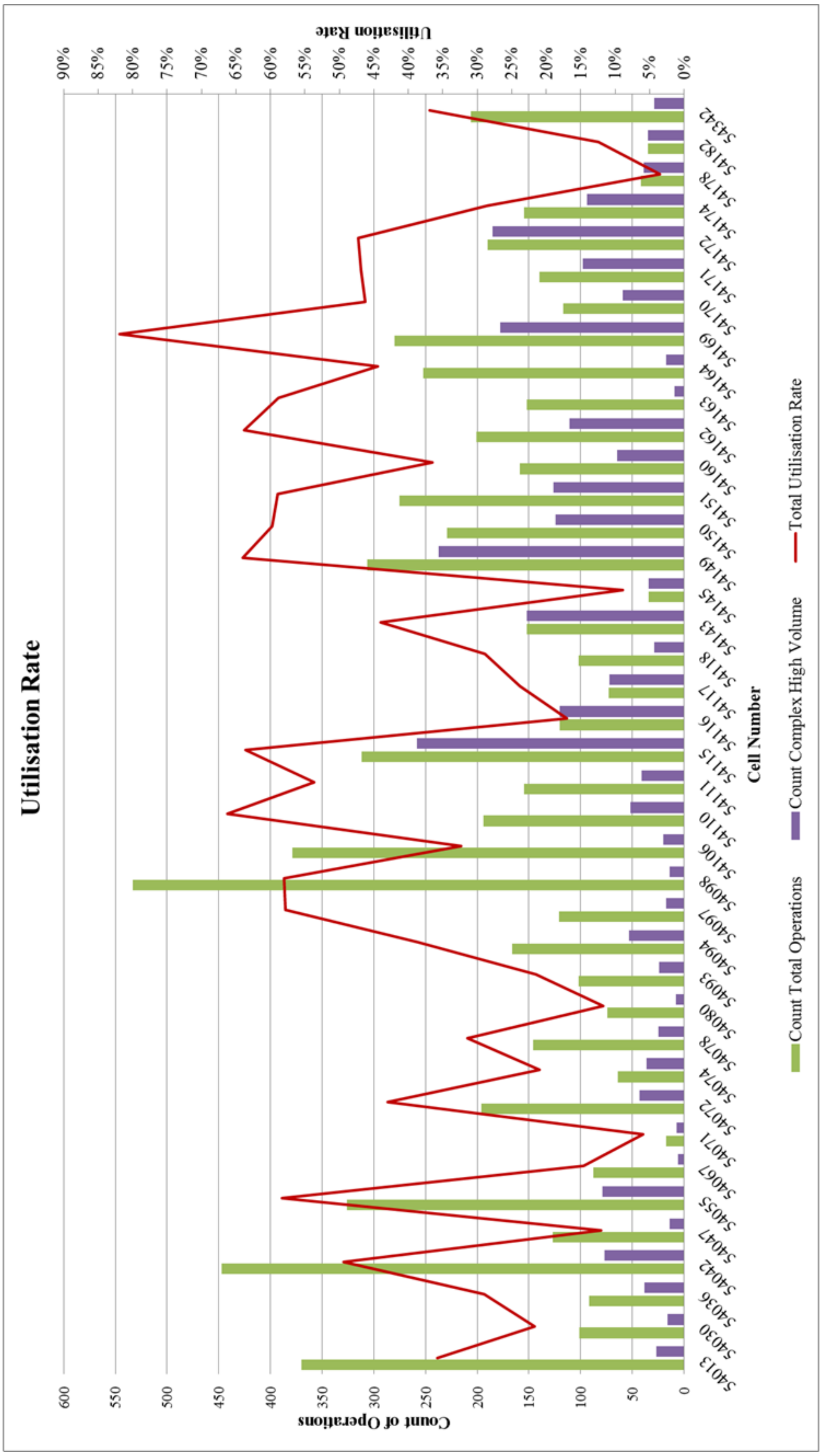
Appendix I: Realistic Lead Times

Finished Product	Description	Estimated LT	Calculated LT
718446S00AK	DAG ZB RUECKWANDTUER MOPF X204 -9K9	30	45,3
718028S00AK	VW ZB HECKKLAPPE GOLF PLUS -9K9	30	40,9
717124S00AK	AUDI ZB HECKKLAPPE B8 -9K9	27	81,8
720112S00AK	VW TUER VO LI TOURAN -9K9	27	28,4
720113S00AK	VW TUER VO RE TOURAN -9K9	27	47,1
717427S00AK	VW ZB HECKKLAPPE GOLF VI -9K9	27	47,5
717430S00AK	VW ZB TUER HINTEN GOLF VI LI -9K9	27	55,4
717431S00AK	VW ZB TUER HINTEN GOLF VI RE -9K9	27	37,9
724630S00AK	VW ZB TUER HINTEN LI PASSAT B6 KD -9K9	27	22
724632S00AK	VW ZB TUER HINTEN LI PASSAT B7 KD -9K9	27	24,2
724631S00AK	VW ZB TUER HINTEN RE PASSAT B6 KD -9K9	27	26,2
724633S00AK	VW ZB TUER HINTEN RE PASSAT B7 KD -9K9	27	48,3
717428S00AK	VW ZB TUER VORNE GOLF VI LI -9K9	27	39
717429S00AK	VW ZB TUER VORNE GOLF VI RE -9K9	27	33,7
718550S00AK	DAG HOOD ASSY SWB BR164 -9K9	21	180,2
713931S00AK	DAG OX ZB MOTORHAUBE W221 -9K9	21	53,6
715029S00AK	DAG ZB MOTORHAUBE V-MOPF W204 -9K9	21	35,8
719995S00AK	OPEL DOOR ASM-FRT SI LH C4400 -9K9	21	70,5
