PRODUCTION LEAD TIMES ANALYSIS AT VERNAY

Bachelor Industrial Engineering & Management

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Production lead times analysis at Vernay

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Preface

Dear reader,

You are about to read the bachelor thesis “Production lead times analysis at Vernay”. This research was conducted from April to July 2020 at Vernay Europa B.V., located in Oldenzaal, as the graduation assignment of the bachelor degree Industrial Engineering & Management at the University of Twente.

I would like to use this section to thank everyone that helped me to complete this thesis. Firstly, I want to thank my supervisor at the University of Twente, Martijn Koot, who was very helpful during the whole research period, always open to help me and giving me feedback, guiding me through the process. Also, I acknowledge my second supervisor Marco Schutten for his contribution.

Moreover, I want to show gratitude to Vernay who gave me the opportunity to grow as a professional during this internship, where I received an amazing treat and help by everyone. I would especially like to thank Sander Munsters and Krzysztof Planeta. Sander, my supervisor at Vernay, supported my research giving me very valuable feedback and opportunities, and getting me in contact with the necessary people inside the organization. Krzysztof showed me how the entire production was working at Vernay and shared plenty of knowledge with me, motivating me for my investigation and career.

Finally, I would like to thank my family for supporting me all over my education.

Ernesto Sanz

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Management summary

The research has been performed at Vernay Europa, in Oldenzaal. Vernay is an American multinational flow control solutions supplier to leading Original Equipment Manufacturers (OEMs), and Oldenzaal location focuses mainly in the automotive market.

Vernay's complex job-shop cellular manufacturing system, the high variety of products and the unstable demand, lead to a low control over production. At the moment there aren't any set standard production lead times, causing that there are high fluctuations in final production lead times. This makes production less efficient, which leads to a high WIP, a high late-deliveries rate and a high backlog, which was accentuated because of the covid-19 crisis. Production, at the moment, has a set date for starting a job, but not an estimated due date, which makes the processes more volatile, and doesn't allow to evaluate performance and improve from it. In order to stabilize production, make it more efficient and tackle the mentioned problems, the following research question is answered in the investigation:

What are the standard lead times of Vernay's products, and how can production stabilize and decrease the lead times in order to achieve the standard?

For setting the standard lead times, a method was designed based on the central tendency and the highest density of the tracked historical lead times of jobs during the previous year; and on an estimated production standards lead time, derived from the value-stream mapping technique of adding value adding (VA) activities and non-value adding (NVA) activities for getting the lead time. For the estimated production standard (EPS) lead time, waste (NVA) of the internal processes was estimated on a 61% of the total estimated lead time.

Finally, the standard lead time (SLT) of the forty-six 'A' products of Vernay were calculated in a combination of the three indicators mentioned, and were implemented, in addition to other lead time and operations performance indicators, in a BI dashboard. This tool is designed to ensure a quick and efficient visualization of data, improve the transparency of the system and support the planners, supply chain and logistics members, and production managers in the decision making and evaluation of production.

Besides, by the use of this dashboard, production performance was analyzed and the main bottlenecks, creating more fluctuations and delays in the processes, were located. These are the following operations: the birth-giver operations, postcuring, external sorting and punching.

Birth-giver operations (molding, assembly and punching), the first jobs' operations, due to gaps in shifts and not performing the job continuously from start to end, have an average productivity of 53.38% in comparison to the production standard expected time. This causes on average a delay of 1.08 days, which difficult the completion of the set standard lead time. Moreover, even if it is the only planned operation, this already counts with an average of 1.04 days of standard deviation, causing since the first moment of production instability in the flow.

Postcuring treatments performed in the general big ovens are found to have an average of 84.77% of waiting time (NVA) for the total tracking group, and an average standard deviation of 2.77 days. This operation, being the second one for most of molding parts, create notorious deviations and waste when being treated in the general ovens, and create uncertainty in all the remaining operations.

Punching has a priority rule giving precedence to normal punching (as birth-giver) jobs over slitting/ID punching and OD punching operations. This causes very high and unstable queueing times on slitting/ID and OD punching, leading to an average standard deviation of 4.21 days for their 'tracking groups'.

External sorting, one of the two operations being outsourced, is done in two different subcontracting companies in Poland: SPG and ESP. By analyzing the reports it is found a notorious difference between both companies: SGP takes on average 4.86 days with an average standard deviation for the four treated parts of 2.52 days, while ESP other four parts take on average 8.33 days with 5.48 days of standard deviation. In addition to this measured time from reports, transport and NVA time since the previous operation is completed until the goods are sent, are calculated

for two parts. It is then obtained an average of 3.75 and 4.50 days since the previous operation is completed until the subcontractor in Poland receives it.

The final main recommendation of this research is to set the calculated SLT as a production due date target and evaluate the production performance based on that, not only on birth-giver operations. Then the SLT and the division of it over the operations, should be used to determine the priorities on production, and then change the system from push to pull. By implementing this in production, with the use of the dashboard, lead times will become more stable, predictable and efficient, solving the three listed action problems: the high WIP, backlog and high late-deliveries rate.

Contents

Glossary of terms

VOL – Vernay Oldenzaal

LT – lead time - time that passes since the start of a process until its conclusion

PLT – production lead time

Cycle time – total time to conclude an operation

EPS LT – estimated production standards lead time

SLT – standard lead time

5D HDI – five days highest density interval lead time calculation

Part – product

VA – value adding

NVA – non-value adding

BOO – Bill of operations

1 Research introduction

This chapter is intended to introduce the research, with first an explanation of the company in *Section 1.1*, then an explanation and analysis on the problem, detailed in *Section 1.2*, and finally *Section 1.3* presents the research design.

1.1 The company - Vernay

Vernay is a flow control solutions supplier to leading Original Equipment Manufacturers (OEMs) and emerging companies in the Automotive, Medical, Specialty, Printer and Small Engine industries. Vernay engineers and chemists are recognized throughout the industry for their tenacious problem solving drive, and for providing co-designed, custom fluid control solutions. With over 85 years of experience, Vernay has a global presence, with testing and manufacturing capabilities in various worldwide locations including the U.S., Italy, Japan, Singapore, China, and the Netherlands, in Oldenzaal, where the research takes place. In addition, there are sales and customer service offices in France, Brazil and Korea. There are also local sales engineers in every region to support customers according to their languages and customs. Vernay Oldenzaal manufacturing plant, referred as VOL or Vernay Europa, focuses mainly on automotive industry products, with applications on brake systems, combustible engines, fuel systems, thermostats and washer systems, among others.

1.2 The problem description

In this section, the actual problems of the company, leading to the motivation of this research will be explained. An explanation and mapping of the problems, including the relationship between them, is presented in *Section 1.2.1*. Next, *1.2.2* presents the action problems of the research, *Section 1.2.3* the core problem, and the final main research question is formulated in *1.2.4*.

1.2.1 Problem cluster

Last year, when coronavirus hit our lives, sales diminished significantly for Vernay, as car manufacturers stopped or dropped-off their production. Then, Vernay, also affected by this crisis and full of uncertainty on the future, decided to reduce their inventory and the make-to-stock production, producing most or their products on orders. In June 2020, when automotive industry started to run again, orders suddenly started increasing, which without a previous forecast and neither a consistent stock, created a vast backlog and made the company deliver most of their orders late (*Figure 1*). After some months, Vernay still couldn't decrease the late deliveries ratio, actually around 64%, nor the backlog, estimated in 10 days (*Figure 2*).

As long as the company keeps having a backlog, it will not be possible to go back to the make-to-stock strategy that some of their main products had, and will have to keep producing on make-to-order, which makes production lead times essential, in order to avoid late deliveries. Do to the high amount of back orders and the production resources constraints, jobs are released to production as late as possible, but this, again, leads deliveries to be late. With over two-hundred fifty different products being produced in the internal manufacturing plant, having different production processes and frequencies, and with some stages of these processes being outsourced, there is a lot of uncertainty on the lead times of products and high fluctuation of output. The products and materials tracking along the whole production processes is untransparent and unprecise, so it makes it difficult to locate the order and to estimate when it will be able to be delivered. Moreover, this lack of standards and transparency leads to an absence of evaluation further than on the birth-giver operation and to an unknown location of bottlenecks.

At the moment, the planning department just schedules a job release date, and the daily product quantity to be produced, but this just focuses on the product's birth-giver operation, which for most of cases it is molding. As a result, the first operation weekly schedule is accomplished properly by production, but after that, the rest of stages are not clearly indicated how long they should take and there is not a defined date for when to have these jobs finished.

Figure 3 presents a problem cluster including all the problems mentioned and their relations. With this mapping, it is seen that the problems lead to an inefficient and unstable production, which at the same time creates a high late-deliveries rate, a high WIP and a high backlog.

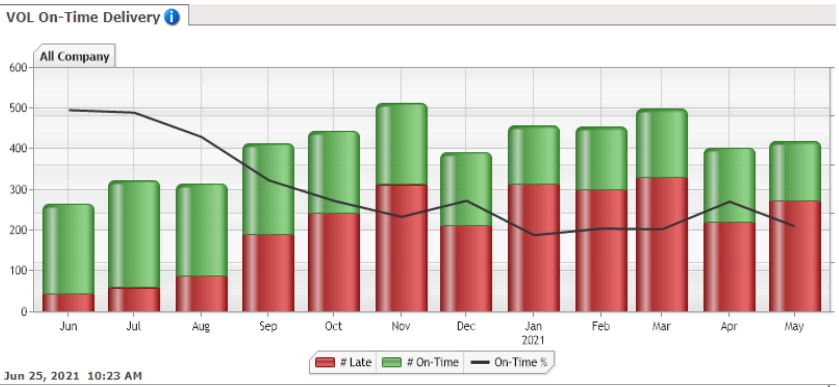


Figure 1. VOL On-time delivery ratio graph (June 2021, Epicor ERP). The Y-axis represents the number of deliveries per month.

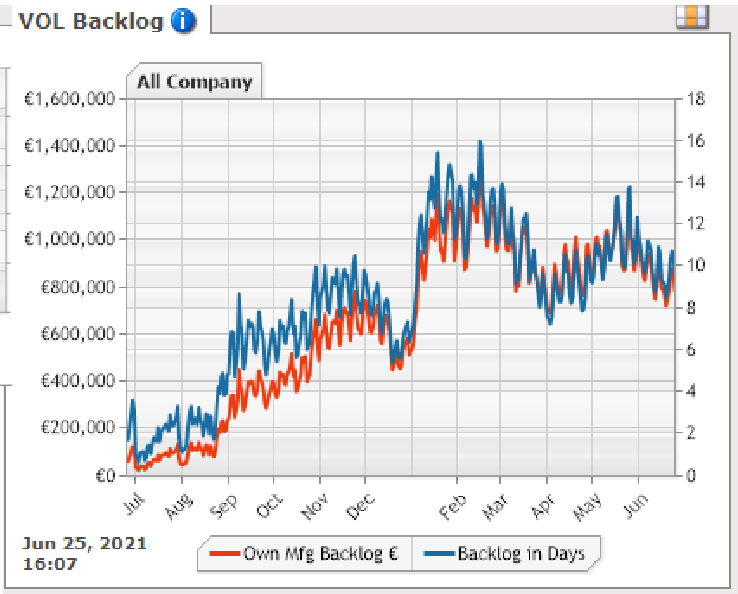


Figure 2. VOL Backlog (June 2021, ERP Epicor). The left Y-axis represents the monetary value of the backlog, while the right Y-axis displays the backlog in days.

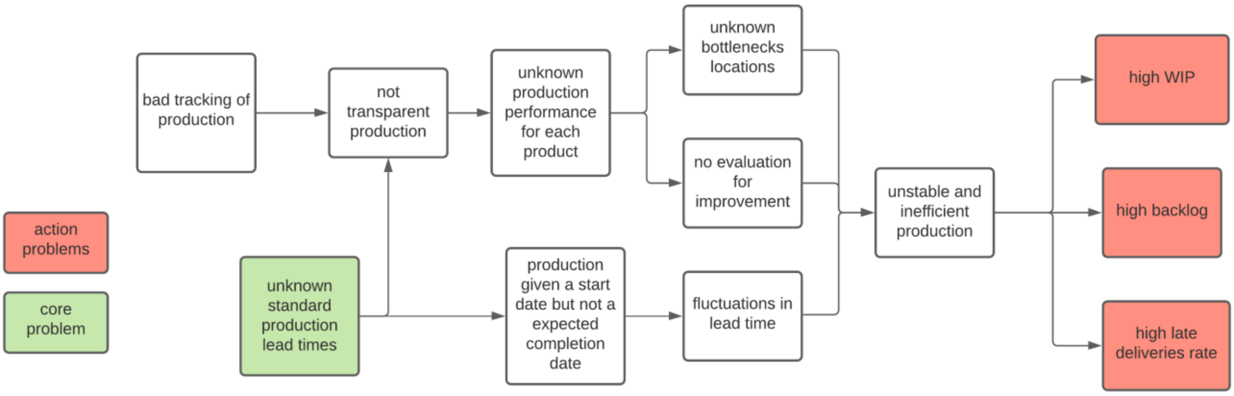


Figure 3. VOL Problem cluster

1.2.2 Action problems

By analyzing Vernay's actual situation, and performing meetings and interviews with several company's stakeholders, it was possible to list and map the main existing problems, relationships, causes and effects into a problem cluster (*Figure 3*). Then, examining the map allows writing down the key action problems. An action problem is a discrepancy between the norm and the reality, as perceived by the problem owner; in other words, any situation that is not how it is wanted to be (Heerkens & van Winden, 2017).

The general problem, the production instability and inefficiency, leads to three action problems: high work-in progress, high back orders and high late-deliveries rate, which are the principal issues that Vernay Oldenzaal wants to counteract at the moment.

Work-in-progress (WIP)

Work-in-progress, is the main indicator of production inefficiency, referring to the number of open jobs in production, so, jobs that have been started but not finished yet. This indicator depends on how long the jobs are taking to be manufactured (production lead time) and the quantity of jobs opened at the same time. By setting a standard lead time, and therefore having a due date, lead time peaks will be reduced, as well as the average, and then the WIP will be reduced, increasing manufacturing efficiency. Having a high WIP supposes an increase of costs in terms of storage, and makes the manufacturing site more messy and difficult to control, totally against the goal of the company of getting Lean, by reducing waste like this one. *Figure 4* graphs the days inventory on-hand (DIO), where WIP is a part of it.

At the moment WIP is estimated in 13 days, 820,961€, and the goal is to reduce it to 10 by the end of the year 2021.

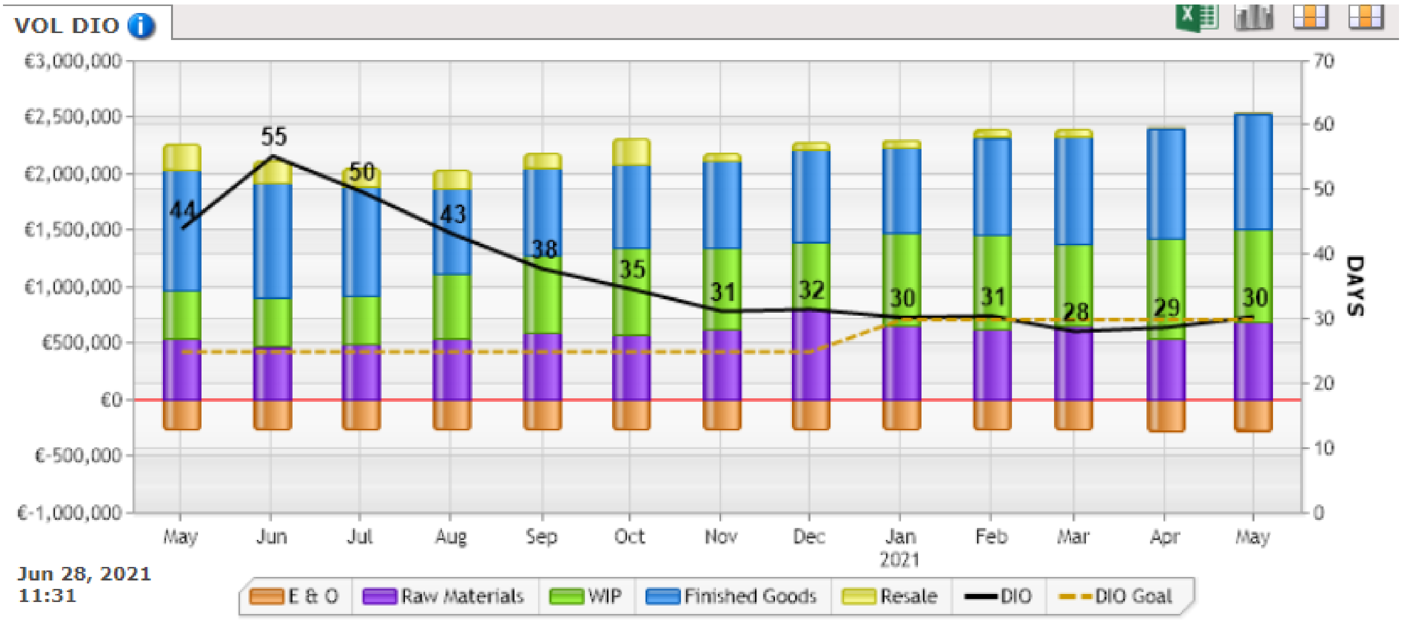


Figure 4. DIO VOL (June 2021, ERP Epicor)

Back orders

As one of the main concerns, back orders keep the company from performing the usual production strategies, not been able to produce a solid stock to control deliveries, and increasing significantly the inventory levels, as there are stored materials for production for regular planning, and in addition, for backorders, which leads to having the warehouse full. Moreover, as long as there are backorders, production will be under a high pressure situation, having to exploit all the resources to their maximum, leading also to decrease its efficiency.

Backorders level is now estimated in ten days *(*Figure 2Figure 1), and has to be eliminated as soon as possible.

Late-deliveries rate

This performance indicator is directly related with the previous, backorders, because, any back order job will be already considered as a late delivery. In addition to this, planned jobs under normal circumstances also pass through a lot of fluctuations in lead times, which lead to late deliveries. This is an important action problem as it directly affects customers, which are mostly official equipment manufacturers supplying car manufacturers, which leads to a very high cost and important problem if these late deliveries makes them stop production and they are not able to supply the car manufacturer, lacking of a material. The automotive industry is a very complex industry with a lot of stress and pressure on quality and delivery times, as there is a very long chain of suppliers until the finished good.

At present time, the late-deliveries rate is at 64% (*Figure 1*), which is impacting customer's satisfaction and the company's quality and professional image, so the target for the end of the year 2021 is to reduce this rate to 25%.

Then the action problems are formulated with the following research question:

How can Vernay's production be made more efficient and stable in order to decrease the WIP, backorders and late-deliveries?

The high pressure and competitivity on prices in the automotive industry makes profit margins per product minimal, making the optimization of production's costs a key preference for the success and progress of a company. Moreover, the manufacturing industry in general is evolving very fast with technology, which makes that a company's production strategy has to adapt and have a continuous improvement over time too, if they want to maintain the competitivity with other competitors of the sector. Therefore, the production plant has to be studied meticulously, as any small improvement can suppose a large cost reduction at the end of the financial year.

1.2.3 Core problem and motivation

Among all the organization's problems, it is important to focus on one where it is estimated that it would lead to an important improvement, defined as core problem. It can be identified by following the chain of problems back to the problem which does not have any cause by itself. The core problem should be related with all the identified problems and possible to be influenced by the research, otherwise, it would just be a loss of time. In the case there are several core problems, only the most important, leading to most significant improvement for the company should be selected. (Heerkens & van Winden, 2017).

Looking at the problem cluster (*Figure 3*), it can be seen that there are two problems that are not caused by another: the bad tracking of production and the unknown standard production lead times. The Vernay's head location, Griffin (USA), recently (December 2020) started a project for improving production tracking in their plants. Then, as this is a very big project, concerning every Vernay's manufacturing plant around the world, and taking a very long time to been able to completely implement it into production, this will not be selected as the core problem for the research. However, I also joined this project as part of Vernay Europa (Oldenzaal) team during the steps taken in my stance at the company, and will be discussed in *Section 6.2.1*.

The 'unknown standard production lead times' is then selected as the core problem for this research. At the moment, there is not a clear lead time set for each product and planners are just using a non-calculated estimation of it, in order to know approximately when to plan the production. Do to the current situation, and turning all the products to make-to-order, production lead times take a much important role in deliveries. Moreover, at production, there are just given a starting date but not a due date for each job, so it is unknown when they are expected to be completed. This target lack, created that there are no priorities for when the batch is running late, and there is not a post-evaluation on the performance of production, related with the time taken until the completion. Furthermore, without a real-time tracking of the products and a stated completion time, logistics can't plan in advance the transport for these, so more time is added to the process, leading to more late-deliveries. Another reason that shows the importance of the statement of the production lead time is customers, so when they contact Vernay, asking for the expected delivery date, it is possible to let them know the estimated completion time, and when they will receive the goods, so they can also plan their production. All in all, this is a core problem that has to be solved in order to improve production, and counteract the action problems efficiently.

Therefore, for this thesis, the selected core problem is formulated as:

'What are the standard production lead times for Vernay's products?'

1.2.4 Research question

By putting together the action problems and the core problem research questions, the following main research question for the research is expressed:

What are the standard lead times of Vernay's products, and how can production stabilize and decrease the lead times in order to achieve the standard?

1.3 Research design

In order to solve the core problem by answering the knowledge question, and work out the action problems, a research is performed. In this section there will be explained the problem solving approach used and the research questions (*1.3.1*), the research scope (*1.3.2*), the research limitations (*1.3.3*) and finally the research deliverables (*1.3.4*).

1.3.1 Problem solving approach and research questions

For performing the research, seven knowledge questions were formulated and then answered based on the seven steps of the Managerial Problem Solving Method (MPSM) developed by Heerkens & van Winden (2017), in the University of Twente, which are shown in *Figure 5.*

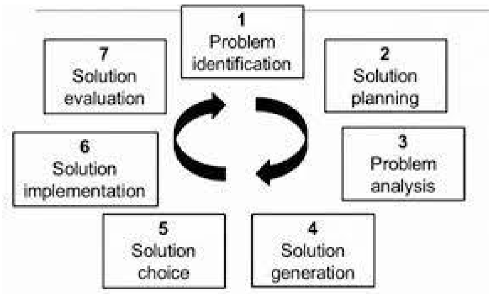


Figure 5. MPSM problem solving cycle

1- *How is production designed and implemented at Vernay Oldenzaal?*

In order to run the research and solve the core problem, first a context analysis has to be done. This stage corresponds to the problem identification step of the MPSM methodology. For solving this knowledge question interviews and meetings are held with the project stakeholders, so their insights and knowledge about the topic are shared. Moreover, the company's database system and ERP are investigated. The planning strategy, supply chain and orders system are also assessed. All this creates a general overview of the company, so that the research can be done with a better criteria. The knowledge question is answered in *Chapter 2.*

2- *Which are the methods used to calculate the standard production lead times in manufacturing plants?*

So as to design the solution planning, as the second step of the MPSM states, a literature review and state-of-the-art review is performed, answering the knowledge problem. Literature from different databases and authors is analyzed and conclusions for adapting the findings to the research are taken. This stage is handled in *Chapter 3*.