719996S00AK	OPEL DOOR ASM-FRT SI RH C4400 -9K9	21	76,8
720110S00AK	VW TUER HI LI TOURAN -9K9	21	21,6
720111S00AK	VW TUER HI RE TOURAN -9K9	21	23,9
724636S00AK	VW ZB TUER VORN LI EOS KD -9K9	21	47,3
724637S00AK	VW ZB TUER VORN RE EOS KD -9K9	21	119,5
717140S00AK	AUDI ZB TUER C6 LIMO L L-9K9	15	36
717141S00AK	AUDI ZB TUER C6 LIMO R R-9K9	15	26
717116S00AK	AUDI ZB TUER HINTEN R C6 R-9K9	15	54,3
713933S00AK	DAG OX ZB MOTORHAUBE VMOPF W212 -9K9	15	33,7
720207S00AK	DAG ZB FAHRERTUER LI -9K9	15	10
718135S00AK	DAG ZB FAHRERTUER LI W/S204 -9K9	15	35,8
720209S00AK	DAG ZB FAHRERTUER RE -9K9	15	19,6
718136S00AK	DAG ZB FAHRERTUER RE W/S204 -9K9	15	49,2
720208S00AK	DAG ZB FONDTUER LI -9K9	15	9,3
718137S00AK	DAG ZB FONDTUER LI W204 -9K9	15	18
720210S00AK	DAG ZB FONDTUER RE -9K9	15	23,4
718138S00AK	DAG ZB FONDTUER RE W204 -9K9	15	30,9
718143S00AK	DAG ZB HECKDECKEL W204 -9K9	15	49,6
714769S00AK	DAG ZB MOTORHAUBE BR245 MOPF ET -9K9	15	45,8
714770S00AK	DAG ZB MOTORHAUBE BR245 V-MOPF -9K9	15	54,4
715007S00AK	DAG ZB HINTERKOTFLUEGEL L W204 -9K9	15	21
715012S00AK	DAG ZB HINTERKOTFLUEGEL R W204 -9K9	15	21,6