3- *Which are the actual and past production lead times?*

For analyzing the dimension and characteristics of the problem, the reality has to be investigated. This step is done by using the company's databases, studying the historical transactions, operations and jobs data registered over time, especially during the last months. For the data mining process, CRISP-DM methodology is used, and its different steps constitute the structure of the section. This will allow to already take some conclusions and having better insight of the actual situation. This is detailed in *Section 4.1*.

4- *Which are the estimated standard lead times and operations cycle times based on production standards?*

This knowledge question is designed for the fourth stage of the MPSM, solution generation. After analyzing the real production lead times, it is time to calculate an independent lead time for each product based on production standards, waiting times estimations, shifts and other approximations. This is a preliminary solution that will allow to make a comparison with the reality. The knowledge question is answered in depth in *Section 4.2.*

5- *Based on the estimated production lead times and operations cycle times, which is the final production lead time for planning?*

By comparing the preliminary calculated production standards lead time to the reality, we can assess the previous findings and adjust the solution calculations, adding new variables based on findings. Therefore, in this stage of the research, performed in *Chapter 4.3*, we already give the production standard lead times solution and calculation.

6- *How should the standard lead times be implemented and which are the main production bottlenecks?*

By answering this knowledge question, representing the solution implementation phase of the MPSM, the implementation of results is explained and presented. A critical analysis and evaluation of production bottlenecks is done based on the previous implementation. This stage is performed in *Chapter 5.*

7- *What are the recommendations and solutions that can be given to Vernay Oldenzaal to optimize the production from my thesis research at the company?*

As a final step of the research, recommendations to the company on actions to take for improvement are given, as conclusions are taken. Moreover, a reflection on the theoretical and practical contribution of the research is made. All this is assessed in *Chapter 6.*

1.3.2 Research scope: lean manufacturing

This research will be based on lean manufacturing as the principal theoretical perspective. Lean manufacturing (or lean production) is a methodology focusing on the reduction of waste within manufacturing systems while maximizing productivity. Waste is called to anything that doesn't add value to the end product. Lean manufacturing is used by many important companies, based on the Toyota production system (Ohno, T.,1988).

The methodology is inspired 5 main principles: value, the value stream, flow, pull and perfection; which are applied for this research and that are the way for improvement at Vernay. Creating **flow** is the way of eliminating functional barriers and identify ways to improve lead time. In the assignment the main bottlenecks are located, which are major interruptions in the production flow, and therefore, locating them is crucial for the elimination of waste. Establishing a **pull system** is another main principle in lean manufacturing, meaning that a new work only starts when there is demand for it, reducing waste such as high inventory. By setting a standard lead time, jobs will be released to production based on when it is desired to be completed, and not in the other way around. At the moment, production just focuses on the start date, and push products through the line based on the capacity of a work station, or the importance of a product. By changing this push system by a pull one, jobs are processed by the different operations depending on the set due date, changing the priorities. Delivery time, which is not accomplished correctly do to fluctuations on lead time, is an important part of the **value** customers place on their products or services. The principle of value is important, so it is possible to locate what customer finds valuable, thus what doesn't add value can be eliminated and the client's optimal price can be achieved. **Perfection**, after lean manufacturing is reached by continuous improvement, known as 'kaizen'. During this assignment, with the finding of bottlenecks and operations' performance we will make possible for Vernay to focus on that areas and reduce waste there, decreasing little by little and stage per stage the lead time in order to, at the end, reach perfection. Finally, **value stream mapping** which follows product's flow, examining each step, in order to find where the waste is located.
Standardization, after the Toyota production systems from Ohno, T. (1988) is also a key procedure for kaizen, and lean manufacturing in general, to maintain stability in processes, in order to perform activities with the lowest level of waste, improving efficiency.

In addition to the lean approach of the research, **statistics** are also key. Statistical analysis is made on tracked data, and is essential in order to summarize large quantities of information into indicators and drag conclusions from it, to detect how data is distributed and which are the central tendencies.

1.3.3 Research limitations

Product range complexity is increasing at Vernay, reaching over two-hundred fifty different products with one-hundred eighty different customers. Based on the Pareto rule, also known as the 80/20 rule, which states that a majority (80%) of the outcomes or problems are assigned to a minority (20%) of the causes, the Vernay products are divided into four different categories depending on their production importance and strategic goal, A, B, C and D. 'A' products constitute 20% of parts and 80% of sales. Therefore, the research will focus just on the **'A' products**.

Another limitation for the research is related the lead time (LT) concept. Lead time can be assigned a different start and end time depending on the approach given and its type, which can be: customer LT, material LT, production LT or cumulative LT. In general, lead time is the period since a new operational task appears in the system until it is marked as completed. In this assignment, then, the selected type is **production lead time**, restricting its calculation from the first operation of production, excluding pretreatment steps, until it is completely finished, with packaging.

1.3.4 Deliverables

The main deliverables of this research are the following:

- Standard production lead time for each 'A' part
- BI dashboard for the visualization of the lead times, production flow and production performance
- Finding of major production bottlenecks and analysis on the production performance
- Solutions and recommendations for improving production lead times, by making production more stable and efficient

2 Production context analysis

This chapter addresses the resulting knowledge question:

How is production designed and implemented at Vernay Oldenzaal?

This is answered by doing a production context analysis divided in different subsections: Production system (*2.1*), product categories (*2.2*), operations (*2.3*), and shifts (*2.4*).

2.1 Production system

Production at Vernay is complex, as the plant mixes two different manufacturing types, cellular manufacturing and job shop, while having a large variety of products and different operations in the processes.

Cellular manufacturing is a manufacturing process that produces families of parts within an individual cell, operated by workers employed only in this line. A cell is a defined production unit within the factory. Once started the process, the cell has complete responsibility over their parts, as all necessary operations to complete for the processes are located in the cell. However, this is not fully like this at VOL's plant.

Job shop manufacturing is based on a high variety of products, being processed by flexible resources giving a range of customization to each part. Resources are organized according to the production task (punching, oven…), called functional layout. Products are produced in batches, more than once, but not continuously.

Therefore, Vernay, mixes these two types of manufacturing. Each part is assigned to a cell, where the birth-giver operation is performed, but then, most of parts have to leave the cell for some operations. The operations that are performed outside the cell are divided by the functional layout, having the ovens room, quality check room, punching, logistics, etc. Cells and their description are presented in *Table 1*, and the layout of the factory is visualized in *Figure 6*.

Resource Group	***Description***
C10	Inserted Diaphragm Cell
C20	Star seal Cell
C30	Poppet & Needle & Ankerplatte Cell
C40	Inserted Seal Cell
C50	Full rubber Cell
C60	Deflector Cell
C70	SPP Cell
C80	Assembly Cell
NPD Cell	NPD Cell
Surface Treatment Cell	Surface Treatment Cell
Oven Cell	Oven Cell

Table 1. Production cells. Cells' products types explained in section 2.2

Figure 6. VOL production plant layout map. Numbers on the grey rectangles represent the press number

Batches of a certain product are released to production as jobs, with the needed materials inside a box. The box is accompanied with some copies of a paper, called 'job traveler' (*Appendix C, Figure 47*). The job traveler indicates the start date, the job number, part number, description of the part, raw material components, quantity to complete, and the operations to perform, in addition to a bar code. When an operator completes a certain quantity of the total work to perform in an operation, he will register this in the VPI, put this in a separate box, and send it to the next operation listed in the job traveler. Then, jobs are divided in different batches, called travelers, and they are not waiting for the whole job to be completed in each operation, and are accompanied by a copy of the initial job traveler, where the boxnumber and the box quantity has to be filled.

2.2 Product categories

The over two-hundred fifty different products are divided into eight different categories, explained briefly next (*Table 2*): poppets, inserted diaphragms, inserted seals, assembly, SPP, full rubber discs and star seal. And examples with pictures of every category are included in *Appendix A*.

PART TYPE	DESCRIPTION AND USE	PART EXAMPLE PICTURE
POPPETS	Poppets are small pieces used for valves and pump systems of the automotive industry. Some examples are the motor, fuel or the suspension systems.	 V450310700
INSERTED DIAPHRAGMS	These parts are membranes designed for the control of gases and pressure. Most of this category products are used in the crankcase ventilation systems.	 V037611400
INSERTED SEALS	Inserted seals are valves designed for controlling pressure in high pressure circumstances.	 V559810100
ASSEMBLY	Assembly products are different one from each other, in general, this category includes every part where two or more inserts are assembled by an assembly machine, most of times automated. Some pieces are used for maintaining vacuum at the same time as avoiding oil to leak in systems in power brakes, others are check valves to maintain pressure in the fuel supply line, etc.	 V115015500
SPP (SMALL PLATFORM PROJECT)	This product category encompasses all products in cell 70, the SPP cell. There are different types of products for different customers. The only A parts from this category are V115018300 and V081619100, also called 'boy' because of the machine supplier name. V115018300 is a suction diaphragm for the return line of an Ad Blue pump. And V081619100, a dump valve or blow-off valve, a pressure release system used in turbocharged engines.	 V081619100
FULL RUBBER	This category is composed by duckbills and umbrellas. A duckbill valve is a rubber with two or more flaps, used to evite backflow, or control the pressure in a side of the valve, used for example in fuel pump systems to allow excess air escape from the tank.	

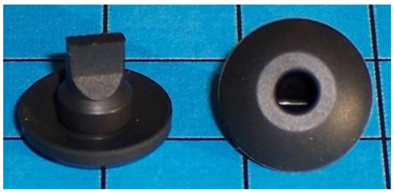
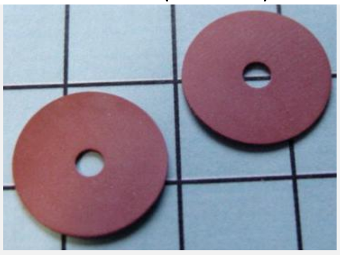
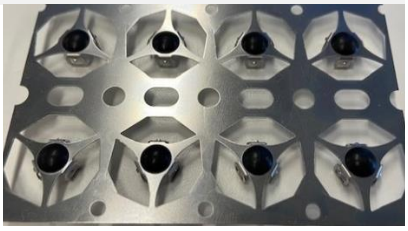
	Umbrellas applications include vessel vent valves such as for automotive fuel tanks, in-and outlet valves for piston pumps, one-way check valves and other fluid control functions.	 V072810900 (duckbill)
DISCS	This category is for disc shaped plastic products, which have different uses as for keeping the brake system vacuum, or in valves from the air filters of the engine.	 V194012600
STAR SEAL	This category is only for one part, the V450612400, which is the most produced part, with one cell (C20), four presses and one automated punching machine, designated only for it. The part is a star shape puppet that is clicked on a holder, used as a pressure regulator in cars.	 V450612400

Table 2. Product categories

2.3 Operations

During the research, A products' operations will be analyzed mostly in Excel, extracting data from the system, then, it is essential to understand what each operation treated in the database is. In this section the twenty-two operations that are part of A products' processes are described. *Figure 7* maps the logical and general order of operations, where only the blue boxes (applied burden, birth-giver operation and packaging) are always present, while the rest of operations in the flow can be present or not depending of the product's routing. Some operations machinery pictures are included in *Appendix B*.

Applied Burden

This operation, the first one registered in the system for each job, is just an office job, in which the indirect costs of production (as maintenance, lightning, installations…) are calculated, enlisted to the job and added to the direct cost of labor and inventory.

Pretreatment

This operation includes all the steps made, since getting the raw materials needed for the job from the warehouse until the box with the needed materials for the birth-giver operation are in place and in front of the station, accompanied by the job traveler papers. Apart from the issuing of materials, these can also need some previous treatment included in the step, as a plasma etching, bonding…

Bonding (Lijmen)

Glue is sprayed over the materials in controlled temperature and humidity conditions, in the gluing room, before it is carried to molding.

Molding (Persen)

This is the main process of Vernay, almost every product counts with this step in their production flow, always as the birth-giver operation. There are four different types of molding performed by many different machines and molds: injection molding, compression molding, hot transfer and cold transfer.

Injection molding is made by introducing molten plastic materials into a mold that cools and hardens the parts.

Compression molding is done by putting materials in a mold where then pressure is applied to force the material into contact with all mold areas, while heat and pressure is applied until the molded material has cured.

Hot transfer is similar to injection molding but by applying more pressure in introducing the molten materials in the mold, and cold transfer the same but by applying a temperature change by a cooling agent while being introduced into the mold.

Assembling (Assemblage)

This is the most common first operation after molding. Assembly constructs a finished product from different components. High technology automated machines perform this process at a high speed.

Punching

There are three different punching operations, but the one registered in the system as 'punching' (or ponsen), is the job assigned to a birth-giver operation. Material are issued to the department, an then, a machine with sharp blades, with the need of an operator, will punch this material giving it the desired shape, normally discs.

OD Punching (Punching)

This operation is similar to the previous one, punching, but is just assigned to intermediate steps of the process, when the part has already been treated. Just the outside diameter (OD) is modified in the operation. Some parts have automated punching machines.

ID Punching/Slitting (Slitten)

In this operation a machine slits some angle of the product and then punches it, forming the inner diameter (ID). Slitting can't be done if the product has been more than two hours since dipped, otherwise it has to be dipped again.

Dipping

Pieces have an immersion bath in water mixed with chemical products for eliminating any dirt and having the material in ideal physical conditions before slitting or punching.

Deflashing (Ontflashen)

This is the step of removing flash. Flash is known as the excess material attached to a moulded product, which has to be removed. Flash is created when there is a leakage of material between the surfaces of the mold. Pieces are placed in a vibrating drum with sand for a period of time, then the sand is removed and pieces are washed.

Postcuring (Ovenkuur)

Pieces, after molding are placed in the oven for an exact amount of time and temperature, depending on the part, as each one has a precise treatment. Postcuring enhances the physical and performance properties of the molded material. This can be done in small ovens placed over the cell, or in the ovens room, where five big ovens are located and which most of the parts use.

Coating (Antistickbehandeling)

Pieces are dipped in a mix of alcohol and a dry-film product, which then after been dried in a centrifuge, create the coating over the piece, for it to not stick to others and be more durable.

In other cases, for three poppets, the coating is done in a different way, called moly coating. The pieces are mixed with three little spoons of an anti-friction high pressure lubricant powder, called moly coat, in a vibrating drum.

Chemical treatment (Chemische behandeling)

Some chemicals, different for each part, are applied to the products creating an kind of antistick coat for altering the properties of the material.

Media Removing (Zeven)

After punching of discs, the waste circles removed from the middle are putted together with the disc, which have to be removed.

Wash dry centrifuge (Wassen Drogen Centrifugeren)

This operation reflected in the system can be done in two different ways. Sometimes it is just putting the pieces in the washing machine, after deflashing. And other times pieces are entered in a centrifuge machine, with Deoxidine for cleaning.

Testing (Controleren)

A special test for controlling quality is performed. This test depends on the part, and there are multiple types, for example leakage or bonding test.

Sorting (Sorteren)

This operation is completed at the end of the production process at the sorting room. Every piece from the job is checked depending on the required qualifications.

There are some parts checked automatically by a machine, named as 'Sorting by Barry'.

Visual inspection (Visuele Controle)

This quality operation can be done at any moment of the process, depending on the part, sometimes it can be done after molding, punching… It is performed by the operator next to the operating machine, normally during the cycle time of this. A loupe is normally used.

Final Audit (Eindcontrole)

This stage can be done in the quality check (QC) room or in the part's cell. Each part has a different process for this operation. It is checked a sample of the job quantity on different qualifications, and also proven that every previous operation has been completed. This step is also completed for some parts before been sent to external sorting, as it has to be ensured that the parts fulfill the necessary requirements and steps, but in this cases it is done faster, as quality is also controlled externally afterwards.

Subcontract Processing

Different types of processes that can't be completed at Vernay as chemical treatment, or plasma etching among others are performed by subcontractor companies in Germany.

External Sorting

These are precise quality check sorting performed in Poland. This processes are not done internally as they require a lot of time or advanced resources for finding small quality issues, needed for extremely high precision parts. Two companies perform these processes, SGP and ESP.

Packaging (Inpakken)

This is the last operation of every job. When the job arrives to the logistics center, operators pack the pieces in plastic bags and boxes, and labels them for storage or transport to the customer.

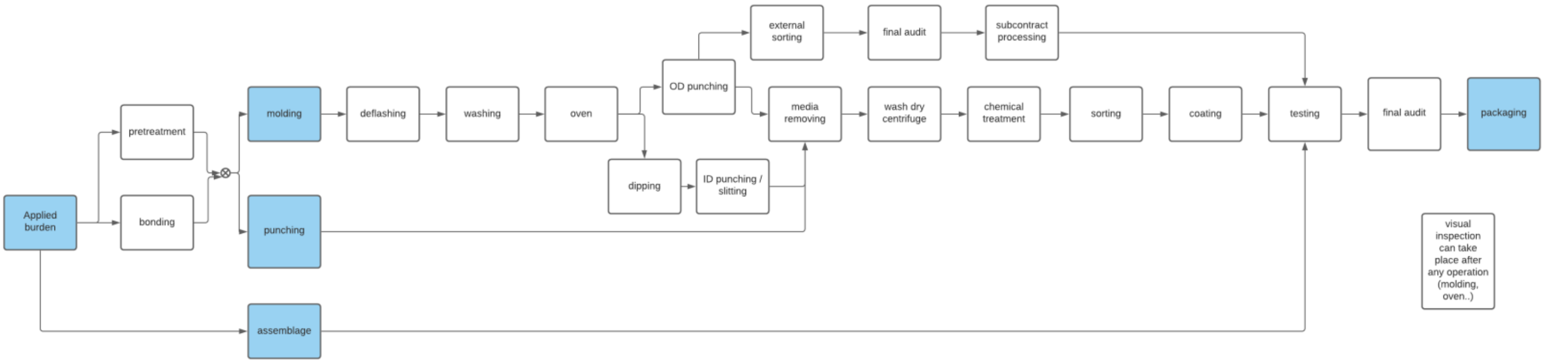


Figure 7. Operations logical order map. Blue boxes represent operations that are always performed.

2.4 Scheduling: shifts

Production plant manning is divided in three eight hours shifts: morning (6:00-14:00), afternoon (14:00-22:00) and night (22:00-6:00), each of them having 0.5 hours of break. Then, the plant is running for 22.5 hours a day, 93%.

Planners make a planning each week for the birth-giver operations of every cell, based on the operators available at each shift. Then, they plan for cell, to which press, punch or assembly machine are workers allocated; for the five working days, morning, afternoon and night shift. Sometimes the planning is then modified by production shift managers because of changes in operators availability. If planning for the week is not accomplished, extra shifts can be scheduled for presses during the weekend.

As said, planners just plan the birth-giver operation, the rest of operations are some performed by this same operators, and other operations are having independent and more constant workers, managed by the responsible manager, as can be the QC room, the ovens room, logistics, etc.

3 Standard production lead times: literature study

In this Chapter a literature and state-of-the-art review is performed by consulting the existing literature over the previous years on the manufacturing and management field. The review was done by consulting different databases as Web Of Sciences, Scopus and Business Source Elite (EBSCO), among others. The literature review is intended for answering the knowledge question:

Which are the methods used for calculating the standard production lead time?

There were different search terms and search methods for the different databases, but the main one was:
(TITLE (lead AND time*) AND TITLE-ABS-KEY (standard AND (estimat* OR calculat* OR predict* OR forecast*) AND (production OR manufacturing)))

As for the Lean manufacturing literature, there were no databases used, and the following books were consulted:

- Ortiz, C. A. (2006). Kaizen assembly: Designing, constructing, and managing a lean assembly line. Boca Raton, FL: CRC Taylor & Francis.
- Ohno, T. (1988) Toyota Production System: Beyond Large Scale Production. Productivity Press, New York.

The data gathered from the literature review is presented in *Section 3.1* and then conclusions are made in *Section 3.2*.

3.1 Literature review

In the manufacturing industry, there are millions of companies, and each of them is a whole different world. There are several studies treating the calculation of lead times, using completely different methodologies or tools for each case, as well as the way in which the estimations are presented.

In some literatures, production lead time is presented in a static way, as Fahimnia et al. (2008), which calculates the PLT as a sum of the setup time, processing time, and non-operation time while in others it is formulated dynamically, updated continuously depending on different factors.

Schneckenreither, Haeussler, & Gerhold (2021) divide the dynamic manufacturing lead times approaches into three groups: reactive, proactive and predictive lead time management, which are assessed next.

Reactive

Reactive lead time management approaches provide lead times by reacting to earlier flow times (Schneckenreither, Haeussler, & Gerhold, 2021).

Askin, & Hanumantha (2017) formulates four different lead time forecasts: Little's Law based, Average Work Completion based, Average Time Remaining and another average time remaining based lead time forecast; which are compared against simulation estimates for a basic model. For the first one, the expected completion time for a job is calculated with a weighted average of waiting times, calculated by Little's Law, for all periods between start and expected completion. Little's Law is a popular forecasting technique stating that:

average lead time = average WIP / average delivery rate.

The use of this law has some requirements, as, that all the items in the system have to be the same; the number of items in the process are constant; WIP value has to be consistent; and that all items entering the system have to go to its end, so no scrap or defaults are possible. (Little, 1961)

Selcuk et al. (2006) updates lead times by taking periodic information in the estimation of lead times for planning the future production orders. This is the so called exponential smoothing forecasting method, based on that prediction are a weighted sum of past observations, decreasing over time for past observations.

Proactive

Proactive lead time management incorporate past information along with current system state, assuming a future behavior of the system for setting the estimated lead time.

Nakayama et al. (2002) propose a method for determining the standard lead time based on a work achievement quotient approach, by analyzing individual variation of workers.

Sellito (2008) uses for production planning, the workload control (WLC), a control technique suitable for high-variety job shop manufacturing, focusing mainly in make-to-order production. The WLC integrates in the system two control sides, the input and output control. The first one controls the arrival of workload to the production system by priority rules, while the other one regulates the outcome of orders by adjustments in the production capacity. Therefore, by an optimization problem, it calculates the optimal lead time for the level of WIP and inventory. Moreover, it also calculates a safety stock as the minimum level of WIP that prevents starvation produced by a difference between the rate of arrival and the throughput.

A more advanced method, used by Mourtzis, Doukas, Fragou, Efthymiou, & Matzorou (2014), is Case Based Reasoning (CBR). This technique solves problems by comparing differences and similarities between current and previous records, adapting acceptable solutions to it by a similarity measurement engine. This approach was applied to lead times estimation, which got to be reduced thanks to it. It is based on a dynamic memory relating the past cases and patterns to new order entering the system, and it returns the estimated lead time for each case by performing a similarity check.

Predictive

Predictive lead time management, in addition of using past data and the current state information, it also anticipates the future state of the system to detect arising issues of future periods and react to them consequently.