Appendix J: Cell Efficiencies

Cell Nr.	Count	Cell Description	Eff. Machine	Eff. Man
54115	23	Univ. Spot Welding Cell 5	79,93	74,89
54169	21	Univ. Spot Welding Cell 7	81,39	75,49
54042	19	Stationary Spot Welding	108,48	75,66
54174	18	Univ. Assembly Controller	89,03	83,90
54172	17	Univ. Laser Welding Cell 3	80,95	73,55
54149	13	Univ. Laser Welding Cell 1	79,83	71,40
54151	13	Univ. Clinch Cell 3	92,61	84,78
54171	13	Univ. Clinch Cell 5	86,35	78,54
54143	10	Univ. Hemming Cell 5	69,07	60,84
54055	9	Manual Spot Welding	58,67	50,54
54094	8	Univ. Spot Welding Cell 4	84,03	66,69
54072	7	Univ. Spot Welding Cell 1	83,17	72,36
54150	7	Univ. Laser Welding Cell 2	77,86	88,55
54116	6	Univ. Spot Welding Cell 5	77,14	69,34
54117	6	Univ. Curing Cell 1	24,40	12,71
54162	6	Univ. Hemming Cell 7	83,37	74,11
54170	6	Univ. Hemming Cell 8	96,60	88,05
54178	6	Universal Hemming Cell no. 9	144,15	49,60
54342	5	Stationary Spot Welding	102,94	82,90
54013	4	Finishing	23,97	94,18
54036	4	Univ. Hemming Cell 1	60,54	37,21
54047	4	Manual Spot Welding	83,05	57,70
54074	4	Univ. Adhesive Cell 1	62,28	45,69
54118	4	Univ. Hemming Cell 4	78,35	57,70
54145	4	DAG Door 245	-	-
54160	4	Univ. Laser Welding Cell 2	76,54	75,01
54078	3	Univ. Hemming Cell 2	62,28	45,69
54080	3	Audi Door A3 (Hemming)	88,59	74,71
54106	3	Manual Bolt Welding	58,20	40,51
54110	3	Univ. Hemming Cell 3	79,51	70,53
54164	3	Manual Nut Pressing	102,02	82,81
54030	2	Univ. Hemming Press	60,58	46,58
54097	2	Manual Spot Welding	76,52	46,53
54098	2	Univ. Lasercutting Cell 1	81,97	67,26
54111	2	Univ. Clinch Cell 2	91,06	84,38
54163	2	Univ. Clinch Cell 4	91,55	85,96
54182	2	Univ. Laser Welding Cell 3	78,25	83,16
54067	1	Univ. Spot Welding Cell	91,34	62,58
54071	1	DAG Hood A8	87,02	78,35
54093	1	Univ. Spot Welding Cell 3	95,47	76,66
		AVG	80,2	67,9

Appendix K: Utilisation Rate per cell



Appendix L: Quality Issues

Date	Product	Description	Impact Assy (Days)
30-1-2017	718137S00AK	DAG ZB FONDTUER LI W204 -9K9	0
9-3-2017	718143S00AK	DAG ZB HECKDECKEL W204 -9K9	5
7-4-2017	718446S00AK	DAG ZB RUECKWANDTUER MOPF X204 -9K9	0
24-7-2017	718446S00AK	DAG ZB RUECKWANDTUER MOPF X204 -9K9	0
28-12-2017	715007S00AK	DAG ZB HINTERKOTFLUEGEL L W204 -9K9	0
7-3-2018	713933S00AK	DAG OX ZB MOTORHAUBE VMOPF W212 -9K9	7
3-11-2017	718138H09AR	DAG ZB INNENTEIL FONDTUER RE W204 -9R9	0
7-11-2017	717140H01AR	AUDI ZSB TUER VORNE A6 (C6) LI L-9R9	0
14-11-2017	717429H01AR	VW ZB TUER VORNE GOLF VI RE -9R9	0
24-1-2018	724636H05AR	VW ZB TUER VORN INNEN LI EOS KD -9R9	0
9-2-2018	719996H01AR	OPEL DOOR ASM-FRT SI RH C4400 -9R9	0
16-3-2018	717140H01AR	AUDI ZSB TUER VORNE A6 (C6) LI L-9R9	0
16-3-2018	717140H01AR	AUDI ZSB TUER VORNE A6 (C6) LI L-9R9	0