The most common technique among literature for this type of lead time management is the artificial neural network computing system (ANN). Artificial neural network is a model of reasoning inspired on biological nervous systems based on a collection of connected units or nodes called artificial neurons. ANNs are growing rapidly because of its large work with pattern recognition, its high level of robustness and learning ability, and because of the capability to function with uncompleted data. (Coury, & Jorge, 1998)

Schneckenreither, Haeussler, & Gerhold (2021), propose an ANN to set lead times in combination with an extended schedule visibility. These are used to anticipate future backorders and adjust the order release decision correspondingly. Moreover, it is also added a safety lead time based on cost ratio of finished goods inventory and backorder cost. These findings are then compared to other forecast-based order release methods using simulation in a rolling horizon setting. Their findings show an increase in performance, especially reducing costs related to timing implementation.

Lean manufacturing, the theoretical scope given to the research, has also a technique for setting the standard lead times to products. Lean uses value-stream mapping (VSM) as a tool for this. Value-stream mapping, one of the main principles of lean (as commented in *Section 1.3.2*), creates an end-to-end detailed visualization of the flow. The processes constituting the VSM have three types of activities: value adding (VA), non-value adding (NVA) and necessary non-value-adding (NVA), therefore, by adding all the processes VA, NVA and NNVA activities, the final lead time is obtained. (Ohno, T.,1988)

Moreover, the general rule to set standards in lead manufacturing, after Toyota production system (Ohno, T.,1988), is by focusing on good and repeatable practices. Establishing standardized work is based on recording data on different forms, which are used by engineers and front-line supervisors to design the process and then operators will adapt these estimations by reducing or increasing the established.

3.2 Discussion and conclusions

It is difficult to adapt a precise methodology to the production system of Vernay, due to the uncommon mixed cellular job-shop manufacturing system, and the alternation of make-to-order and make-to-stock products. However this literature review gives a good insight of the techniques and methods used for calculating the standard lead time, as well as for predicting it and implementing it into their production system.

Little's law theory, one of the most known techniques, is not applicable to this research because of the complexity of the plant and variety of products.

The exponential smoothing forecasting method, used by Selcuk et al. (2006), is a technique that could actually be used in this research, as takes a high range of past performances into account, and at the same time prioritizes for the final result the most recent ones.

ANN are difficult to implement right now at Vernay do to the lack of standards and data needed for feeding the computing system, but however would be a very good tool to use in the future, once there is a higher control, tracking and standards of production, as it is one of the most accurate methods for forecasting lead times dynamically.

Due to the actual conditions and following the research scope of the investigation, the most useful technique to apply for this research is the lean manufacturing one, as it is not a strict methodology as the others, it is flexible and can adapt to any manufacturing system seeking for improvement, stabilization and control. The calculation of the PLT will be based on the two lean manufacturing approaches mentioned in *3.1*: the VSM and the standardization approach.

First a calculation of the lead time is done based on the VSM, but it will not be performed graphically, due to the high number of parts (46) to be analyzed, but a similar approach will be used, by calculating an estimated lead time based on the sum of non-value adding estimated time plus the working VA time based on production standards (*Section 4.2)*. This allows to go through the production flow, operation per operation, and in each one state the expected working time, where value is added to the product; and the estimated waste time, in which there is no value being added, but anyways takes part in the total PLT, so it has to be taken into account. This calculation of the LT is referred in the research as estimated production standards lead time (EPS LT).

Moreover, lean manufacturing states that for standardizing a process, first the process in designed and then the operators adapt it. Then, this is what it is done in the second phase, once the PLT based on VSM is obtained, this is adjusted to the reality, what operators and production in general, are achieving. For comparing the calculated PLT to the actual performance, the central tendency where repeatable good records lie, as also specified by lean, is calculated by mean of statistical indicators (*section 4.1.4*). Then, after these different PLTs are calculated, they are combined into a final standard lead time (*section 4.3*), which is set as a production target.

4 Production lead times

This chapter analyses the actual lead times and its data mining process (*4.1*), the estimated production standard lead times (*4.2*) and the planning final standard lead times (*4.3*).

4.1 Actual lead times: data mining

This section is intended to answer the following knowledge question:

Which are the actual and past production lead times?

A large number of parts have to be studied, each of them having different paths over the production plant, and each one having different outcomes in similar operations. Moreover, the frequency at which each part is produced is completely different. There are 'A' parts, as the inserted diaphragm V450612400, used for the pressure regulator of cars, which has a whole cell with four molding presses designated only for it, has a continuous daily production. While there are others, as for example the assembly part V115013300, which are just produced a few times a year. Therefore, do to these reasons, the long production duration of parts and the inconsistency of results, the data gathering can't be based on real time observation in the manufacturing plant, taking into account the three months duration of the research at Vernay. Then, a data mining process will be performed using CRISP-DM process model. Cross-industry standard process for data mining, known as CRISP-DM, is an analytics model consisting on six phases: Business Understanding (*4.1.1*), Data Understanding (*4.1.2*), Data Preparation (*4.1.3*), Modeling (*4.1.4*), Evaluation (*4.1.5*) and Deployment. (Shearer C., 2000)

Subsections one to five include the first five steps of the methodology. And then, to end up with the last step, deployment, is part of the implementation of the final dashboard, in *Section 5.1*.

4.1.1 Business Understanding: goal

The first step of the methodology is determining the business objectives, so, what the stakeholder wants to accomplish. As already explained in *Chapter 1.2*, the research objective, and therefore the stakeholder's, is to know the standard lead times of 'A' products, and how to get production more stable and efficient in order to accomplish these. Therefore, the data mining goals are to gather the information related with historical production flow, and to model it in a way that allows the customer to visualize and asses the performance of the parts' lead times in the most transparent way.

The data mining has to answer the knowledge question: 'Which are the actual and past production lead times?'

As previously mentioned, due to the type of production and other factors, it is not possible to do the data gathering with direct observation, therefore, the ERP system (Epicor) and the local central databases are used.

4.1.2 Data Understanding: data gathering

The basic information needed for just stating the production lead time would be start and end production time of each job of each product for the previous years. But in order to understand better the lead time, it is important to know what is happening in between, during the whole production flow. Therefore, it is decided to look for a database on Epicor, Vernay's ERP system, including the historical detailed transactions per operation per job per part. '*Scrap details by transactions*' database, from 2019 until the moment, May 2021, containing the previously mentioned detailed transactions, was exported to an Excel file. This dataset is used as the main reference and the base for the research. In order to compare the completed transactions on operations against the standard it is needed a dataset containing the standard operations and their order for each part. For this purpose, '*Part check*' database is loaded into Excel, including the list of standard operations per part (Bill of operations (BOO)), the estimated production LT by planners, as well as their production standards. Moreover, '*VOL Part update*' dataset was also exported from Epicor, containing general characteristics of each part. A summary of these three databases is included in *Table 3*.

Database	*Description*	*Initial size (rows x columns)*
Scrap details by transaction	Historical transactions from 2019 until the date	500000x25
Part check	List of operations (Bill of operations (BOO)) per part and production standards	6504x34
VOL part update	Main information per part. Planner, standard quantity, planners' LT	1086x21

Table 3. Main databases used. (Epicor)

Each 'Scrap details by transaction' row is a completed transaction, so, every time a worker was registering a performed work quantity of the job in the system. This is explained better looking at the job example in *Figure 8*. It can be seen that 1893 units (of 3000 total) of job VOL-059048 of part V547610300 were registered in the third operation of the process, molding, with operation code 106, in the system the 22/06/2021, clocking in at 23:58 and out at 00:00, so the registered work time was of two minutes. The normal process is to register the job in the cell's VPI when molding starts and clock out in the VPI when the molding for a certain quantity is finished. But this is not applied consistently, as sometimes the system shows zero or a very reduced working time for a work that is certainly taking longer, while other times the clocking in and out is properly registered. Therefore, the difference between clock-in and out, supposed to be the 'working time', is not taken into consideration do to its unreliability. There are other columns giving information about this transaction, as the operator performing this transaction, the scrap quantity, the burden hours registered, additional comments, and other columns with no values filled in, which are not included in the example (*Figure 8*).

Before dragging results it is essential to make clear what is calculated as 'production lead time'. In the operations' BOO of every product, the first one always corresponds to 'Applied Burden', and afterwards there are operations present as 'Pretreatment' or 'Bonding', explained in *Section 2.3*. These operations will be kept in the database as references but are not meaningful for the production lead time calculation, as they are just part of the preparation

A parts	Molding	Assembling	Punching
V037611400	X		
V039310300	X		
V039310600	X		
V072810900	X		
V081615900	X		
V081616200	X		
V081617400	X		
V081617600	X		
V081619100	X		
V115013300	X		
V115013800	X		
V115014600		X	
V115015500		X	
V115015900		X	
V115016300	X		
V115016500		X	
V115016600	X		
V115017700	X		
V115018300	X		
V140414200	X		
V140414600	X		
V140417300			X
V164711100	X		
V176310600	X		
V176810700	X		
V194010500	X		
V194012600			X
V295711000		X	
V295715300		X	
V295715700		X	
V295716000		X	
V295716500		X	
V295716700		X	
V450310200	X		
V450310500	X		
V450310700	X		
V450311300	X		
V450612400	X		
V455110800			X
V455110900	X		
V470910300	X		
V494610100			X
V559810100	X		

Table 4. Birth-giver operations

of the incoming process and are done for all parts commonly at the starting of the morning shift, or, in the case of Applied burden, it is merely a financial transaction's procedure performed in the offices, in parallel to production processes. Therefore, the measuring will start since the first birth-giver operation start is registered until Packaging is finished. The birth-giver operation is the first step of the process, scheduled by planners as the release to production. The most common birth-giver operation is molding or assembly, but there are also some products starting with punching. The starting operations for the A parts are shown in *Table 4.*

By analyzing the operations' transactions, it is found out that not every operation listed in the bill of operations (BOO) of each part is actually tracked. Using the previous example, by comparing job VOL-059048 transactions in *Figure 8* to its BOO in *Figure 9*, it can be seen that from the eight operations listed only three had transactions registered. Sometimes untracked operations contain fake transactions, created by the system replicating the next tracked operation's transactions (called 'backflush operations'), and some other times they have directly no transactions. Then, for reducing deviation, having a consistent tracking, and using this transactions processed wisely it was decided to choose the 'tracking operations' for each part. Birth-giver operations (molding, assemblage and punching), as well as the end of packaging, are always tracked, which allows to calculate correctly the total lead time, from starting to end of production. However, in between, most of operations are not. *Figure 10* represents the percentage of A parts for each operation having a consistent tracking registered in the system, and the number of A parts including each operation in their BOO.

Taking all these mentioned circumstances into account, the operations are then tracked in groups, which will be referred as '**tracking groups'**. Apart from this, the calculation is complex, as the job uses to divide into different batches (travelers), but it will be assumed for the 'tracking group', that it starts when the previous operation is completely finished, so, since last transaction registered; and is tracked until the last transaction of the last operation of the tracking group. The 'tracking operations' list will be constituted by every operation (excluding 'applied burden') tracked in more than 70% of jobs. Going back to the example in *Figure 8*, for part V547610300, of the eight present operations (Applied Burden is not counted), there are two 'tracking operations', Molding and Packaging. Then Molding will be calculated since the first transaction clock in, until the last transaction clock out; and afterwards, the next 'tracking group' (constituted by Postcuring, Coating, Vacuum drying , Final audit and Packaging), will be calculated since the last transaction clock out of Molding until the last transaction clock out of Packaging. The job's birth-giver machine doesn't need any previous operation to be tracked, but the next tracking operations need the previous tracked operation in order to get the lead time calculated, otherwise it will not be computed.

Company	Create Date	Employee	Job	Part	Market	Part Quantity	Received Quantity	Opr	Operation	Description	Labor Hrs	Labor Quantity	Scrap Quantity	Unit Cost	Scrap Cost	Scrap %	Burden Hrs	Clock In	Clock Out	Payroll Date
VOL	6/22/2021	70000	VOL-059048	V547610300	Non-Medical	30000	21760	10	250	Applied Burden	0.67	800	0	0.11161	0	0	0.67	16.44	17.1	6/22/2021
VOL	6/22/2021	70000	VOL-059048	V547610300	Non-Medical	30000	21760	10	250	Applied Burden	0.75	900	0	0.11161	0	0	0.75	17.37	18.12	6/22/2021
VOL	6/22/2021	70000	VOL-059048	V547610300	Non-Medical	30000	21760	10	250	Applied Burden	0.08	100	0	0.11161	0	0	0.08	0.09	0.17	6/23/2021
VOL	6/22/2021	29692	VOL-059048	V547610300	Non-Medical	30000	21760	30	106	Persen (Molding)	0.02	1893	0	0.11161	0	0	0.02	23.98	0	6/22/2021
VOL	6/22/2021	20192	VOL-059048	V547610300	Non-Medical	30000	21760	30	106	Persen (Molding)	1.73	3770	0	0.11161	0	0	1.73	16.22	18.45	6/22/2021
VOL	6/22/2021	29633	VOL-059048	V547610300	Non-Medical	30000	21760	30	106	Persen (Molding)	0	2000	0	0.11161	0	0	0	16.33	16.33	6/22/2021
VOL	6/7/2021	20237	VOL-059048	V547610300	Non-Medical	30000	21760	80	132	Inpakken (Packaging)	0.57	0	0	0.11161	0	0	0.57	15.52	16.08	6/7/2021
VOL	6/7/2021	20237	VOL-059048	V547610300	Non-Medical	30000	21760	80	132	Inpakken (Packaging)	1.97	0	0	0.11161	0	0	1.97	17.62	20.08	6/7/2021
VOL	6/8/2021	20014	VOL-059048	V547610300	Non-Medical	30000	21760	80	132	Inpakken (Packaging)	0	13760	0	0.11161	0	0	0	12.87	12.87	6/8/2021
VOL	7/1/2021	20221	VOL-059048	V547610300	Non-Medical	30000	21760	80	132	Inpakken (Packaging)	0.1	0	0	0.11161	0	0	0.1	20	20.1	7/1/2021
VOL	7/2/2021	20099	VOL-059048	V547610300	Non-Medical	30000	21760	80	132	Inpakken (Packaging)	0	8000	0	0.11161	0	0	0	15.7	15.7	7/2/2021

Figure 8. Scrap detail by transaction database example. Job: VOL-059048, part: V547610300 (Epicor, June 2021)).

Part	Opr	Operatio	OpDesc
V547610300	10	250	Applied Burden
V547610300	20	140	Pretreatment
V547610300	30	106	Persen (Molding)
V547610300	40	109	Ovenkuur (Postcuring)
V547610300	50	120	Antistickbehandeling (Coating)
V547610300	60	116	Vacuum drogen
V547610300	70	131	Eindcontrole (Final Audit)
V547610300	80	132	Inpakken (Packaging)

Figure 9. V547610300 operations list (BOO). Tracking operations example ('Part check', June 2021)

Operations	# A parts including the operation	Number of times selected as 'Tracking operation'
Inpakken (Packaging)	46	46
Persen (Molding)	30	30
Assemblage (Assembling)	11	11
External Sorting	8	8
Ponsen	5	5
Ponsen (OD Punching)	4	4
Slitten (ID Punching/Slitting)	1	1
Visuele Controle (Visual Insp)	2	1
Controleren (Testing)	7	2
Sorteren (Sorting)	8	2
Applied Burden	46	0
Eindcontrole (Final Audit)	43	0
Ovenkuur (Postcuring)	26	0
Pretreatment	19	0
Antistickbehandeling (Coating)	10	0
Zeven (Media Removing)	6	0
Wassen Drogen Centrifugeren	5	0
Subcontract Processing	5	0
Lijmen (Bonding)	3	0
Ontflashen (Deflashing)	2	0
Chemische behandeling	1	0
100% Controle Auto Inspecting	1	0
Final Audit / Packing	1	0
Dipping	1	0

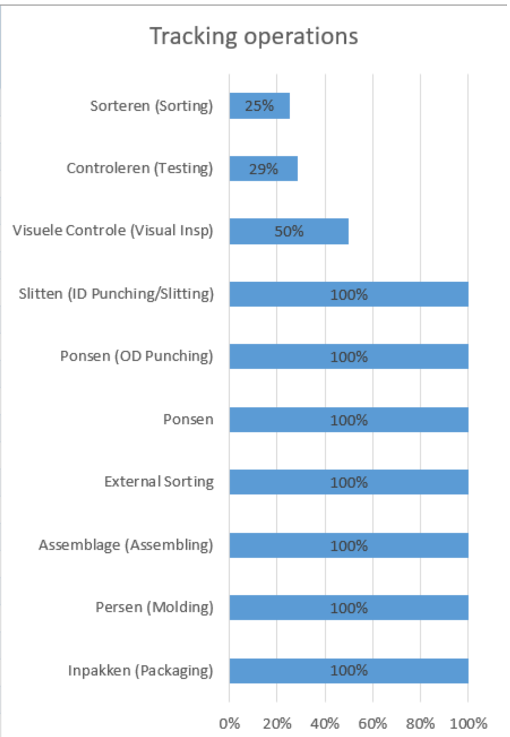


Figure 10. Tracking operations and number of A parts including each operation

4.1.3 Data Preparation: data cleaning

'Scrap details by transaction' large quantity of data has to be cleaned in order to make the database more efficient and allow the program to run faster. Therefore, first, the irrelevant columns to the investigation will be deleted, leaving twelve columns (summarized in *Figure 12* in addition to the new added columns), but still over 500000 rows remain. Hence, after making a first problem analysis, by having an overview over all three-hundred fifty-nine products present in the database, to have a general view of the difference between runners (A products) and other categories, it is decided to delete the non-runner parts, and to keep the forty-six A products. The main goal of the research is to do this analysis for runners, due to the Pareto rule, as stated in the research limitations (*section 1.3.3*), that is why the rest of products are then deleted.

Moreover, there are many transactions with quantity equal to zero, which are the product of operators errors when registering batches in the VPI, therefore, every row with labor quantity zero is deleted. This will be done with exception of external sorting transactions, as is explained in *Appendix D*. In addition, sometimes there has to be a rework in some operations because errors are found in some pieces during the quality checks. When this happens, the error pieces are marked in the operation where it has to be redone with a negative labor quantity value, equal to the needed rework quantity. Afterwards new transactions are added again with the new quantities produced. As these are not standard procedures, just occur in some cases, and deviate the total time of the operation, the negative labor quantities and the later added transactions on the operation are deleted.

From the twelve columns remaining from the 'Scrap details by transaction', 'clock in' time and 'create date' are merged in one cell for determining the start time and date together in one cell. The same is done with 'clock out', for determining the end of the transaction. 'Start job' column is also added to the dataset determining the first transaction clock in of the birth-giver operation of the job. The same is done in 'job end', determining the last transaction of packaging, and the finishing of the lead time. Then, by subtracting these two last columns, it is calculated in another one the total lead time of the job. If packaging or the birth-giver operation are not registered, they will appear as “-“, same as the lead time column variable. This way, it will not compute wrong lead times which don’t have the whole process registered, and would have a shorter value than real, leading to errors. Final columns in the dataset are listed in *Figure 12*.

The database includes data from 2019 until now, but, as the manufacturing plant, processes and demand have been changing considerably since then, 2019 lead times records may not be representatives or comparable to the actual performance of the plant. Moreover, production and demand passed though some unusual states due to the covid-19 pandemic, during part of the year 2019, where the plant stopped producing and then suddenly increased, leading to abnormal performances. Therefore, most of the products, will be analyzed on the last seven months’ time range, since October 2020 to end of April 2021. In spite of this, some parts don’t have a sufficient sample size to analyze, or changed the performance during the time do to process changes, and then, the time range will be different, shown in *Table 5.* This is just the time range selected for the main parts analysis, however, the database is still kept since 2019, as the final dashboard (*Section 5.1*) gives the possibility to select the analysis data range, and then, older jobs are also available for study. *Figure 11* shows a visualization of the production volume per part since 2019 and the actual tracked volume for the main analysis.

analysis time range	parts
Jan/20 - Apr/21	V470910300, V194010500, V450310700, V039310600, V081617600, V295716500, V295716700, V115015500, V295715300 and V295716000
Aug/20 - Apr/21	V039310300
Jan/21 - Apr/21	V081619100
Apr/21	V609510200
Oct/20 to Apr/21	the rest

Table 5. Analysis time range per parts

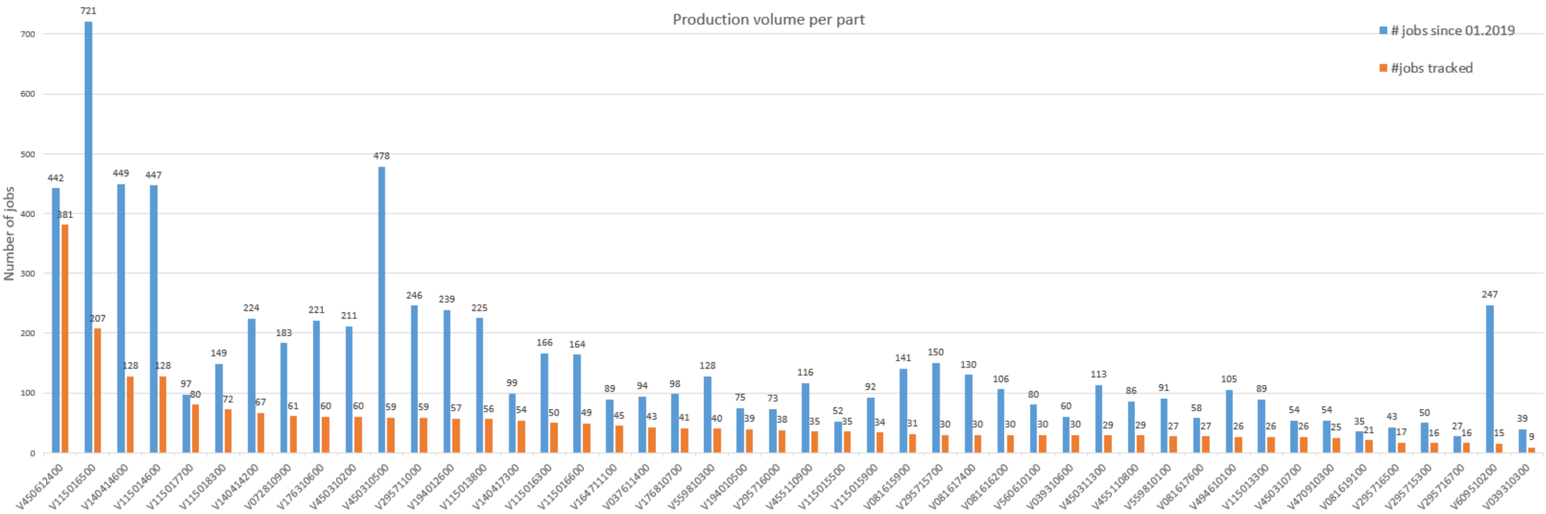


Figure 11. Production volume per part. Quantity of jobs since 2019 and quantity of jobs tracked in analysis date range

‘VOL Part update’ and ‘Part check’ are also cleaned from the useless columns and non-A-products are deleted too. See in *Figure 12* the remaining columns and the relationship between them. Arrows indicate connection between values and the dashed lines indicate comparable variables.

Scrap details by transaction	Part check	VOL part update
Start transaction time	Prod. Std	Planner ID
Job number		
Part	Part	Part
Part Quantity		standard job size
start job time		
Operation order	Operation order	
Operation number	Operation number	
Description name	Description name	
Labor Quantity		
Labor Hrs		
Burden Hrs		
Clock In		
Clock Out		
finish time		
job end		
lead time		Planners estimated Lead Time

Figure 12. Cleaned datasets variables (columns). Arrows indicate connection between values and the dashed lines indicate comparable variables.