Appendix M: Current State Bottleneck Analysis

CURRENT STATE BOTTLENECK ANALYSIS			
Finished Product	Semi-Finished Product	Cell Nr.	Production Time (hours)
713931S00AK	713931H02AR	54071	22
713933S00AK	713934S00AR	54111	16
714769S00AK	714769H11AR	54094	18
714770S00AK	714769H11AR	54094	18
715007S00AK	715007H81AR	54097	57
715012S00AK	715012H81AR	54097	57
715029S00AK	715029H04AR	54111	36
717116S00AK	717116H02AR	54094	16
717124S00AK	717124H02AR	54174	26
717140S00AK	717140H02AR	54115	32
717141S00AK	717141H02AR	54115	33
717427S00AK	717427H05AR	54093	45
717428S00AK	717428H03AR	54172	18
717429S00AK	717429H03AR	54182	17
717430S00AK	717430H32AR	54150	33
717431S00AK	717431H32AR	54160	42
718028S00AK	718028H08AR	54169	17
718135S00AK	718135H09AR	54149	20
718136S00AK	718136H01AR	54162	15
718137S00AK	718137H01AR	54162	18
718138S00AK	718138H01AR	54162	14
718143S00AK	718143H03AR	54162	30
718446S00AK	718446H21AR	54078	16
718550S00AK	718550H11AR	54067	29
719995S00AK	719995H14AR	54072	24
719996S00AK	719996H14AR	54072	19
720110S00AK	720110H06AR	54171	24
720111S00AK	720111H06AR	54171	25
720112S00AK	720112H05AR	54169	21
720113S00AK	720113H06AR	54171	29
720207S00AK	715025H05AR	54115	13
720208S00AK	715026H04AR	54115	9
720209S00AK	715021S00AR	54143	13
720210S00AK	715022S00AR	54143	19
724630S00AK	724630H02AR	54115	11
724631S00AK	724631H08AR	54169	20
724632S00AK	724630H02AR	54115	11
724633S00AK	724631H08AR	54169	20
724636S00AK	724636H05AR	54055	4
724637S00AK	724637H05AR	54055	4

Appendix N: Future State Bottleneck Analysis

FUTURE STATE BOTTLENECK ANALYSIS			
Finished Product	Semi-Finished Product	Cell Nr.	Production Time (hours)
713931S00AK	713931H02AR	54071	22
713933S00AK	713934S00AR	54111	16
714769S00AK	714769H11AR	54094	18
714770S00AK	714769H11AR	54094	18
715007S00AK	715007H81AR	54097	57
715012S00AK	715012H81AR	54097	57
715029S00AK	715029H04AR	54111	36
717116S00AK	717116H02AR	54094	18
717124S00AK	717124H02AR	54174	26
717140S00AK	717140H02AR	54115	32
717141S00AK	717141H02AR	54115	33
717427S00AK	717427H02AR	54143	54
717428S00AK	717428H03AR	54172	18
717429S00AK	717429H03AR	54182	16
717430S00AK	717430H32AR	54150	33
717431S00AK	717431H32AR	54160	42
718028S00AK	718028H08AR	54169	17
718135S00AK	718135H09AR	54149	20
718136S00AK	718136H01AR	54162	15
718137S00AK	718137H01AR	54162	18
718138S00AK	718138H01AR	54162	14
718143S00AK	718143H03AR	54162	30
718446S00AK	718446H21AR	54078	16
718550S00AK	718550H11AR	54067	29
719995S00AK	719995H14AR	54072	24
719996S00AK	719996H14AR	54072	19
720110S00AK	720110H05AR	54169	13
720111S00AK	720111H05AR	54169	17
720112S00AK	720112H05AR	54169	21
720113S00AK	720113H08AR	54169	22
720207S00AK	715025H05AR	54115	13
720208S00AK	715026H04AR	54115	9
720209S00AK	715021S00AR	54143	13
720210S00AK	715022S00AR	54143	19
724630S00AK	724630H02AR	54115	11
724631S00AK	724631H08AR	54169	20
724632S00AK	724630H02AR	54115	11
724633S00AK	724631H08AR	54169	20
724636S00AK	724636H05AR	54055	4
724637S00AK	724637H05AR	54055	4