4.1.4 Modeling: calculating the tracked lead times

Once there is constructed a solid, broad and clean database adapted to the research needs and available resources, it is time to think of what it is wanted to be transformed to and how it is going to be used. Due to its size, quantity of parts to be analyzed and the quantity of jobs, operations, and transactions each part has over the last years, the representation and visualization of it has to be smart, so the data can be used wisely for conclusions. Therefore a dynamic representation which allows to the introduction of filters and the efficient overview is the best option. For this reason a **pivot table** is used, filtered primarily by parts, and then by date and job. This will return every job, with each operation of the selected part in the given date range, with a start date and end date. This format allows to know the duration of each job divided by operations, and by the mean of Excel formulas, a column will be added to calculate the 'tracking group' registered time. In addition to this, there is a table summarizing the pivot table, connected to the same filters, showing the quantity and production lead time for each job.

In this research, for setting the standard lead times we want to focus on the most possible outcome, one which is proved to be able to be completed by production and that will be possible to be set as a target. The focus has to be on the frequencies of records, not in the lowest registered time, which setting it as benchmark will suppose having every job late, and then will be useless; nor the highest, which will be easy to be completed and then will suppose a decrease in performance in production, creating an increase on times do to the good results compared to this set due date. Therefore, the eyes have to be putted on central tendency, as well as the variability, essential for a descriptive analysis. Setting an achievable but challenging target to production will make that they try to reduce their inefficiencies and fluctuations in order to get to this goal, setting priorities when jobs approach the end date. This will also allow to make a good evaluation on performance.

For the output pulled from the database to the dynamic dashboard, statistical indicators have to be used in order to summarize the broad amount of data and different jobs, so parts can be analyzed as a whole and conclusions can be taken on the actual production lead times. The used indicators and their use motivation is presented next in *4.1.4.1*. These are the mean, mode, median, percentiles, five days highest density interval, standard deviation, sample size and quantity.

4.1.4.1 Lead time statistical indicators

Mean

The arithmetic mean is the most known average indicator, which is the sum of all data divided by the number of values, and allows to have a general estimation of the dataset as every value is included in the calculation, but can be easily deviated by outstanding high or low values, also known as outliers, and give a wrong indication of the central tendency of records. That is why it is useful to use it, but always in addition to other average measures.

Mode

This is the most frequently occurring value in the data set, therefore it is a good indicator to predict in the future the most possible lead time too, but of course, not in every case it will be representative of the standard lead time we are looking for, as this repeated value may be caused because of a precise cause, and it can be that the rest of the cases are not related at all with this result. This measure is more useful for parts in which the lead time range is more reduced, as it is more probable to have repeated values.

Median

The median is the value that is in the middle of the dataset ordered from low to high. In other words, it is the value that divides the dataset into two halves, the 50% lowest and 50% highest data. This is a good indicator of the central tendency as it is not affected by outliers. If this calculation differs considerably from the mean, it means that the dataset is skewed, and then the median is a more representative value.

Percentiles

Within a dataset, the n^{th} percentile indicates the value below which the n% of the values are located when sorted. For example, the 90^{th} percentile of a dataset with 100 values indicates the value which divides the 90 lower values from the 10 highest values. Percentiles are very useful as they don't need to be given a statistical distribution while it provides meaningful benchmarks between the minimum and maximum of the observed data, so it also indicates the spread. Percentiles are representatives for any type of distribution, not as other central tendency indicators, that are more representatives for normal distribution. More explicitly, the used percentiles for the analysis are 20^{th}, 50^{th} (median), 70^{th} and 95^{th}. The 20^{th} percentile is calculated to have an estimated reference of at which value the datasets starts to approximate the central tendency. The 70^{th} will be used for setting the point at which values are considered 'high'. And the 95^{th} percentile will be used as a reference for obviating the highest values of the dataset, outliers that may deviate the central tendency results.

Five days highest density interval (5D HDI)

This designed indicator measures the mean among the five days range with more density among the dataset. In other words, it is looked at the five days interval with more jobs finished in between, and then the mean is calculated. This indicator is used with the intention of setting a central tendency, based on the most repeated range records, so the calculation returns a value with a high probability to be repeated. Five days were chosen as for setting a standard lead time a deviation of two days over or below this value is, in general, an acceptable value.

Standard deviation

Moreover, in contrast of the previously explained statistical indicators, the standard deviation is not used for estimating the tendency, but for valuing the dispersion of a dataset in relation to the mean. This indicator is essential for this research as fluctuations are one of the main problems of production, and the standard deviation just measures that, how the data deviates from the mean, how spread it is. If the standard deviation is low, it means that values are more stable, they are around the mean, and then the central tendency is more solid, and there is less uncertainty when estimating the production lead time, as the dataset would show that jobs use to finish into an estimated short interval. The larger the standard deviation is, the more possible is that, estimating the mean as production standard, the job will finish substantially earlier or later.

Sample size

The sample size just estates the number of values used in the dataset. It is a basic indicator, but important, as in this case it will tell how many jobs are given in a date range. The sample size is also significant for the quality of estimations, as the larger the dataset is, the more jobs are analyzed, the better conclusions and tendency analysis is made.

Jobs quantity

This includes a few different indicators related with the jobs quantities. Parts use to have a standard job quantity, however, this can in some cases variate. Therefore, in order to understand the lead time, the job quantity has to be also considered, as a major job may end up in a larger lead time. Therefore, some summary statistics are used for understanding quickly the job sizes for a certain part: mean, standard deviation and mode; indicators also used for the lead time, and already explained in this section. In addition, the correlation between the job quantity in the lead time is also included as an indicator, which allows to understand the influence the quantity has over the total production LT.

4.1.5 Evaluation : Conclusion

This subsection corresponds to the fifth step of the CRISP-DM methodology. In this stage, an evaluation on whether the model meets the business success criteria, and a conclusion is done. It is intended to answer the section's knowledge question: 'Which are the actual and past production lead times?'. Do to the quantity of parts and indicators intervening in the state of the lead times, this question can't be answered explicitly for each part, however, the dashboard presented in *Section 5.1* allows to consult each part independently.

Figure 13 visualizes the major statistical indicators explained in *4.1.4.1* for the five A parts with highest production volume as well as the five with the lowest ones. It calls out that for every part the mean is larger than the median, and this one major than the mode. This means that the distribution is positively skewed and the major outliers are located in the high end of the distribution. This can be seen in the example in *Figure 14* for part V450612400, where the most repeated value (mode) is fifteen, the median 17.57, and 87% of the jobs are finished between thirteen and twenty-two days; however, outliers, extreme high lead times recorded (sixty-eight, seventy and seventy-five days), skew the distribution to the right, increasing the mean and the standard deviation. The 70th percentile bar, also represents that 70% of the jobs are located under 20.11 days. Do to these outliers the mean is less representative of the central tendency as it is biased, and then, it makes it necessary to calculate a lead time benchmark that allows to decide from which value, lead times are considered extremely high and can be excluded from the analysis do to abnormal results (*Subchapter 4.2*).

If the difference is high between the 70th percentile and the mean, it means that the distribution of data is very spread, as the standard deviation is not just coming from outliers. This is the case of V470910300 (6th part in *Figure 13*), whose distribution can be seen in *Figure 15*. This part has only twenty-five jobs registered from January 2020 to April 2021, which hinders the analysis. However, it can be seen how spread the data is, with an average of 28.78 days and a standard deviation of 9.71; leading to values ranging from thirteen to fifty-two days, without any clear peak or mode, as the maximum frequency is two (repeated in six occasions).

The five days highest density interval (5D HDI) bar, is in most *Figure 13* cases between the mode and the median, and always bellow the mean. This is because it is not affected by outliers and calculates an average in the five days most populated range, which leads to a good estimation of the central tendency of results.

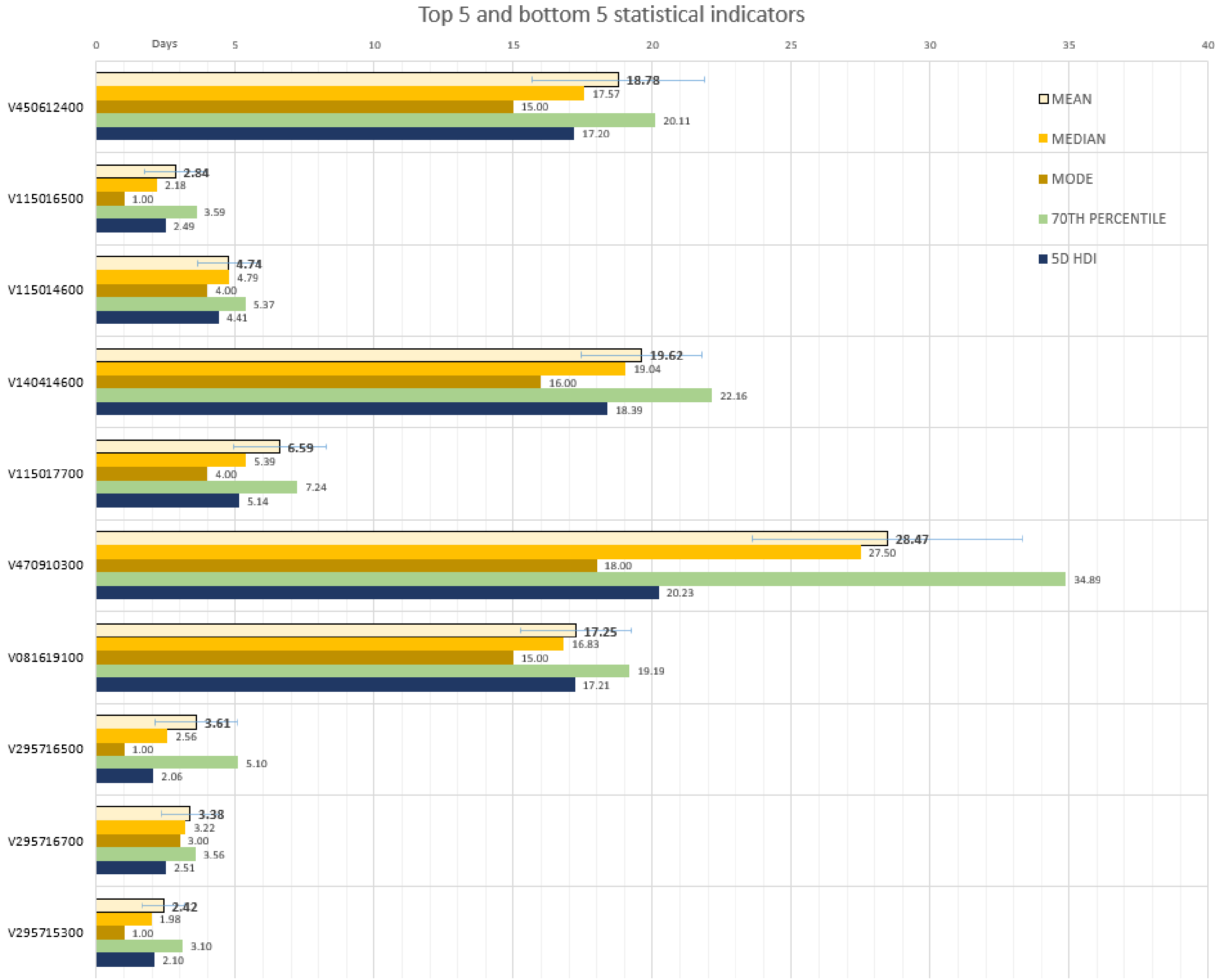


Figure 13. Top 5 A parts with higher volume (above) and 5 part lower volume (below). Major statistical indicators. Standard deviation added to mean bar

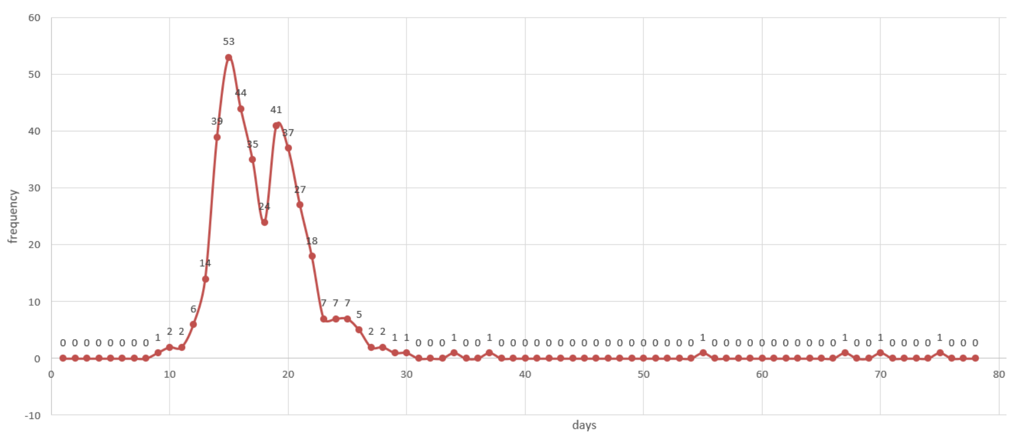


Figure 14. V450612400 lead times frequency and distribution

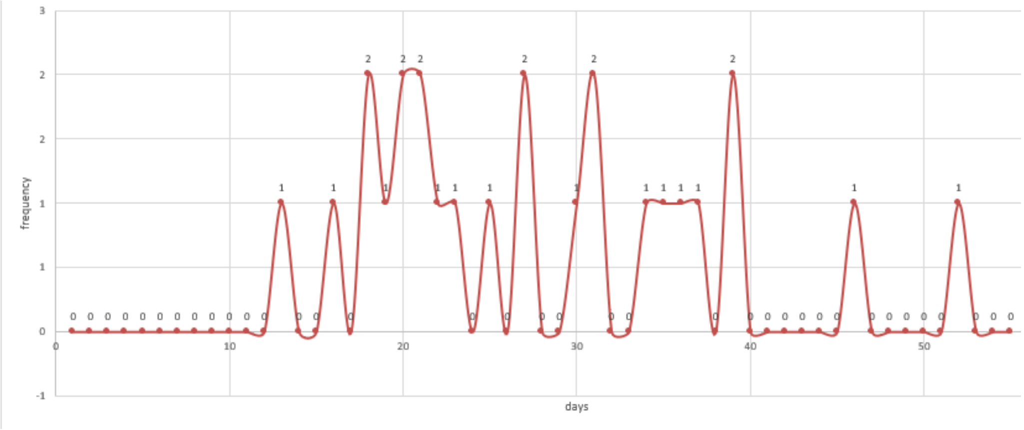


Figure 15. V470910300 lead times frequency and distribution

Moreover, thanks to the data gathering, analyzing the 'tracking groups' tracked times, it can also be located the distribution of the lead time over the flow, where the most time is spent and where are the fluctuations on the total time coming from. For example, for parts V450612400 and V470910300, the two parts previously mentioned with a large data distribution spread, it is found that instability is mostly coming from the 'External sorting' operation. However, as explained in *subsection 4.1.2*, tracking is not precise, consistent nor transparent, which makes that operations have to be tracked in groups. From the total sum of runner's operations, just 45.7% are tracked consistently, which mightily decreases the transparency of processes and production in general, obstructing the performance evaluation on particular operations, and then need a larger individual analysis, which will be done in *Section 5.2*.

4.2 Estimated production standards lead times (EPS LT)

In this section the following knowledge question is answered:

Which are the estimated standard lead times and operations cycle times based on production standards?

For answering this, an approach based on lean management value-stream mapping (VSM) (discussed in *Chapter 3*), is used. This estimated LT, referred in this report as 'estimated production standards lead time' (EPS LT), is composed of two parts: value adding activities (VA), treated in *subsection 4.2.1*; and non-value adding activities (NVA), handled in *4.2.2*. *Figure 16* represents in a value-stream map an example of how the EPS LT is calculated based on VA and NVA time.

The reason to calculate this estimation of the standard lead time is to have a non-biased reference to compare the tracked historical lead times (*4.1*) to, and at the same time, to set a benchmark for evaluating their performance.

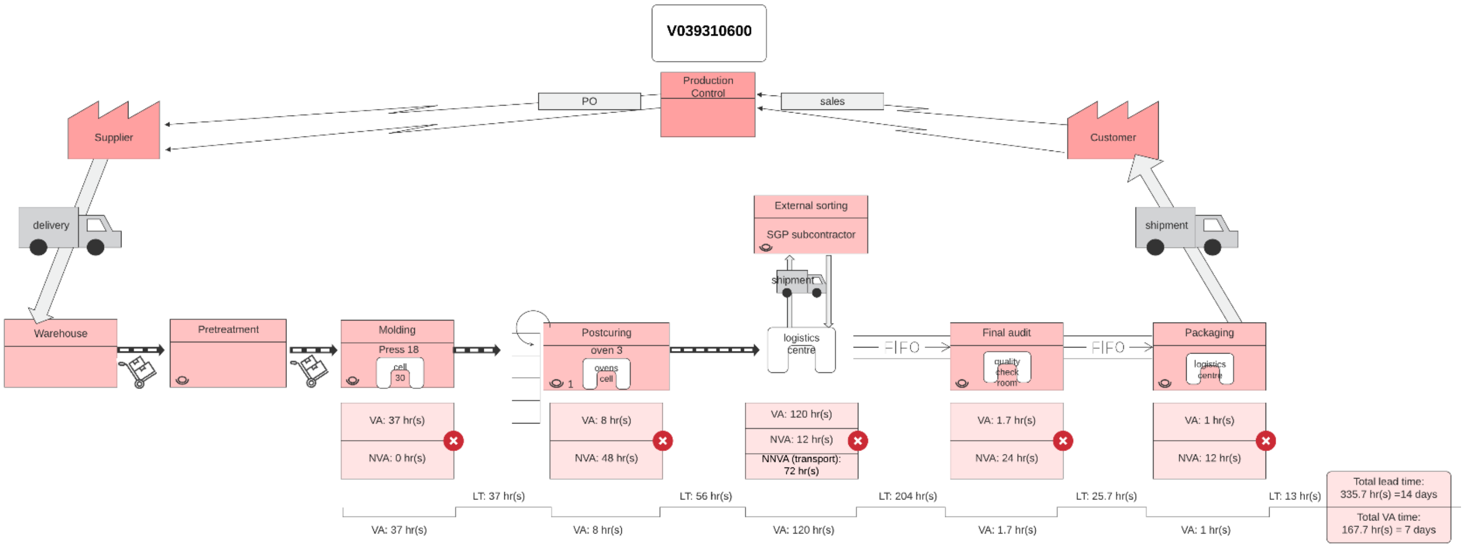


Figure 16. V039310600 Value stream mapping example

4.2.1 Value adding: production standards working time

In order to analyze the performance of tracked lead times, it is needed to compare it to a reference. The normal references for performance estimation and productivity in the manufacturing world are production standards. There are different types of standards at Vernay: frozen standard, ideal standard, production standard and maximum cycle time.

Production Standards quantify the amount of time required to make a part. They are set to reflect the reality of what happens in production, including normal sources of inefficiency. They are based on a reasonable, demonstrated rate of production and manning profile, and consider normal hurdles and inefficiencies expected to occur.

Therefore, in this case, the most appropriate standard to use is the Production Standard, exported from 'Part check' database in Epicor, as it is the most realistic reference for production, where a 100% productivity should be perfectly doable, and therefore set as the goal. The estimated working time (VA activity time) per job in each operation is calculated by dividing the standard quantity, gathered from the database 'VOL part update', by the production standard.

However, there are some operations which are exceptions for this calculation: applied burden, bonding, pretreatment, postcuring, external sorting and subcontract processing.

Applied burden, **bonding** and **pretreatment** are the previous steps to production, which are also registered in the system as operations but are not taken into account for the final production lead time calculation, which is considered from the first production step (molding, assemblage or punching) until packaging is finished.

The oven processes, stated as '**posturing'** in the system, are given a fixed working time, independently of its quantity, as the whole job fits together in the oven. The value given depends on the oven treatment each part receives, which has a specific curing time and temperature, stated in *Table 6*.

External sorting and **subcontracting** don't have any production standard as they are external processes. Then estimations are given based on their usual duration, their location, and the agreements with the collaborating companies. These estimations are done assisted by planners co-workers on their assigned products. *Table 7* presents the estimated times, estimated in working days, without considering the weekends in between.

Finally, *Figure 17* graphs the average value adding time, based on production standards and the previous estimations, for every operation.

Part	operation order	Oven treatment	Treatment time (hours)	Oven temperature (°C)	oven size (big/small)	estimated waiting time (hours)
V081619100	40	O06	4	125	small	0.5
V115018300	40	O09	4	150	small	0.5
V140414200	30	O17	8	170	small	0.5
V450310200	60	O16	7	230	small	0.5
V450311300	40	O16	7	230	small	0.5
V450612400	40	O19	8	200	small	0.5
V037611400	40	O19	8	200	Big	2
V039310300	40	O19	8	200	Big	2
V039310600	40	O19	8	200	Big	2
V072810900	30	O16	7	230	Big	2
V081615900	40	O12	4	200	Big	2
V081616200	40	O27	10	180	Big	2
V081617400	40	O12	4	200	Big	2
V081617600	40	O34	4	230	Big	2
V115013300	40	O16	7	230	Big	2
V140414600	30	O17	8	170	Big	2
V164711100	30	O17	8	170	Big	2
V176310600	30	O12	4	200	Big	2
V176810700	40	O27	10	180	Big	2
V194010500	30	O22	6	200	Big	2
V450310500	40	O16	7	230	Big	2
V450310700	60	O16	7	230	Big	2
V455110900	40	O19	8	200	Big	2
V470910300	50	O19	8	200	Big	2
V559810100	40	O09	4	150	Big	2
V559810300	40	O09	4	150	Big	2

Table 6. Oven (postcuring) treatments and estimated waiting times per part

Part	opr	Operation	OpDesc	expected duration (days)	company
V039310600	50	142	External Sorting	8.0	SGP
V081617400	50	142	External Sorting	8.0	SGP
V081619100	50	142	External Sorting	8.0	SGP
V194010500	50	142	External Sorting	8.0	ESP
V450310200	80	142	External Sorting	8.0	ESP
V450310700	70	142	External Sorting	5.0	ESP
V470910300	60	142	External Sorting	8.0	ESP
V450612400	60	142	External Sorting	8.0	SGP
V039310300	60	121	Subcontract Processing	15.0	
V081615900	60	121	Subcontract Processing	5.0	
V081617400	70	121	Subcontract Processing	5.0	
V140414200	50	121	Subcontract Processing	8.0	
V140414600	50	121	Subcontract Processing	10.0	

Table 7. External operations estimated times

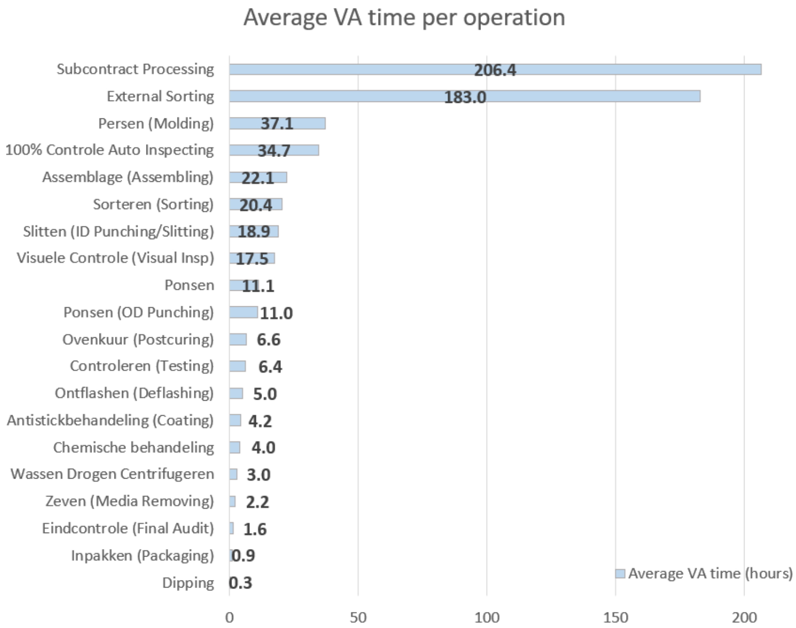


Figure 17. Average VA time per operation

4.2.2 Non-Value adding: estimated waiting times

In perfect circumstances, and being totally lean, the EPS lead time should be just based on the sum of operations' production standards, but unluckily, VOL manufacturing plant is still far from this, as most of the constituting lead time is NVA time, where jobs are waiting for been processed in each operation. Therefore, in order to be realistic, and compare these estimated lead times with the real ones, and set a standard to use as a reference for planning, it is needed to add a NVA time or buffer estimation before each operation handling. These estimates were stated with the consensus and agreement of production shift managers, planners, operations workers, and in comparison with the historical tracked records, by the use of the created database and indicators presented in *Section 4.1*.