Appendix O: Uniqueness of Patterns

CHILD				GOAL	PARENT								
-4	-3	-2	-1	CELL	1	2	3	4	5	6	7	8	9
				54013	54097 - 10	54170 - 4							
				54030	54072 - 7								
				54036	54094 - 4	54115 - 3	54171 - 1						
			54042 - 2	54042									
				54047									
		54172 - 1	54182 - 1	54055	54115 - 6	54072 - 4	54169 - 4	54172 - 2	54182 - 2				
			54042 - 2	54067	54042 - 4	54072 - 2							
			54164 - 1	54071	54164 - 3								
	54042 - 1	54163 - 2	54047 - 4	54072	54047 - 13	54072 - 13	54055 - 4	54163 - 4	54042 - 2				
				54074	54115 - 3	54171 - 2	54094 - 2						
				54078	54094 - 4	54150 - 1	54160 - 1						
				54080									
			54342 - 2	54093	54151 - 3	54342 - 3							
		54080 - 1	54042 - 2	54094	54042 - 8	54149 - 7	54080 - 6						
			54098 - 2	54097	54098 - 4	54106 - 4	54342 - 2						
				54098									
			54342 - 2	54106	54149 - 2								
				54110	54111 - 10	54151 - 4	54117 - 1	54071 - 1	54110 - 1				
			54151 - 1	54111	54151 - 9	54042 - 2							
54080 - 2	54169 - 2	54118 - 4	54171 - 6	54115	54172 - 14	54171 - 12	54115 - 10	54080 - 6	54150 - 3	54143 - 2			
				54116	54116 - 10	54150 - 3	54172 - 2						
				54117	54072 - 7	54094 - 6	54110 - 3	54111 - 2					
				54118									
		54149 - 1	54094 - 4	54143	54143 - 10	54115 - 7	54145 - 5	54149 - 4	54150 - 4	54116 - 4	54118 - 4	54094 - 3	54055 - 1
				54145	54145 - 5	54115 - 4	54118 - 4	54094 - 2					
			54042 - 5	54149	54149 - 16	54042 - 14	54078 - 5	54143 - 3	54160 - 2				
	54174 - 1	54151 - 1	54055 - 2	54150	54093 - 5	54160 - 3	54174 - 3	54055 - 3	54150 - 2	54151 - 2	54169 - 1		
54174 - 1	54042 - 1	54342 - 1	54151 - 1	54151	54164 - 4	54174 - 2	54342 - 2	54042 - 2					
		54150 - 1	54151 - 1	54160	54151 - 5	54174 - 1							
			54151 - 1	54162	54149 - 8	54067 - 4	54150 - 3	54160 - 1					
				54163									
			54164 - 1	54164	54164 - 2								
	54042 - 2	54169 - 4	54171 - 4	54169	54172 - 16	54169 - 14	54174 - 12	54171 - 6	54151 - 3	54042 - 2			
				54170	54055 - 6	54169 - 5							
			54174 - 1	54171	54172 - 5								
		54171 - 1	54151 - 1	54172	54169 - 28	54115 - 12	54172 - 11	54055 - 5	54151 - 2	54171 - 2	54182 - 2		
			54174 - 4	54174	54169 - 7								
				54178	54115 - 8	54184 - 4							
			54151 - 1	54182	54151 - 2								
				54342	54184 - 13	54174 - 4	54042 - 3						

Appendix P: Margin of Error in Changeover SAP

Equipment number	Changeover in Reality (hours)	Set Changeover time (hours)
54013	0,00	0,17
54030	9,92	4,00
54036	4,88	0,75
54042	0,00	0,50
54047	0,00	0,33
54055	0,00	0,33
54067	1,67	1,00
54071	0,00	1,00
54072	1,61	1,00
54074	1,47	0,75
54078	3,17	0,75
54080	0,19	0,75
54093	1,17	1,00
54094	1,82	1,00
54097	0,22	0,33
54098	1,37	0,50
54106	0,00	0,33
54110	2,88	0,75
54111	1,50	0,75
54115	1,36	1,00
54117	0,53	0,50
54118	1,67	0,75
54143	2,94	0,75
54145	0,44	1,00
54149	1,32	0,75
54150	2,02	0,75
54151	1,32	0,75
54162	2,31	0,75
54163	1,77	0,75
54164	0,00	0,33
54169	3,42	1,00
54170	4,41	0,75
54171	3,09	0,75
54172	1,58	0,75
54174	0,06	1,00
54178	0,59	1,00
54342	0,00	0,50