This NVA time sets an estimate of the normal, acceptable or standardized time that is taken since the job is fully completed with the previous operation until the actual operation starts to be processed. The estimate also takes into account the number of shifts the operation is active and the inactive production hours due to shifts changes and breaks. For example, postcuring, has an operator working two out of three shifts (62.5% of the day) and a standard policy of putting the job in the oven if it has been waiting for three days, but has a lot of fluctuation and sometimes it takes 1 day and others 4. Then the waiting time (NVA) set as estimated and 'acceptable' is two, as it is a time considered as 'Okay' taking into account the actual circumstances. Of course, this is not the optimal value, as in a complete lean and optimized system, there should not be waiting times, or at least not take that long, but if the target is to compare it to the reality and set it as a reference, this is a good NVA time estimation.

These estimated waiting times are also based on assumptions. It is assumed that the job is always going together, so, it is not divided in different batches, 'travelers', as this variable is unpredictable and difficult to control.

'A' parts count with twenty four different operations, ones that are present in many parts, as final audit; and others more unusual, as dipping, only used for one part. General NVA estimations were given for each operation, but then some parts have those operations' NVAs adjusted because of counting with a different process leading to different NVA times. *Table 8* shows the general set NVA in common for every part, some of the exceptions noted next, the average NVA per operation, the average cycle time (NVA+VA) and the number of parts including each operation in their processes.

As shown in *Table 7* and *Table 8*, postcuring is given two different estimated waiting times depending on the oven type used. There are some parts using the general (big) ovens and others using the cell (small) ovens. General ovens (ovens 1, 2, 3, 4 and 5) are located in a separate room, with an operator solely dedicated to it, during two shifts, as mentioned previously in the section, and are used by a lot of different parts, with different treatments. Small ovens are located in the cells and are dedicated only to some parts in that cell. The large capacity of big ovens make that small quantities stand waiting in the ovens room for a longer time, as the operator waits until the car is more full so the utilization of the oven during the treatment is increased. On the other side, cell ovens, with a shorter capacity, and dedicated to less parts, allow jobs to be putted to the oven, in most cases, directly after finishing the previous operation, reducing the waiting times and fluctuations. That is why the waiting time estimations differ that much between these two different oven operation categories, estimating two days of waiting time for parts using big ovens, and half a day for parts using small ones.

Oper. code	Operation	Estimated general NVA time	general exceptions	Average estimated NVA time	average total cycle time (VA+NVA)	# A parts having operation
103	Controleren (Testing)	0.5		0.50	0.77	7
106	Persen (Molding)	0	first operation	0.00	1.58	30
107	Ponsen (OD Punching)	1	more some parts	1.00	1.46	4
108	Slitten (ID Punching/Slitting)	4		4.00	4.79	1
109	Ovenkuur (Postcuring)	2	0,5 small ovens	1.65	1.93	26
111	Ontflashen (Deflashing)	0.5		0.50	0.71	2
112	Chemische behandeling	0.5		0.50	0.67	1
113	Zeven (Media Removing)	0.5		0.50	0.59	6
114	Assemblage (Assembling)	0	first operation	0.00	0.92	11
116	Wassen Drogen Centrifugeren	0.5		0.50	0.63	5
117	Sorteren (Sorting)	1	0,5 sorting by barry	0.75	1.60	8
118	100% Controle Auto Inspectin	0		0.00	1.45	1
119	Visuele Controle (Visual Insp)	1		0.63	1.35	2
120	Antistickbehandeling (Coating	1		0.90	1.08	10
121	Subcontract Processing	0.5		0.50	9.10	5
122	Final Audit / Packing	1		1.00	1.02	1
124	Lijmen (Bonding)	0		0.00	0.07	3
131	Eindcontrole (Final Audit)	1	0,5 for assembly 0,25 before ext. sorting	0.78	0.84	43
132	Inpakken (Packaging)	0.5		0.50	0.54	46
134	Ponsen	1	0 if first operation	0.20	0.66	5
140	Pretreatment	0		0.00	0.00	19
142	External Sorting	0.5		0.50	8.13	8
145	Dipping	0.5		0.50	0.51	1
250	Applied Burden	0		0.00	0.00	46

Table 8. NVA estimations and average cycle time per operation

4.2.3 Conclusion

For getting the final estimate, the previous two sections (*4.2.1* and *4.2.2*) calculations are summed. Therefore, this is the result of the estimated production standards lead time, calculated in working days. Taking into account that the plant is not working during weekends, in exception of the birth-giver operations (molding, assemblage and punching) which in case the production week planning is not completed, will plan extra shifts during Saturday or Sunday, as explained in *Section 2.4.* This is the reason why birth-giver operations were not added any estimated waiting time, which also take into account the no-shift time, as, apart from not been supposed to wait between operations because of been the first one, weekends were not taken into account, while still sometimes working. Results are graphed in *Figure 18.* A screenshot of the excel tool used for calculating and adjusting the estimations is attached in *Appendix E.*

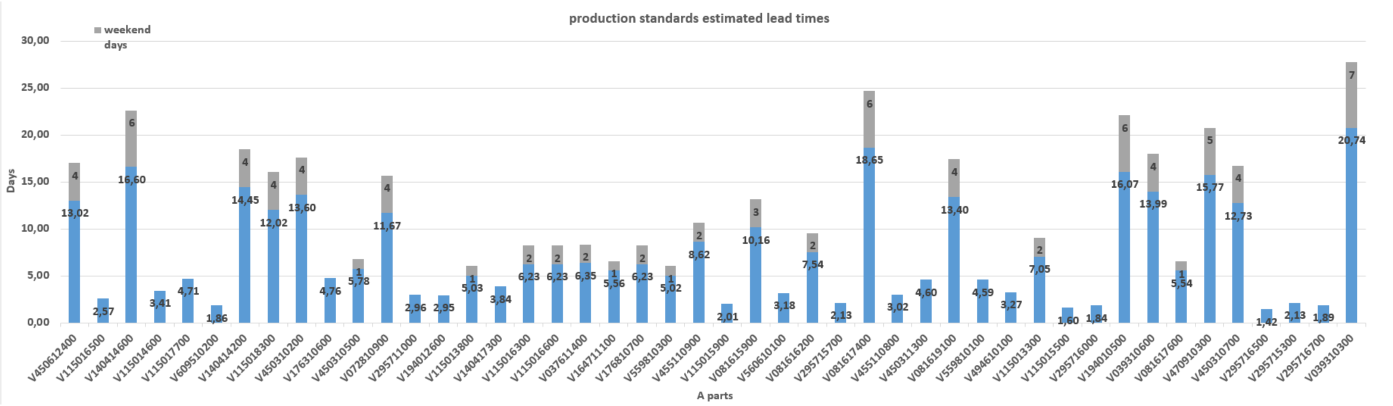


Figure 18. Production standard estimated lead times

To compare this estimated production standards lead times with the reality (*Section 4.1*), calculated in total days, it is necessary to add weekends to the result. Therefore, for transforming working days to calendar days it was used the following formula on excel:

*=IF(WD/5<=(TRUNC(WD/5)+0.2),(TRUNC(WD/5)-1)*2+1+WD,TRUNC(WD/5)*2+WD)*

WD= WORKING DAYS ESTIMATED VALUE

This formula adds two days every five days with the function TRUNC, which truncates the result of working days/5 to return an integer. However, if the calculated value adds another weekend just because of one day, in the last weekend, instead of adding two days weekend, it just adds one, as otherwise it would create more deviation from the expected. For example, if the working days estimate is eleven days, there would be a week of five working days plus two weekends, and another week of five working days and just one day added of weekend, so fourteen days in total instead of fifteen.

From the total lead time estimation, a comparison is made between the time providing from VA time (working time based on production standards) and the estimated NVA time (waiting time). The calculation obviates the external processes and the preproduction operations. This shows that from the estimated lead time, only 39.08% of the time is actually supposed to be working, adding value to the product (*Figure 19)*. By adding the 1.5h of not operating plant to the calculation, the result would be of 41.70% of the total time, with an impressive 58.30% of waste estimated.

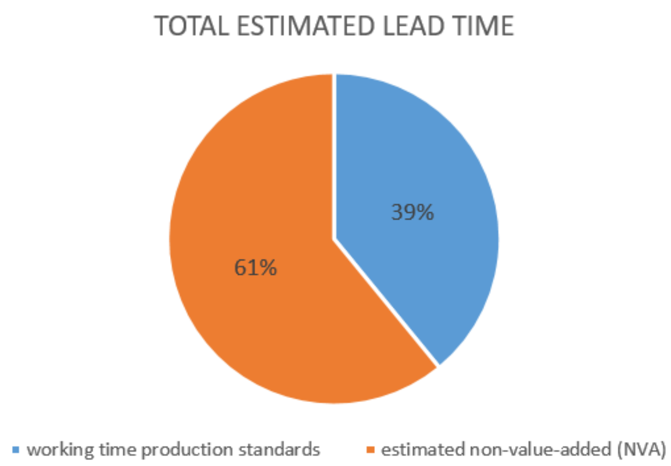


Figure 19. Estimated lead time. Working time vs NVA time

4.3 Planning final standard lead time (SLT)

This section presents the answer to the knowledge question:

Based on the tracked and estimated lead times, which is the final standard production lead time for planning?

4.3.1 Calculation

After gathering and analyzing historical data (*Section 4.1*), and estimating the expected lead time based on production standards and NVA estimations (*Section 4.2*), it is now possible to set a final standard lead time that planners can use for setting a production due date, and have an estimate of how this total time is distributed over the different operations in the process flow.

As already mentioned in Section 4.1, the goal is to focus on the central tendency of lead times' distribution, and reach a value fitting in between the central tendency and the estimated production standard lead time. The estimate will give an approach of how long it should take, while the central tendency indicators, will show how long it is actually taking in reality, which lead times are reproducible and most probably to be repeated in reality by production. Among the repetition and tendency, we focus on the best records that have showed to be able to be reproduced, so the outliers and values that are far higher than should be, based on the EPS LT are obviated from the standardization calculation. Therefore, the standard lead time final calculation will be an average of three indicators: the estimated production standard (EPS) LT, the central mean, and the five days highest density interval (5D HDI).

Estimated production standard LT (EPS LT)

The motivation to use this reference for the final calculation is that the estimation is not biased by outliers, tendencies or production problems. It is a reference so even if the lead times start to take more than the expected, the EPS LT would always remain the same. It is based on the production standards and estimations for waiting times, agreed with different stakeholders, so it is a representative value that should always remain related to the standard. Sometimes it can be larger than the average, but then it will signify that production is performing properly compared to the normal. It could also be shorter than most of registered records, then it will indicate that this final PLT should be tried to be reduced, and that it is perfectly reducible taking into account the actual resources. So, it will be a reference to avoid the lead time syndrome. The lead time syndrome is an effect that causes lead time to increase because of having a forecast based just in previous records, so, if last PLTs increase, the forecasted SLT set for production will also increase, and then, because of this increase in the expected due date, next PLTs will increase again, creating a loop, leading to extremely high PLTs (Schneckenreither, Haeussler, & Gerhold, 2021). In order to avoid this effect, there has to be a PLT that can set as a reference, and which can calculate the upper bound of 'maximum value', which in this case will be done by the EPS LT.

Central mean

This indicator is obtained by calculating the mean of the records with values standing between the lowest estimated value and the 70th percentile. The lowest estimated value is calculated by dividing the EPS LT by two, and is set as a reference for indicating which values are too low and may be coming from a tracking error or from an exceptional circumstance, deviating the result from the goal. The 70% percentile is set as an upped boundary, from which values above it are not relevant for studying the central tendency, and are expected to be corrected after setting a standard in production. Values above this indicator are normally a result of a production issue, or an accumulation of circumstances that create this deviation. Therefore, this mean will indicate which is the behavior and the tendency of results among normal cases, the research main focus.

Five days highest density interval (5D HDI)

This indicator was explained in *Section 4.1.4.1*. The calculation is included in the final result because the density factor is of high importance when forecasting, as the set standard has to tend to favor the most repeated value range, as it is proven to be an usual value.

The abovementioned three indicators values for each part, and their means, final standard lead time values, intended to be used for planning, are shown in *Figure 20* for the top ten most produced parts since October 2020 to April 2021. When the EPS LT is shorter than the 5D HDI and the 70th percentile LT, it means that the reality is taking longer than the estimations, which can be because of a too optimistic estimation of the NVA times or directly a bad production performance. When the EPS is larger than the two other bars, it signifies the opposite, and most of the jobs are produced in a shorter time than expected. The combination of the three indicators for the final SLT leads to a balance point in which, if production performance is higher than expected, it will not be pushed extremely, and it will be tried to keep that line, with a SLT slightly higher than the central tendency; and by the opposite, if they are doing bad, the SLT set as target for production will still be achievable as it takes into consideration the actual performance.

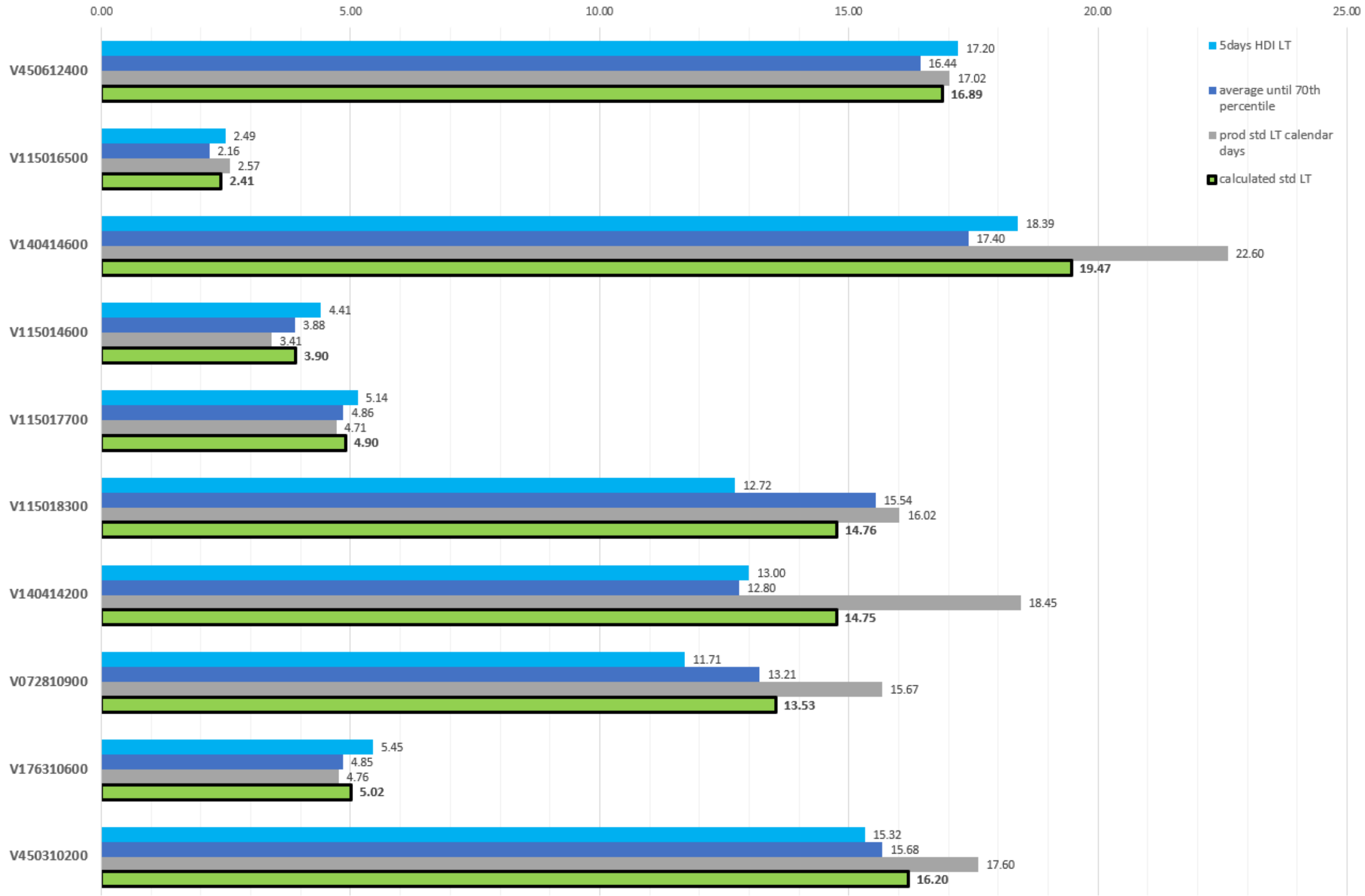


Figure 20. SLT calculation indicators for Top 10 most produced parts

In order to know the performance of the records in comparison to this just set standard, predicting the probabilities these are accomplished once putted into use and the degree of improvement the production lines requires for meeting the expectations; there are some indicators that will be used: bounded average LT, 95th percentile mean LT, the bounded standard deviation and the percentage of accomplishment.

The **bounded average LT** and the **95th percentile mean LT** are very similar indicators. The first one is almost alike the normal mean, already calculated in *Section 4.1.4.1,* but excluding extremely high values (outliers) for reducing the bias and increasing the representativeness of central tendency; taking as a reference the double of the EPS LT. The 95th percentile mean LT, is also done calculating the mean lying between two sides bounds. The lower bound is the lowest estimated value, as the central mean indicator, and the upper is the 95th percentile. These are just two similar methods of calculating the mean by eliminating outliers that could deviate the representativeness of the central tendency that is wanted to be compared with. The same bounds are used for the **standard deviation** (explained *Section 4.1.4.1*), where it is also important to remove the outliers that can confound about the real spread and consistency of LTs.

Finally, the **percentage of accomplishment** indicator, flashes the percentage of the jobs tracked in a given data range that had a tracked LT lower or equal than the estimated. So, the percentage of jobs that would have been completed on time with the given SLT.

A low percentage of accomplishment doesn't mean that the set standard is bad and that it is not realistic to set it as a due date. The SLT as based on proven achievable and repeated records, so production should be able to complete the job before the due date at any time. By having this as a due date, production will focus on it as a target, prioritizing jobs when needed, so the completion rate will be increased considerably compared to the rate calculated for past performances, when the SLT due date was still not set. Moreover, this will also allow to look at the reasons why a job is not completed on time, and take decisions from it for future improvement.

4.4 Conclusion

In this section, for concluding the chapter *Figure 21*, *Figure 22* and *Figure 23,* summarize the previous gathered and calculated values for each A part. This clustered bar chart is the best tool to precis the main indicators for analyzing the final calculated standard lead time (SLT). The graphic representation displays as a variable the LT used until the date by planners for planning production, the bounded average LT and the calculated standard LT (SLD). Moreover, the figure also includes the percentage of jobs tracked completed with a LT inferior to the SLT and the number of jobs tracked. Also, a standard deviation error bar is added at the end of the bounded average LT bar, representing graphically the spread of the values tracked, which are also important to take into consideration for preventing the risk of the end dates set, and the unpredictability these could have.

The graph is ordered from the major number of jobs tracked to the parts with less jobs, as the most usual parts results are more important for the company since they are produced more often and a light decrease in LTs will suppose a major improvement for production and for the company in general. Moreover, parts' results with more tracked jobs are obviously more reliable, as the data to analyze is larger and better conclusions can be taken.

The main feature that calls the attention of the graph is the difference between the SLT and the mean LT, with the planners LT. Planners LT is far from been precise, as it was not properly calculated, it was just estimated without a solid base or methodology. In some cases it is seen that the planners LT is twice as it should be, compared to the mean or SLT; and for other cases too low, especially for assembly parts, making it impossible to complete them on time.

Leaving this indicator aside and looking to the new calculated one, the SLT, comparing it to the mean, in most of cases it is slightly shorter, and lying close to the minimum of the standard deviation error bar. For short SLTs, the percentage of completion on time is in most cases low, as any deviation from the standard calculated, like a weekend in between or a couple of non-operating shifts for the initial operation, can already make the job's LT to be higher than the SLT, even if it is a short difference that will not cause a lot of problem for planning and logistics, but the completion on time percentage statistic is decreased. For example V176310600 (*Figure 21*, 10th part), the SLT (4,98) is very close to the mean LT (5,57), and the standard deviation is not that extreme, but, as the range of values is very short, a short difference has a high consequence in the on-time completion rate (30%), even if this is a good value for setting the due date. So, this indicator, the on-time completion rate, is not always representative of the accuracy and quality of the estimation, and how this will be reflexed in the future completion rates after implemented and used for planning and production as a due date.

Moreover, there are some parts with outstanding values, such as very low on time completion rate, big difference with the mean or high standard deviation, as V115018300, V194010500, V039310600, V039310300. V115018300 (*Figure 21* , 6th part) remarkable 13.09 days of standard deviation is due to a change in the quality operations processes, which creates that during the last months the lead time has been unstable, as each job had different procedures. V194010500 (*Figure 22* , 7th part), has an striking difference between the SLT and the mean LT, because the standard quantity set by the company, 6000 units, which is used for calculating the EPS LT, is different than the most usual (mode) produced quantity, 12000. V039310600 (*Figure 22* , 15th part), has a low on-time completion rate (23.33%) and a three days difference with the mean LT do to an delay created in molding and external sorting, whose estimate is shorter than the performance, creating lateness and deviation. V039310300 (*Figure 23*, last part) just has nine jobs tracked since August 2020, so not relevant conclusions can be taken, but the high difference between the SLT and the mean LT is because of an external operation taking extremely longer than expected, which should be taken into consideration by the company. These are just some highlights that call of from the graph, but general bottlenecks to be solved, and then decrease those gaps, are addressed in *Section 5.2*.

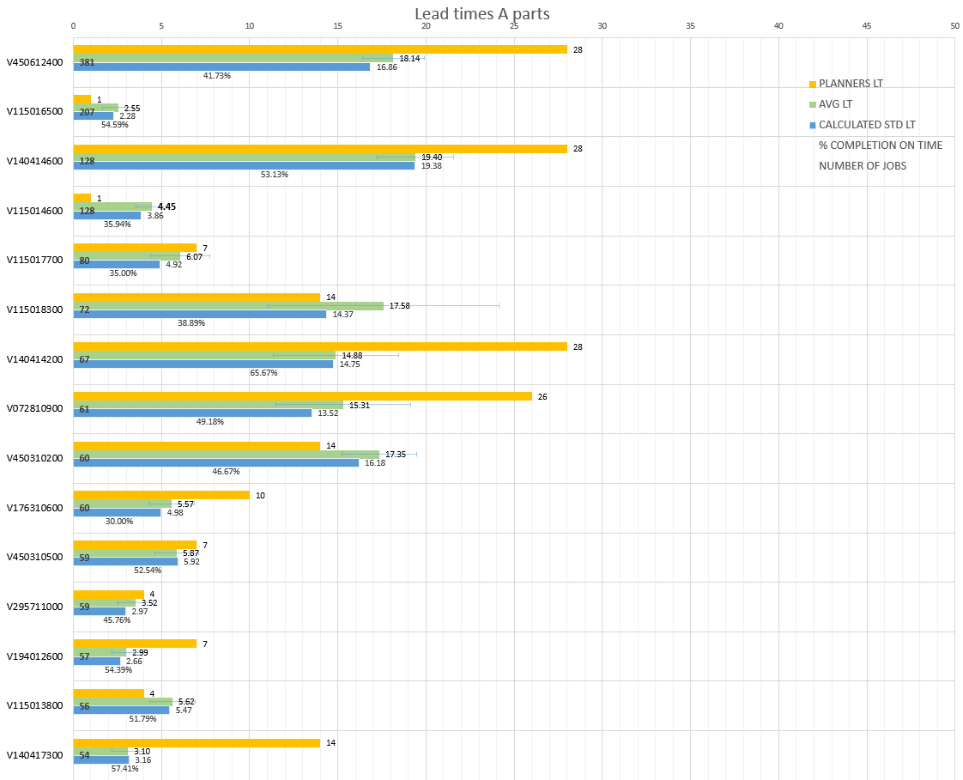


Figure 21. Lead times A parts. 1. Legend in the top-right corner. Standard deviation represented with error bar next to average bar.

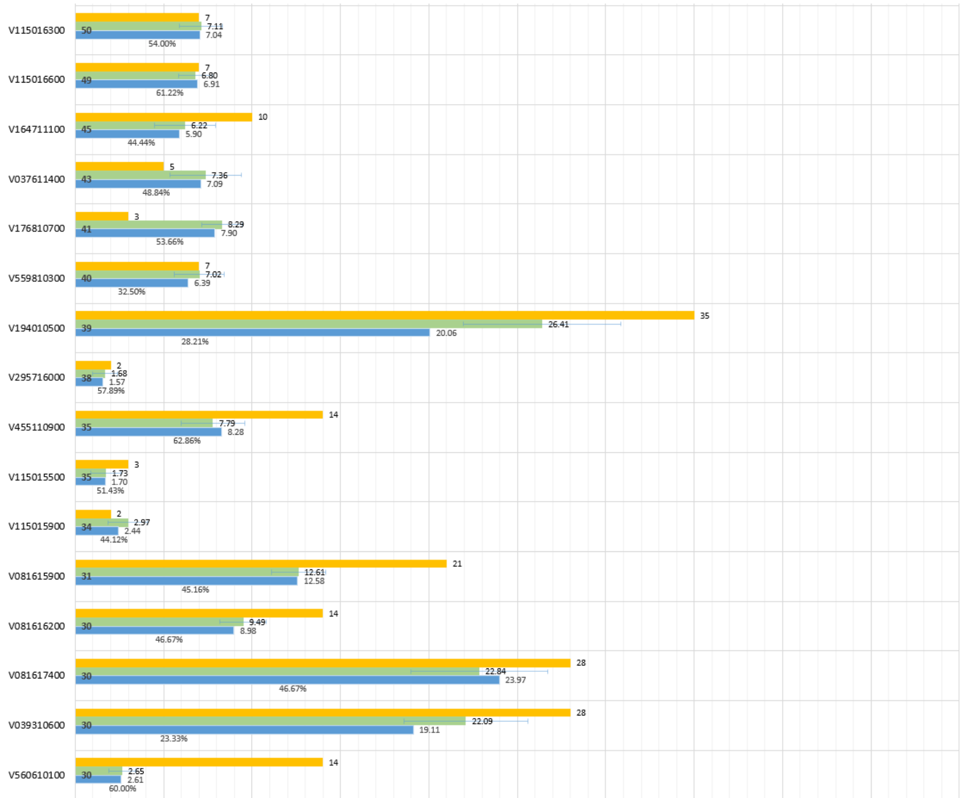


Figure 22. Lead times A parts. 2

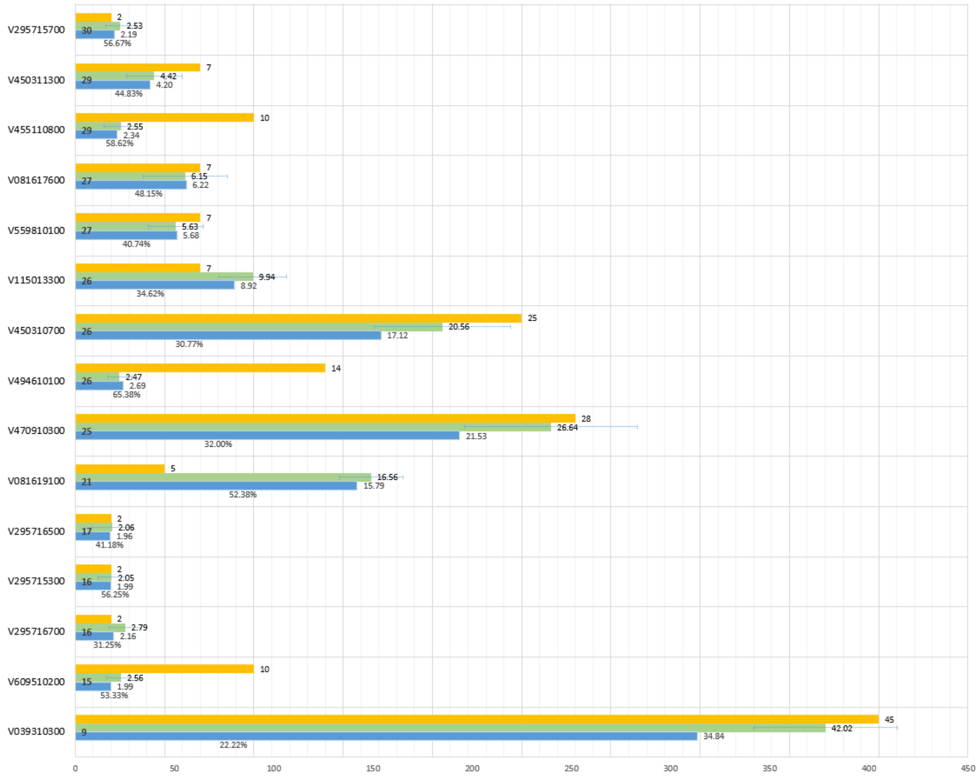


Figure 23. Lead times A parts. 3

5 Implementation and evaluation

This chapter is designed to answer the stated knowledge question:

How should the standard lead times be implemented and which are the main production bottlenecks?

The first part of the question, about the LTs implementation, is addressed in *Section 5.1*, while the production bottlenecks are tackled in *Section 5.2*.

5.1 Implementation: Parts lead times visualization dashboard

For the implementations of the findings from *Chapter 4*, putting together the tracked historical transactions and lead times, the production standard estimates and the final standard lead time, a business intelligence (BI) tool is designed especially for production and planning use.

This is a BI dashboard combining two types: strategic and analytical dashboard. Strategic dashboards are done to track KPIs; and analytical ones process data to identify trends, predict outcomes and discover insights based on historical data. This tool is designed mainly to enable a better informed decision-making and strategic planning for planners, the logistics department and production department. The used extensive databases and production indicators have to be made easily comprehensible for every user, who doesn't have to be necessarily skilled in analytics. The BI dashboard is also intended to increase the information sharing in the organization, as, at the moment, there is a lot of data on production, but this is not transparent, and finding information is very difficult and time-consuming. Planners don't know exactly how the parts production time is distributed over the process, and when customers call asking for their order, it is uncertain where the job should be located at that moment, and how long it is expected to take until finally produced, then, the dashboard would add great value for this. With this tool, in only one file it is possible to see all this information summarized, which will save a lot of time, and allows to visualize directly the production problems and discuss it easily with other members of the organization, in order to find possible improvement gaps and bottlenecks.

The stakeholders of the project, and the end users of the dashboard, main visualization objective is to understand the performance of production, in terms of total lead time and operations cycle times, as well as visualizing which is the new set standard lead time, that is recommended to use as a production due date. Therefore, taking into account the Business intelligence visualization techniques and theories, as well as the end product usage target of the dashboard, the following is designed.

Excel is the program used for this because of its usability and because of the formulas functions. Users from Vernay are already trained in Excel and are friendly with this program, that is already installed in every company device. This helps the usability of the user, which will feel more keen and comfortable using the tool, as will also avoid having to download and adapt to a new program, which, when not installed, may repel the worker. Moreover, Excel offers many tools and functions for programming, modelling and the execution of complex formulas by the mean on functions. The dashboard is performing the calculations in the same sheet, so it can be visible and accessible to users, so they can understand what is been computed. Moreover, Excel allows the dashboard to be customized by the enterprise users, as it will always be possible to be edited easily. This is important, as after my research is finished I will leave the company, and in case the company needs to adapt or edit some feature in the future, this will be then possible.

The dashboard is filtered by part and date range, as can also restrict jobs and operations, which makes it fully dynamic. Graphs and tables allow the direct visualization for a fast decision making.   is a screenshot of the dashboard showing the distribution and representation of data, tables and graphs. This screenshot doesn't allow to see the information precisely but the content will be explained next, and more precise screenshots are included in *Appendix F*. The BI dashboard includes **data filters**, a **pivot table of jobs transactions**, **jobs lead times table** and histogram, a **indicators summary data table** and bars chart, a **new quantity SLT** calculation, operations **tracked performance comparison with EPS** LTs table, expected **cycle times per operations to achieve SLT** chart, LT **variations over time** graph, and **tracked operations** times chart.

Data filters

The dashboard can be filtered by part, date range (based on the start time of the jobs), jobs and operations. The dashboard is specially made for selecting on part at a time, because otherwise the rest of data representation tools would not be useful. The reference date range used is from starting of October 2020 until end of April 2021, as these are the most recent jobs to be analyzed, but the range can be extended until January 2019. It is not recommended to use a very broad date range as the production plant has been changing, so lead times in 2019 are not fully comparable to the actual ones. In some cases, there are some operations that are just tracked in a few jobs, so they are not constant nor reliable, and then just create deviation and distract from the real references that are the tracked operations. Then, if there are some intermittent operations, there is an option to remove them with the filter.

Pivot table jobs' transactions

As mentioned in *Section 4.1.4*, this Pivot table, placed in the left side of the dashboard is the base for the rest of calculations, as the information is extracted from the main database 'Scrap transactions'. This table includes 10 columns, in addition of some other columns used for calculations, and each row indicates one operation tracked of each job. The three first columns indicate the Job code, the operation order and the operation code. Then, the pivot table returns the three next ones from the database, the start of the operation (first operation clock in), the start date of the job and the end of the operation (last clock out). Then, based on the fields returned by the pivot table, there are some columns with calculations, based on them, by using excel functions. Next columns indicate the number of days since the job started with the birth-giver machine until the operation starts and until the operation ends. 'tracked LT' column, calculates the total time since the first transaction of the operation until the clock out of the last transaction, so, it doesn't take into consideration the previous operation nor the tracking operations group. Then, the last column calculates the value of the cycle time per 'tracking group', as explained in *Section 4.1.5*.

Jobs lead times table and histogram

The table located in the right side of the dashboard, lists all the jobs tracked with the given filters, and returns in four columns: the start and end dates of the job, as well as the total lead time and the job quantity. A histogram is made from this table data, showing with lead times frequency the central trend and the general distribution of the lead times. This chart gives a very clear understanding of the status and fluctuations of the parts in production, and allows a better understanding of the calculated SLT.

Indicators summary

On the top-central part of the representation, there are two tables including the indicators explained in *Section 4.1.4.1.* The left one includes the indicators related with the total lead time and deviation, while the right one includes the quantity related indicators and the percentiles.

Besides, there is a bar chart below the left table summarizing the seven main LT indicators: average LT, the average between the lowest and 95% percentile, the median, the average between the lowest and 70% percentile, the five days highest density interval (HDI) LT, the estimated production standard (EPS) LT and the LT used by planners until the date.

New quantity SLT calculator

In case planners want to release a job with a different quantity than the standard, there is a tool, added at the top of the dashboard next to the quantity statistical indicators, that calculates the new SLT based on this new quantity. SLT are calculated for the standard job size, as the EPS use the quantity for estimating the value-added time, then, for this new quantity, the VA part of the EPS is recalculated and then a new SLT is obtained. This will allow more precision than by using the SLT of a different quantity than the standard one.

Operations' performance table

This table includes the part operations' list, and in the next columns 'tracking operations' performance is evaluated. There is a column for the tracked average time for the tracking group, next to it the expected time for each operation, and then the same information but divided in tracking groups. This allows performance to be evaluated in the next columns with the following indicators: productivity, standard deviation and coefficient of variance. In the top right column of the table the cycle time per tracking group to achieve the SLT is stated, which is commented next.

Additionally, the tracking operations list is visible in a table next to the operations performance one.

Expected cycle times for SLT achievement

These values, represented in the operations performance table and in a bar chart above, indicate, based on the calculated SLT, the production standards estimated cycle times for each operation. So, which should be the cycle times per operations group, in order that the total sum is equal to the SLT, and this can be achieved. These are based on an adjustment between the EPS times and the average tracked time for each tracking group. The calculation is founded on a formula that adjusts the values depending on if the tracking operation has a good or bad performance compared to the EPS, and if the tracked and EPS cycle times sum is higher or lower than the SLT. The calculation is made in the sheet '*calculation operation times for SLT*', included in the same Excel file as the dashboard.

Tracked operations times chart

Another bar chart is present at the bottom of the dashboard, with its respective table, where it can be seen the real registered tracking of the transactions, what has been really tracked, so it can be seen when operations are not having a proper clock in-clock out, or when operations start before the previous is finished. This chart is not intended to be for making conclusions on production, but rather to have an understanding on how the process is tracked.

Lead times variation over time line chart

This chart shows how the lead time of a part has been changing since 2018 per month, so it can be associated with production or demand special situations, as can be backlog or the corona crisis, and it can be understood quickly how certain situations are impacting the performance, and conclusions can be taken for the future.

The use of the tool is simple. First the part that wants to be analyzed is selected in the two available part filters. And then, if the date range, jobs or operations shown, wants to be changed, it can also be done in their indicated filters. Finally, the user can click on the big 'part number' button in the top-middle part of the dashboard and the axis range of the histogram is adjusted.

Apart from the dashboard, another Excel file was created to analyze all the 'A' parts together in one same sheet without the need of being looking one by one, and then be able to see the data and indicators summarized, and compare the different parts and operations performances quicker. An example of some products is visible in *Figure 25*. This includes the lead time statistics dragged from the dashboard, the performance comparing estimated versus reality and the quantity indicators, also included in the dashboard.

Moreover, from this just mentioned file, a final summary table is created (*Figure 26*), in order to sort parts and find directly the best-worst performers based on different indicators. It contains the lead time indicators and calculated SLT; a column in which the difference between the SLT and the average LT is calculated, so it can be sorted in this aspect; the number of jobs tracked; information on the category, cell and birth-giver machine of the part, as well as indicators on the birth-giver operation performance; then two columns are showing as '1' if the part includes an operation in the big ovens or an external operation, so it can be sorted by this attribute for taking later conclusions, which will be discussed in *Section 5.2*; and finally two indicator columns calculating the variability of the jobs quantities per part and the difference between the average and the stated standard quantity, for which the SLT is calculated for.

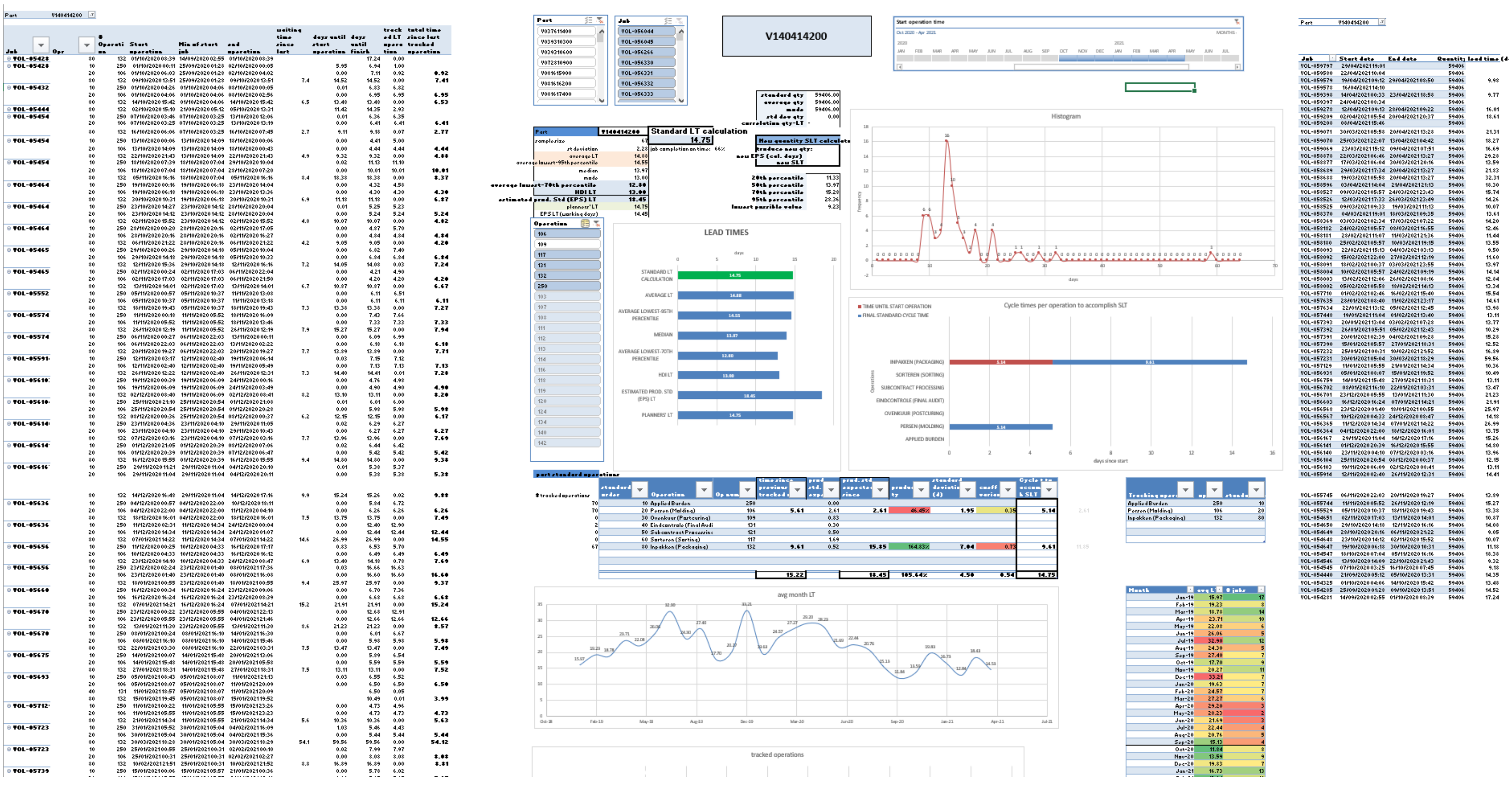


Figure 24. Parts lead times analysis dashboard. Example for V140414200

			#	Operation	Op nu	time since previous tracked (d	prod std. expected oper. t (d)	estimated prod std tracking group (d)	productivi	st dev	coeff of variance		
V450612400	381		10	Applied Burden	250		0.00					standard qty	9142.00
Std LT calc	16.86	42%	20	Pretreatment	140		0.00					average qty	8328.35
average LT	18.14		30	Persen (Molding)	106	1.51	0.87	0.87	57.51%	0.69	0.45	mode	8000.00
average lowest-95% pe	17.79		40	Ovenkuur (Postcuring)	109		0.83					std dev qty	1026.93
prod. std LT (calendar d	17.02		50	Ponsen (OD Punching)	107	1.38	1.19	2.02	147.11%	1.17	0.85	correlation qty-LT	-0.41
prod. std LT (working d	13.02		60	External Sorting	142	13.60	8.50	10.50	77.20%	3.11	0.23		
st deviation	3.52		70	Eindcontrole (Final Audit)	131		1.13						
			80	Inpakken (Packaging)	132	1.44	0.50	1.63	113.33%	1.67	1.16		
V115016500	207		10	Applied Burden	250		0.00					standard qty	5760.00
Std LT calc	2.28	54.59%	20	Assemblage (Assembling)	114	1.94	1.07	1.07	55.02%	1.14	0.59	average qty	6021.82
average LT	2.55		30	Controleren (Testing)	103		0.50					mode	5760.00
average lowest-95% pe	2.96		40	Eindcontrole (Final Audit)	131		0.50					std dev qty	1584.63
prod. std LT (calendar d	2.57		50	Inpakken (Packaging)	132	0.57	0.50	1.50	263.12%	1.00	1.75	correlation qty-LT	0.35
prod. std LT (working d	2.57		60										
st deviation	1.75		70										
V140414600	128		10	Applied Burden	250		0.00					standard qty	10000.00
Std LT calc	19.38	53.13%	20	Persen (Molding)	106	1.54	0.78	0.78	50.65%	0.79	0.51	average qty	10000.00
average LT	19.40		30	Ovenkuur (Postcuring)	109		2.33					mode	10000.00
average lowest-95% pe	19.00		40	Visuele Controle (Visual Insp)	119		0.26					std dev qty	0.00
prod. std LT (calendar d	22.60		50	Subcontract Processing	121		10.50					correlation qty-LT	-
prod. std LT (working d	16.60		60	Sorteren (Sorting)	117	17.12	1.21	18.30	106.90%	4.04	0.24		
st deviation	4.34		70	Eindcontrole (Final Audit)	131		1.01						
			80	Inpakken (Packaging)	132	0.68	0.50	1.52	223.14%	1.48	2.18		
V115014600	128		10	Applied Burden	250		0.00					standard qty	40000.00
Std LT calc	3.86	35.94%	20	Assemblage (Assembling)	114	3.97	2.31	2.31	58.33%	1.43	0.36	average qty	40000.00
average LT	4.45		30	Eindcontrole (Final Audit)	131		0.58					mode	40000.00
average lowest-95% pe	4.34		40	Inpakken (Packaging)	132	0.49	0.52	1.10	224.60%	0.90	1.84	std dev qty	0.00
prod. std LT (calendar d	3.41		50									correlation qty-LT	-
prod. std LT (working d	3.41		60										
st deviation	1.85		70										

Figure 25. Part operations performance and indicators overview file

A parts	calculated std LT	% jobs completed on time	prod std LT calendar day	5days HDI L	average until 70th percenti	average LT	average until 95th percentile	difference avg LT SLT	stdev	#jobs tracked	cell	category	birthgiver machine	expected LT birthgiver machin	productivity first machin	st deviation first mach	delay birth machine	big over	external proces	difference avg qty and std	st dev qty
V039310300	34.84	22.22%	27.74	34.75	42.02	42.02	43.79	7.18	8.06	9	C30	Poppets	Press 27	1.34	40.42%	1.86	1.98	1	1	-9681.82	5394.75
V194010500	20.07	28.21%	22.07	15.59	22.54	26.50	26.50	6.43	8.92	39	C50	Full Rubber	Press 09	1.60	36.54%	1.80	2.78	1	1	56410.26	8469.30
V470910300	21.53	32.00%	20.77	20.23	23.60	26.64	27.48	5.11	9.72	25	C50	Full Rubber	Press 08	1.06	40.88%	0.99	1.53	1	1	0.00	0.00
V450310700	17.12	30.77%	16.73	16.31	18.33	20.56	21.74	3.44	7.65	26	C30	Poppets	Press 23	0.68	44.21%	0.55	0.86	1	1	9629.63	14651.88
V039310600	19.11	23.33%	17.99	20.06	19.28	22.21	22.69	3.10	7.01	30	C30	Poppets	Press 18	1.54	55.67%	1.06	1.23	1	1	0.00	0.00
V115018300	14.76	38.89%	16.02	12.72	15.54	17.60	19.82	2.84	13.09	72	C70	Boy	Press 52	2.17	75.62%	0.93	0.70	0	0	-3143.36	788.66
V072810900	13.53	49.18%	15.67	11.71	13.21	15.34	16.63	1.80	7.65	61	C50	Full Rubber	Press 03	1.40	50.59%	1.23	1.37	1	0	0.00	0.00
V450612400	16.89	41.73%	17.02	17.20	16.44	18.18	17.85	1.29	3.52	381	C20	Star seal	Press 36	0.87	57.51%	0.69	0.64	0	1	-813.65	1026.93
V450310200	16.20	46.67%	17.60	15.32	15.68	17.39	17.34	1.19	4.25	60	C30	Poppets	Press 11	1.09	61.27%	0.79	0.69	0	1	281.69	2356.79
V115017700	4.90	35.00%	4.71	5.14	4.86	6.08	6.08	1.18	3.36	80	C30	Poppets	Press 28	1.98	72.37%	0.66	0.75	0	0	50.00	312.25
V115013300	8.92	34.62%	9.05	8.70	9.00	9.94	10.59	1.02	3.81	26	C30	Poppets	Press 13	1.71	41.96%	1.66	2.36	1	0	-1851.85	9442.63
V559810100	4.70	40.74%	4.59	4.04	5.48	5.51	8.00	0.81	3.05	27	C30	Inserted Seals	Press 18	0.91	57.25%	0.76	0.68	1	0	185.19	944.26
V295716700	2.31	31.25%	1.89	2.51	2.54	3.10	3.44	0.78	1.78	16	C80	Assembly	Assy 08 - Radine	0.38	41.56%	0.48	0.53	0	0	9265.63	5951.28
V559810300	6.37	32.50%	6.02	6.73	6.35	7.06	7.50	0.69	2.86	40	C30	Poppets	Press 25	1.34	69.13%	0.88	0.60	1	0	162.70	646.67
V115014600	3.90	35.94%	3.41	4.41	3.88	4.54	4.41	0.64	1.85	128	C80	Assembly	Assy 02 - Bosch 2	2.31	58.33%	1.43	1.65	0	0	0.00	0.00
V295711000	3.10	45.76%	2.96	3.13	3.19	3.71	4.15	0.61	2.01	59	C80	Assembly	Assy 04 - Gerald	0.50	45.36%	0.58	0.60	0	0	0.00	0.00
V081619100	16.66	52.38%	17.40	17.21	15.36	17.25	16.77	0.59	3.55	21	C70	Boy	Press 53	2.50	68.23%	1.54	1.16	0	1	-2300.55	3697.16
V176310600	5.02	30.00%	4.76	5.45	4.85	5.61	5.58	0.59	2.57	60	C10	Inserted Diaph	Press 47	1.08	46.56%	1.12	1.23	1	0	-132.64	1027.42
V115015900	2.49	44.12%	2.01	3.04	2.41	3.04	3.37	0.55	2.22	34	C80	Assembly	Assy 11 - DNOX6-	0.99	42.08%	1.17	1.37	0	0	0.00	0.00
V081616200	8.98	46.67%	9.54	9.07	8.34	9.49	9.46	0.51	2.66	30	C30	Poppets	Press 16	2.40	69.16%	1.25	1.07	1	0	-2322.58	9955.99
V455110800	2.69	58.62%	3.02	2.42	2.63	3.20	3.69	0.51	1.85	29	C50	Discs	Press 04	0.25	46.73%	0.34	0.28	0	0	0.00	0.00
V295715700	2.21	56.67%	2.13	2.58	1.93	2.70	2.83	0.49	1.65	30	C80	Assembly	Assy 09 - Schraul	1.11	55.68%	1.06	0.88	0	0	533.33	1995.55
V037611400	7.09	48.84%	8.35	6.47	6.46	7.49	7.79	0.40	4.06	43	C10	Inserted Diaph	Press 46	1.67	57.10%	1.29	1.25	1	0	-177.78	1434.32
V176810700	7.90	53.66%	8.23	8.27	7.19	8.29	8.13	0.39	2.32	41	C30	Poppets	Press 24	2.22	66.67%	1.21	1.11	1	0	-1341.46	4655.76
V609510200	2.01	53.33%	1.86	2.41	1.77	2.41	2.41	0.39	1.61	15	C80	Assembly	Assy 14 - Fluid o	0.83	59.40%	0.95	0.57	0	0	0.00	0.00
V081617600	5.90	48.15%	6.54	5.65	5.52	6.29	7.22	0.39	4.72	27	C30	Poppets	Press 16	1.74	57.51%	1.37	1.29	1	0	0.00	0.00
V115015500	1.73	51.43%	1.60	1.86	1.72	2.08	2.62	0.35	1.74	35	C80	Assembly	Assy 15 - Bosch 3	0.58	42.93%	0.75	0.77	0	0	11173.97	10046.96
V164711100	5.88	44.44%	6.56	5.56	5.52	6.19	6.84	0.31	3.45	45	C10	Inserted Diaph	Press 19	1.58	56.89%	1.32	1.20	1	0	0.00	0.00
V194012600	2.80	54.39%	2.95	2.94	2.52	3.08	3.33	0.28	1.59	57	C50	Discs	Press 14	0.56	38.97%	0.57	0.87	0	0	0.00	0.00
V295716000	1.62	57.89%	1.84	1.68	1.35	1.90	2.03	0.27	1.40	38	C80	Assembly	Assy 08 - Radine	0.83	55.70%	0.87	0.66	0	0	828.95	2027.04
V115016500	2.41	54.59%	2.57	2.49	2.16	2.68	3.00	0.27	1.75	207	C80	Assembly	Assy 10 - DNOX 5	1.07	55.02%	1.14	0.87	0	0	261.82	1584.63
V450311300	4.20	44.83%	4.60	4.15	3.85	4.43	4.70	0.23	3.11	29	C30	Poppets	Press 11	1.10	63.85%	0.77	0.62	0	0	0.00	0.00
V560610100	2.71	60.00%	3.18	2.58	2.38	2.92	3.02	0.20	1.51	30	C50	Discs	Press 14	0.33	43.23%	0.40	0.43	0	0	0.00	0.00
V140414600	19.47	53.13%	22.60	18.39	17.40	19.62	19.23	0.16	4.34	128	C40	Inserted Seals	Press 12	0.78	50.65%	0.79	0.76	1	1	0.00	0.00
V115013800	5.49	51.79%	6.03	5.42	5.03	5.65	5.54	0.15	2.59	56	C30	Poppets	Press 35	2.78	72.56%	1.08	1.05	0	0	-2631.58	14573.02
V140414200	14.75	65.67%	18.45	13.00	12.80	14.88	14.55	0.13	7.11	67	C40	Inserted Seals	Press 06	2.61	46.45%	1.95	3.00	0	1	0.00	0.00
V115016300	7.02	54.00%	8.23	6.60	6.23	7.12	6.97	0.10	2.40	50	C30	Poppets	Press 33	2.45	60.28%	1.42	1.62	0	0	0.00	0.00
V295715300	2.03	56.25%	2.13	2.10	1.86	2.10	2.38	0.07	1.56	16	C80	Assembly	Assy 09 - Schraul	1.11	53.27%	1.17	0.97	0	0	0.00	0.00
V295716500	2.00	41.18%	1.42	2.06	2.53	2.06	3.70	0.05	2.31	17	C80	Assembly	Assy 09 - Schraul	0.42	39.47%	0.48	0.64	0	0	9722.22	6547.31
V081615900	12.58	45.16%	13.16	13.36	11.22	12.61	12.32	0.03	3.06	31	C30	Poppets	Press 17	1.59	73.32%	1.08	0.58	1	1	-1687.50	6578.55
V081617400	23.97	46.67%	24.65	26.26	21.01	22.84	23.85	0.00	7.73	30	C30	Poppets	Press 17	1.08	56.67%	0.81	0.83	1	1	0.00	0.00
V455110900	8.28	62.86%	10.62	7.14	7.08	7.79	8.55	0.00	3.60	35	C50	Discs	Press 04	1.04	47.78%	1.12	1.14	1	0	-914.29	5331.16
V450310500	5.92	52.54%	6.78	5.64	5.35	5.87	6.23	0.00	2.45	59	C30	Poppets	Press 26	0.63	40.64%	0.71	0.91	1	0	-122.95	952.37
V115016600	6.90	61.22%	8.23	6.41	6.04	6.80	6.54	0.00	1.91	49	C30	Poppets	Press 34	2.45	59.52%	1.78	1.67	0	0	0.00	0.00
V140417300	3.18	57.41%	3.84	2.92	2.78	3.12	3.76	0.00	1.79	54	C50	Discs	Press 15	1.44	84.77%	1.41	0.26	0	0	0.00	0.00
V494610100	2.72	65.38%	3.27	2.68	2.21	2.54	3.11	0.00	1.34	26	C50	Discs	Press 14	0.74	54.31%	0.58	0.62	0	0	-50000.00	0.00

Figure 26. A parts performance summary table

5.2 Evaluation: Bottlenecks and problem-causing operations

In this section a gap analysis is performed between the estimated and expected times, and the reality, in order to find the major production issues. After every parts is analyzed particularly in the dashboard and compared to each other in the performance list file created (*Section 5.1*), it is possible to conclude which are the general bottlenecks, which cause the delays, inefficiencies, or deviations, leading to a lower rate of completion of the SLT, and lower control over production. These can’t be proven with certainty, as the tracking is not done precisely for each operations, but tracked by groups, as explained in earlier *Section 4.1.5*. The main found bottlenecks are the birth-giver operations (assemblage, molding and punching), postcuring, OD/ID punching and external sorting.

Birth-giver operations

Molding, assembly and punching, are set as the 'starting date' of jobs' production. These operations, start giving shape to the end product. As this operation is the first, and is not highly influenced by other production factors, it is the one planners use for planning the weekly production and the jobs release, as explained in *Section 2.4*. As this is the only planned operation and calculated from the first transaction to the end, there are no previous to start waiting times, and therefore, when estimating the EPS LT, it is not added any NVA time estimation or 'buffer'. The working time is very efficient in these operations, and operators reach a 90-100% on productivity compared to the standard, especially in assembly, where the work is done by automated machines. However, the graph shows poor results on total productivity of the operations. This is caused because of scheduled shifts. If these operations would be working without stopping, they would reach a high rate of productivity, however, this is interrupted by gaps on operator shifts scheduled to work on the job, while the job is still not finished, which reduces the performance dramatically, with an average of 53.38% (*Figure 27, Figure 28* and *Figure 29*). For example, the assembly part V295715700 (*Figure 29*), assembled in the fully automated machine Schraubstutz, should take (after the production standards, which as in this case it is an automated machine should be achieved) 1.11 days, so, almost four shifts; while the tracked average is of two days, two more shifts.

Planners, when planning the distribution of shifts, are constrained by the operators capacity, availability and the skills of each one. In most cases it is not possible, with the available operators, to plan shifts for a job from start to end, using all the available capacity to increase the utilization, and at the same time not delaying excessively other jobs. In some occasions, planners decide that it is better to plan molding for a part of the job, even if the rest is completed a few days later, because of the customers' pressure. Backlog makes that there is no stock, and customer orders are not fulfilled, then, in some cases, customers have an extreme high need of receiving the ordered parts, for not having to stop their production, and then, they are sent as soon as possible deliveries, even if it is not from the full job/order size, for satisfying their priority needed quantity.

Splitting the molding production in parts, instead of starting and finishing, without shift gaps, creates, that the initial operation, the only planned one, is already having high instability, with an average standard deviation of 1.04 days, which affects already the planning of the rest of production steps. Moreover, this creates from the start an average delay of 1.08 days, which can impact the final completion of the SLT.

A parts	cell	category	birthgiver machine	expected LT birthgiver machine	productivity first machine	st deviation first machine	delay birth machine
V039310300	C30	Poppets	Press 27	1.34	40.42%	1.86	1.98
V194010500	C50	Full Rubber	Press 09	1.60	36.54%	1.80	2.78
V470910300	C50	Full Rubber	Press 08	1.06	40.88%	0.99	1.53
V450310700	C30	Poppets	Press 23	0.68	44.21%	0.55	0.86
V039310600	C30	Poppets	Press 18	1.54	55.67%	1.06	1.23
V115018300	C70	Boy	Press 52	2.17	75.62%	0.93	0.70
V072810900	C50	Full Rubber	Press 03	1.40	50.59%	1.23	1.37
V450612400	C20	Star seal	Press 36	0.87	57.51%	0.69	0.64
V450310200	C30	Poppets	Press 11	1.09	61.27%	0.79	0.69
V115017700	C30	Poppets	Press 28	1.98	72.37%	0.66	0.75
V115013300	C30	Poppets	Press 13	1.71	41.96%	1.66	2.36
V559810100	C30	Inserted Seals	Press 18	0.91	57.25%	0.76	0.68
V559810300	C30	Poppets	Press 25	1.34	69.13%	0.88	0.60
V081619100	C70	Boy	Press 53	2.50	68.23%	1.54	1.16
V176310600	C10	Inserted Diaphragm	Press 47	1.08	46.56%	1.12	1.23
V081616200	C30	Poppets	Press 16	2.40	69.16%	1.25	1.07
V037611400	C10	Inserted Diaphragm	Press 46	1.67	57.10%	1.29	1.25
V176810700	C30	Poppets	Press 24	2.22	66.67%	1.21	1.11
V081617600	C30	Poppets	Press 16	1.74	57.51%	1.37	1.29
V164711100	C10	Inserted Diaphragm	Press 19	1.58	56.89%	1.32	1.20
V450311300	C30	Poppets	Press 11	1.10	63.85%	0.77	0.62
V140414600	C40	Inserted Seals	Press 12	0.78	50.65%	0.79	0.76
V115013800	C30	Poppets	Press 35	2.78	72.56%	1.08	1.05
V140414200	C40	Inserted Seals	Press 06	2.61	46.45%	1.95	3.00
V115016300	C30	Poppets	Press 33	2.45	60.28%	1.42	1.62
V081615900	C30	Poppets	Press 17	1.59	73.32%	1.08	0.58
V081617400	C30	Poppets	Press 17	1.08	56.67%	0.81	0.83
V455110900	C50	Discs	Press 04	1.04	47.78%	1.12	1.14
V450310500	C30	Poppets	Press 26	0.63	40.64%	0.71	0.91
V115016600	C30	Poppets	Press 34	2.45	59.52%	1.78	1.67

Figure 27. Molding performance

A parts	cell	category	birthgiver machine	expected LT birthgiver machine	productivity first machine	st deviation first machine	delay birth machine
V455110800	C50	Discs	Punch 1	0.25	46.73%	0.34	0.28
V194012600	C50	Discs	Punch 13	0.56	38.97%	0.57	0.87
V560610100	C50	Discs	Punch 1	0.33	43.23%	0.40	0.43
V140417300	C50	Discs	Punch 6	0.44	26.08%	1.41	1.26
V494610100	C50	Discs	Punch 13	0.74	54.31%	0.58	0.62

Figure 28. Punching performance

A parts	birthgiver machine	expected LT birthgiver machine	productivity first machine	st deviation first machine	delay birth machine
V295716500	Assy 09 - Schraubstutz	0.42	39.47%	0.48	0.64
V295716700	Assy 08 - Radine 2	0.38	41.56%	0.48	0.53
V115015900	Assy 11 - DNOX6-poppet assen	0.99	42.08%	1.17	1.37
V115015500	Assy 15 - Bosch 3	0.58	42.93%	0.75	0.77
V295711000	Assy 04 - Geraldo	0.50	45.36%	0.58	0.60
V295715300	Assy 09 - Schraubstutz	1.11	53.27%	1.17	0.97
V115016500	Assy 10 - DNOX 5.2	1.07	55.02%	1.14	0.87
V295715700	Assy 09 - Schraubstutz	1.11	55.68%	1.06	0.88
V295716000	Assy 08 - Radine 2	0.83	55.70%	0.87	0.66
V115014600	Assy 02 - Bosch 2	2.31	58.33%	1.43	1.65
V609510200	Assy 14 - Fluid oTech	0.83	59.40%	0.95	0.57

Figure 29. Assembly performance

Postcuring

As explained in *Section 4.2.1*, postcuring operations are divided in two categories depending on their treatment location, big ovens and small ovens. When estimating the lead time based on production standards, postcuring operations from big oven, were given a waiting time buffer of two days, while small ones are given an estimate of just half a day. Small ovens are placed in the parts' corresponding cells, and just used by one or a few number of different parts, while big ovens are five ovens placed in a separate room, shared by a high range of parts, with many different treatments, which can't be mixed in the same processing. This variety and quantity of parts and treatments, makes that jobs start to queue in front of the oven, and wait an estimated average of two days. This waste and non-value added time is not the only problem, but it is also accompanied by high variation on the output time. The high deviation on the process, creates already, since the second operation of these processes, high uncertainty on the final lead time, and unpredictability in the next operations. This bottleneck can't be proved with full certainty because it is not tracked by itself, so for estimating its performance it has to be analyzed in tracking groups, together with other operations. *Figure 30* shows the tracked performance of big oven parts. Parts that share the tracking group with any external process are not included, as external processes already create a lot of fluctuation by themselves and then the result is not reliable to take conclusions for the postcuring process. The figure screens the standard deviation per tracking group, which can be associated to the average tracked, and the performance of it compared to the estimated time, the operations which postcuring shares the tracking with, and the treatment type. These deviations are extremely high, 2.77 days on average for the listed parts, for a process that doesn't depend on operator's performance, which is just putting the parts in the oven. Most of the listed, share the tracking group with final audit and packaging. Packaging is relatively constant, but final audit can be also impacted, taking longer and being more irregular than it would be if the oven would not create that uncertainty. Final audit needs for some jobs specially skilled workers in order to make the quality control, which can't be planned in the workstation if it is unknown when the job will arrive. So, when a skilled operator is needed, he may be busy in another operation and take longer than normal to go to the operation and complete it, creating a queue of jobs to be completed, and then, even more fluctuations are produced.

The performance indicators for the tracking group (*Figure 30*) are high in most of cases, but the reason of this is because the estimated lead time is already taking into account and estimating very high waiting times. Estimated waiting times (NVA) constitute on average 84.77% of the total estimated time for the tracking groups listed.

big ovens	standard deviation	average time tracking group	performance	tracking group	oven treatment
V176310600	2.22	3.26	112.94%	oven, final autit, packaging	O12
V450310500	1.87	**2.32**	127.71%	oven, automated sorting by barry	O16
V037611400	3.94	5.04	92.98%	oven, testing, final audit, packaging	O19
V164711100	2.81	**3.54**	112.53%	oven, final audit, packaging	O17
V176810700	2.07	**4.81**	83.27%	oven, final audit, packaging	O27
V559810300	2.91	**5.70**	64.67%	oven, final audit, packaging	O09
V081616200	2.40	**5.88**	121.46%	oven, coating, final audit, packaging	O27
V559810100	3.15	**4.42**	83.39%	oven, final audit, packaging	O09
V115013300	2.91	**6.20**	118.43%	oven, sorting, final audit, packaging	O16
V081617600	3.44	**3.49**	107.45%	oven, final audit, packaging	O34

Figure 30. Big ovens tracked performance

External sorting

External processes, both 'external sorting' and 'subcontract processing', create uncertainty because, as they don't depend merely on Vernay, there is a lack of control and visibility on the process. External sorting is estimated to take around 10 calendar days, including transport, and 'subcontract processing' between one and two weeks, depending on the part, as each one goes to a different supplier (*Table 7*). There are five parts going for 'subcontract processing' to Germany and eight going for 'external sorting' to Poland. There are some transactions in the system for external sorting, tracked in Poland, which were unknown by Vernay the exact meaning of these transactions, what they represented, and then, by comparing them to some existing reports sent by the subcontractor companies, the last existing transactions were used as an estimate for the shipping subcontractor-VOL date, as a reference, even if this is not completely reliable (explained more in depth in *Appendix D*). SGP and ESP, the two external sorting subcontractors, started sending reports to Vernay since this year, including for each job treated: arrival to subcontractor, start working date, end of working on the job date and shipping to VOL date. Taking into account that 'external sorting' has available transactions and reports, while 'subcontract processing' has no records at all, and the distance, complexity and time variability of work is larger for 'external sorting', the bottleneck analysis will focus on this, as there are no sufficient resources and to investigate the other operation. SGP reports were analyzed from October 2020 to May 2021, and the Exact Systems (ESP) ones from January to May 2021, as there are not previous records in the report. From these, the time since arrival to shipping back to VOL was calculated and indicators were calculated for analysis, visible in *Table 9.* It can be seen that there is a notorious difference between the performance of both subcontractors. SGP takes on average 4.86 days with an average standard deviation for the four treated parts of 2.52 days, while ESP other four parts take on average 8.33 days with 5.48 days of standard deviation. SGP takes a similar time for every part, while ESP has large difference between products.

Time considered for the 'external sorting' operation is not only the time the parts take at the subcontractor, but the transport, and the logistics time taken to send this goods also play a role in the process. Therefore, the time taken since the job is completed in the previous operation, until it arrives to the subcontractor (waiting time plus transport time), is calculated for V450612400 and V194010500, which are the only parts having a tracked operation before the subcontracting operation. *Table 7* includes, in the fifth column, the average since the last transaction of the previous operation, OD punching for both cases, until the registered arrival date of the report, for the tracked jobs. The results, 4.13 days on average, calls out, as it is almost as high as the operation itself, and still has to be added the shipping time to come back, estimated in 1.5 days. This makes a final time for the operation of twelve days (70.41% of the SLT, 16.89 days) for V450612400 and nine days for V194010500 (44.76% of the SLT, 20.07 days).

One of the reasons of the variability of work performed at the subcontractors is because they don't know when the jobs are going to arrive to their company to be sorted, they know about the incoming job once they receive them in their plant, there is no communication or planning, so they can't plan the workers in advance to perform the work. If small batches arrive they can accomplish the work in the estimated time, otherwise, if the quantity of pieces is large, they need extra time to get workers and to finish all the quantity and send it back to VOL.

A parts ext sorting	average	standard deviati	jobs quantity	avg. time since end previous operation until arrival subcontractor	Subcontractor company
V194010500	3.73	2.86	11	3.76	ESP
V450310200	7.30	4.44	46	-	ESP
V450310700	10.67	3.68	3	-	ESP
V470910300	11.63	10.95	8	-	ESP
V039310600	4.75	1.95	16	-	SGP
V081617400	4.56	3.60	25	-	SGP
V081619100	4.23	1.99	39	-	SGP
V450612400	5.89	2.52	439	4.50	SGP

Table 9. External sorting reports calculated indicators

Punching (OD and ID/slitting)

As already described in *Section 2.3*, there are three types of punching operations: normal punching as birth-giver operation of discs, outside diameter (OD) punching, and slitting plus inside diameter (ID) punching.

Normal punching's performance is already commented in this section, as a birth-giver operation, however, the bigger problem lies in the other two types. The punching resource group, located in cell 50 (full rubber cell), gives always priority to normal punching over OD and ID, which makes that these two start to queue until there is no more punching work to perform, and then operators start treating these jobs. This priority rule create impressively high fluctuations on output time, as jobs can sometimes be done fast if there are no waiting jobs already or no initial punching to perform, but other times jobs can reach a very large number of days waiting to be processed. There are five A parts performing these operations (only one of them doing slitting/ID punching), but the star seal V450612400 is excluded from the analysis as it is processed differently than the others, in an automated machine in Cell 20 dedicated only for it, so the performance is good and not comparable to the rest of OD/ID punching operations. *Table 10* summarizes the registered performance of the tracking group which the parts are tracked with, and *Figure 31* graphs the fluctuations.

The full rubber part V072810900, which is the only one having the slitting/ID punching operation, is the one with more fluctuations. This is because the operation is more complex than the others. It is constituted by two processes: slitting is done first, and then the inside diameter punching. Before, this used to be done by completing a few pieces in slitting, then in punching, and later slitting again with the next pieces. Now, ID punching only starts when the whole batch is completed with slitting, then, it can be that in between these processes more waiting time is added, when shifts change. Moreover, if more than four hours pass since dipping (the previous operation) is done, the materials need to go back to this step again, due to the physical properties needed for performing the operation; and therefore, more time in between is added, as dipping can sometimes take until one day to give the batch back if the operation is busy with many other jobs.

Also, another factor that reduces the performance in slitting/ID punching is the tracking system. Normally, operators register the quantity completed and the time taken for it, which motivates them to work faster. However, as this operation is divided in two processes, operators after completing slitting are registering the worked quantity as zero in the VPI, as then the quantity is registered properly after the next operator completes the ID punching step. This creates that operator's performance in slitting is recognized as the same in the system, no matter how efficient he was.

Looking at V470910300's graph in *Figure 31*, it can be seen that many jobs complete the tracking group, coating and OD punching, in less than one day. However, others are done in four, or even in one case, twenty-one days, which means that a job has been waiting almost three weeks in the punching sub-cell without being processed. This kind of deviations from the normal, and standard, are the ones causing the WIP to increase massively, and to have that many fluctuations on total lead times. And the same happens with the other two, V194010500 and V455110900, which could be completed in respectively three and one days, in most of cases, but then, due to the high peaks, the average is finally of 5.32 and 4.03, which makes the total lead time for the job unpredictable.

Punching part	punching type	tracked average group	estimated time in punching	estimated time tracking group	performance	standard deviation	tracking group operations
V072810900	Slitten (ID Punching/Slitting)	**10.05**	4.79	**9.59**	95.47%	7.16	oven, dipping, ID punching/slitting
V194010500	Ponsen (OD Punching)	**5.32**	2.00	**4.25**	79.82%	3.50	oven, OD punching
V455110900	Ponsen (OD Punching)	**4.03**	1.30	**4.65**	115.37%	3.61	coating, oven, OD punching
V470910300	Ponsen (OD Punching)	**3.04**	1.33	**2.34**	77.10%	2.56	coating, OD punching

Table 10. Punching parts, tracking group performance

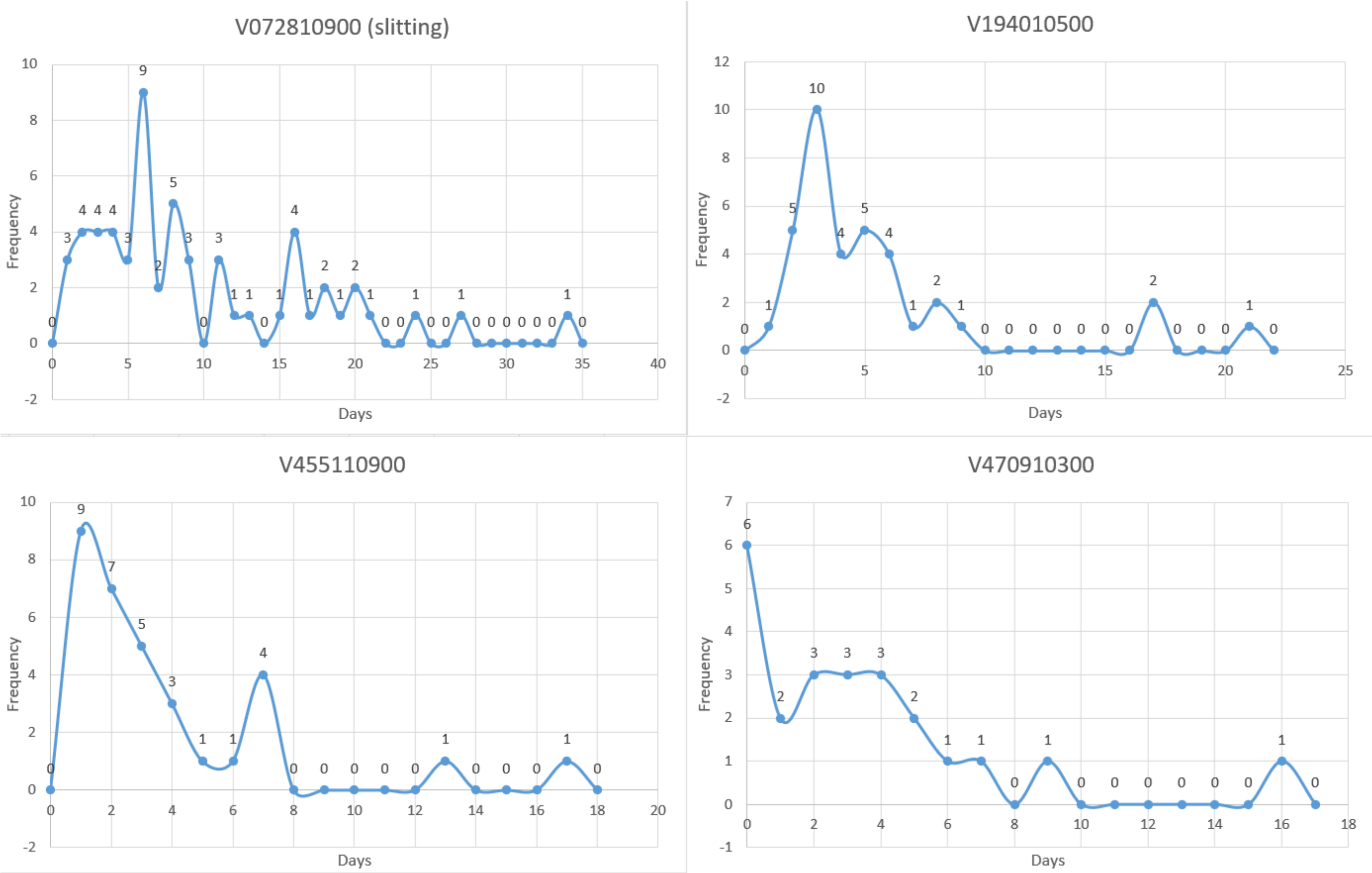


Figure 31. Punching parts variability of tracking group, graph

6 Conclusions and recommendations

This last chapter of the report is intended to answer the subsequent knowledge question:

What are the recommendations and solutions that can be given to Vernay Oldenzaal to optimize the production from conducting the thesis research at the company?

In order to answer this question, first, conclusions on the research are made in *subchapter 6.1*, then, recommendations and future research is treated together in *Section 6.2* and then, to end up, the theoretical and practical contributions of the research are commented in *Section 6.3*

6.1 Conclusions

The research was intended to tackle the core problem: *'What is the standard production lead time for Vernay's products?'* in order to treat the action problems; and thus, the research question was set: *'What are the standard* *lead times of Vernay's products, and how can production stabilize and decrease the lead times in order to achieve the standard?'*

The production standard lead time for each part was obtained in *Section 4.3*, by an statistical analysis on the historical tracked jobs performed in the previous year, and by calculating an estimated production standards (EPS) lead time based on value adding activities and an estimation of the non-value adding times of the manufacturing plant. From the internal manufacturing plant activities, value-adding (VA) time, only represented 39% of the total time, which means that it is estimated a 61% of waste (NVA) in production (*Section 4.2*). The SLT, based on demonstrated, repeatable and doable performances, and on the central tendency or records, has an average completion rate over the tracked jobs of 46.57%, which prove the viability of setting this times as target, reducing the waste from high variability, and then reducing the WIP.

In order to implement this statistical analysis, calculations and results, and make it useful for the company, a BI dashboard on Excel was designed (*Section 5.1*), for the visualization of these. This tool allows any worker, mainly planners, logistics workers and production managers, to consult the dashboard, which will ease the decision-making process, and will save a lot of time, due to the efficient representation of data. This instrument improves the production transparency of A products lead times and flow over the different operations in their processes, and performance indicators in the dashboard can be evaluated in order to take action and optimize production.

The calculated SLT will allow to change the production system from push to pull, by giving priorities in operations based on the set due date and estimated cycle times per operations, in order to achieve on time the SLT, by making the whole process more stable and predictable, as lean management states. (*Ohno, T.,1988*)

Section 5.2 addresses the major bottlenecks and operations creating the main problems on production, which keeps it from having stable lead times, and decrease the efficiency: birth-giver operations, postcuring, external sorting and punching (slitting/ID and OD).

Birth-giver operations (molding, assembly and punching) due to gaps in shifts, and not performing the job fully from start to end, due to the manning capacity restrictions and decisions that have to be taken by planners, have an average productivity of 53.38% (*Figure 27, Figure 28, Figure 29*) in comparison to the production standard expected time. This causes on average a delay of 1.08 days since the first operation, which difficult the completion of the SLT. Moreover, even if it is the only planned operation, this already counts with an average of 1.04 days of standard deviation, causing since the first moment of production instability in the flow.

Postcuring is divided in big central ovens and small cell ovens. The last ones perform properly, as they are only used for a few different parts, but general ovens have a high queuing time waiting for treatment estimated in two days. The parts which were having more precise 'tracking groups' were analyzed, and were found to have an average of 84.77% NVA time for the total tracking group time, and an average standard deviation of 2.77 days (*Figure 30*). This operation, being the second one for most of molding parts, create notorious deviations and waste when being treated in the general ovens, and create uncertainty in all the remaining operations, especially 'final audit', which in repeated occasions takes place after 'postcuring', and can't plan skilled workers and shifts to perform the work due to this ambiguity in postcuring output time.

Punching has a priority rule that prioritizes normal punching (as birth-giver) jobs over slitting/ID punching and OD punching operations, which make that these have very high and unstable queueing times, that create high uncertainty on the finishing time, leading to an average standard deviation of 4.21 days for the tracking groups of parts having these operations, and avoid to plan transport for external sorting and other operations in advance. Moreover, slitting has an inefficient VPI tracking system that could be a source of unproductivity of operators in the slitting part of the process, in addition to 'dipping', that has to be done again if the job took more than four hours to be processed, adding more time to the operation.

As tracking for this External sorting is very poor, the reports from subcontractor companies (ESP and SGP) were analyzed. It is found a notorious difference between both companies: SGP takes on average 4.86 days with an average standard deviation for the four treated parts of 2.52 days, while ESP other four parts take on average 8.33 days with 5.48 days of standard deviation. Moreover, to this measured time from reports, transport and NVA time since the previous operation is completed until the goods are sent are calculated for two parts, obtaining an average of 3.75 and 4.50 days for each of them since the previous operation is completed until the subcontractor in Poland receives it. To this, shipment back (Poland – VOL) has to be added, estimated in 1.5 days which leads to high total time of the external sorting operation, but the most preoccupying is the fluctuations on time and uncertainty this creates because of the lack of control and communication.

These four bottlenecks possible solutions are treated in the recommendation section (*6.2*) next.

By performing this research, it has been shown and proven to the company the lack of transparency and the deficient tracking system, which makes the data-gathering and performance analysis very difficult and time consuming, at the same time as it decreases the precision of the conclusions and findings, as operations have to be tracked in 'tracking groups', since not every operation is tracked. As explained in *Section 1.2.3*, the company is starting to work on the digital traveler project, related to this, which is assessed in the recommendations (*Section 6.2.1*).

6.2 Recommendations and future research

This section discusses the recommendations for the digital traveler project, SLT and dashboard usage, and the possible solutions to the bottlenecks previously explained and quantified in *Section 5.2*. Likewise, the unit also includes the future research that the company has to continue performing in order to solve these issues, as, due to the length of the internship, it is not possible to treat all this solutions for the bottlenecks in depth, and the digital traveler is still an ongoing project.

6.2.1 Digital traveler

This is a new project, starting in the Griffin (USA) and Asti (Italy) plants of Vernay, for the digitalization of the job traveler (addressed in *Section 2.1*) by including QR codes. The main objectives of this project, and the improvements compared to the actual job traveler are:

- Provide traceability between parts, materials, operators and resources
- Enforce the order of operations rules are followed by operators, leading to a decrease in errors
- Ensure every operation is completed
- Ensure every traveler created is completed
- Collect more accurate and live process data, implementing the visualization in the ERP system

I was able to take part in a couple of meetings of this project during my internship, but this is still far to be implemented in the manufacturing plant at VOL.

By doing this research and visualizing all the impediments the actual tracking system suppose, it is seen all the improvements a good production tracking could generate. This would be an step to approach the industry 4.0, from which Vernay is still far, as the ERP and tracking system are outdated. By performing the investigation I realized which is the data VOL needs to collect from production in order to make this digital traveler shift effort fully worthy. Therefore, the steps to track from the production flow, in order to retrieve valuable data are listed below.

Steps to track from the production flow:

- When traveler (part of the full job) is started to be processed in the operation
- When operator is finished with this traveler processing
- When traveler arrives to the next operation
- When traveler starts to be processed in this next operation
- …
- When traveler is completed with the last operation (packaging)

All these steps need to be registered in the VPI (IPad) by scanning the QR code, and then, operation, quantity, time and traveler number will be registered every time.

Short operations, that are done next to the previous resource, as 'visual inspection', can skip the 'traveler arrives to operation' and 'traveler starts to be processed', as it is assumed that the operation starts straight after the previous operation (molding for example) is completed, and there is not a high NVA time in between, but the time until completion is still needed to be tracked.

For external processes, the tracking should include the following:

- Traveler arrives to logistics
- Traveler is shipped
- Traveler arrives to the subcontractor company
- Traveler starts to be processed
- Traveler finishes being processed
- Traveler is shipped back to VOL
- Traveler arrives to VOL

There are many steps to track in the process, so the VPI system should be efficient so the operator doesn't take long every time he has to register a traveler step. Moreover, at the moment there are 23 IPads available in the plant, as not that many steps are tracked, but do to this increase, the organization should consider an investment in more devices so there is always a device available near every operation, and the process is done more efficient. But this is part of the future research.

Anyways, before being able to implement the system, VOL has to fill all the production data in the system and standardize procedures, as resources needed for every operation, operators level needed, location of the operation… which is not filled properly yet in Epicor (ERP), especially for quality operations, that are completely untransparent, and the location (QC room or cell) is uncertain.

All in all, digitalization and big data collection, and analysis, for controlling and taking actions on performance evaluation, is the way for Vernay to become more efficient and optimize their production flow, approaching industry 4.0, and then, this project and the proper implementation of it is essential and key for Vernay's future.

6.2.2 Birth-giver operations

As possible recommendations for solving, or reducing the effect caused by the previously commented in *Section 5.2* birth-giver operation bottleneck, I propose the following:

- Avoid as much as possible to leave gaps in between shifts for a job. This in most cases can' t be possible given the available operators, then, it is recommended to discuss with the production managers the hiring of more operators, and train them to have the sufficient skills to perform the operation in the machines where more flexibility in shifts is needed. By increasing the flexibility of operators, this will allow to have a more constant number of operators available in the shifts among the week. At the moment, there are some cells in which operators available sometimes fluctuate, for example, from eleven to seven in two constant shifts, which makes that there are four of the previous eleven worked jobs that have to stop their production in between, for later continuing with the task in the next shift, which is totally inefficient. This is an issue that has to be tackled by Vernay, and part of the future research.
- As the previous recommendation may not be possible, due to a lack of operators offer, time taken to train operators to be fully efficient with their work, and possible cost constraints; there is another possible way to decrease the impact of the problem. As planners already know, before the starting of the production week, which are expected to be those gaps in shifts, for each job, they can add to the final due date given by the SLT, the time gap created by non-operating shifts. For example, in the case that since the start of molding, until the planned end, there are three shifts gaps in between, then, the planners can add one day to the estimated due date, so the expected delay created by this operation is already taken into account, and the delay possibility on the final lead time is decreased.

6.2.3 Postcuring: Oven scheduling

In order to improve the efficiency of the postcuring operation, and reduce its fluctuations and the uncertainty this process creates in the rest of the production processes, an oven scheduling conceptual system was designed.

This system is intended to be implemented with the use of the digital traveler real time data, in the VPIs. The system would consist on the following summarized steps taking place in the general ovens room (graphed more precisely in *Figure 33,* bigger in *Appendix G Figure 53*):

1- Traveler arrives to the ovens room.
2- Digital traveler QR code is scanned in the VPI.
3- The VPI returns (based on the oven treatment type) the quantity of the traveler, the job quantity waiting for treatment and the remaining job quantity to arrive and its expected arrival time (conceptual calculation in *Appendix G, Figure 52*), among others; whether it is scheduled an 'appointment' for the oven, if it was already planned, or not, and has to wait. Scheduling rule is graphed in a conceptual map in *Figure 33.*
4- Details for the scheduled appointment are given by the VPI, as oven, oven car in which traveler has to be placed, hour, quantity already scheduled, etc.
5- Next operations are notified of this scheduled oven appointment for a certain job quantity, so they can plan the operators for its future arrival.
6- The traveler waits until the scheduled appointment, or until an appointment is given to it by the system (taking into account availability of oven, arriving travelers and waiting time).
7- Ten minutes before the appointment, the VPI notifies the operators of the appointment, so he remembers and places the car in the oven on time. Parts in the car are checked with the scanner before being introduced so there are no errors.

The system's pros and cons are commented next.

Pros:

- Optimizes the postcuring operation efficiency.
- Reduces the fluctuations on the process.
- Makes the output more predictable.
- The operation doesn't depend anymore on the operators planning skills and decisions.
- There is a better communication between operations, as next operations are notified of when the job is arriving to their station, then uncertainty is reduced, can plan workers, and increase their efficiency.

Cons:

- It is complex to implement.
- Operators need to be taught.
- If operator doesn't enter on time a car, it can create a collapse in all the next scheduled oven appointments.
- It is very optimistic taking into account the low level of digitalization of the plant, that digital traveler is still not implemented and its future performance is unknown.

If this system is not decided to be implemented there can be other two solutions that may not be as efficient as this one, but may be more simple. It could be considered to reduce the use of big ovens, and purchase more small ovens, which have shown that their performance is better. Also, another basic priority rule can be implemented instead of the actual one, which is not efficient at all. Right now the operator is told not to introduce a car in the oven if it is not at least half full, and that if there is a job waiting for three days, to introduce it. However this doesn't seem to be done, as many time travelers stand more time waiting. All in all, this is part of the future research VOL has to perform on the oven, to decide how to improve this process, where my recommendations can be taken into account.

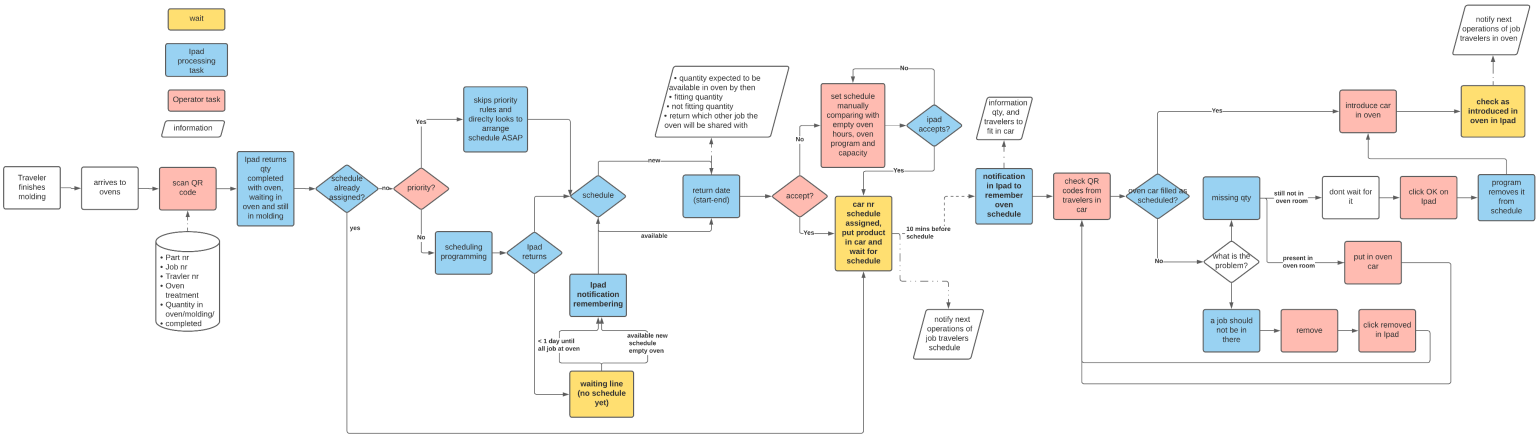


Figure 33. Oven scheduling process

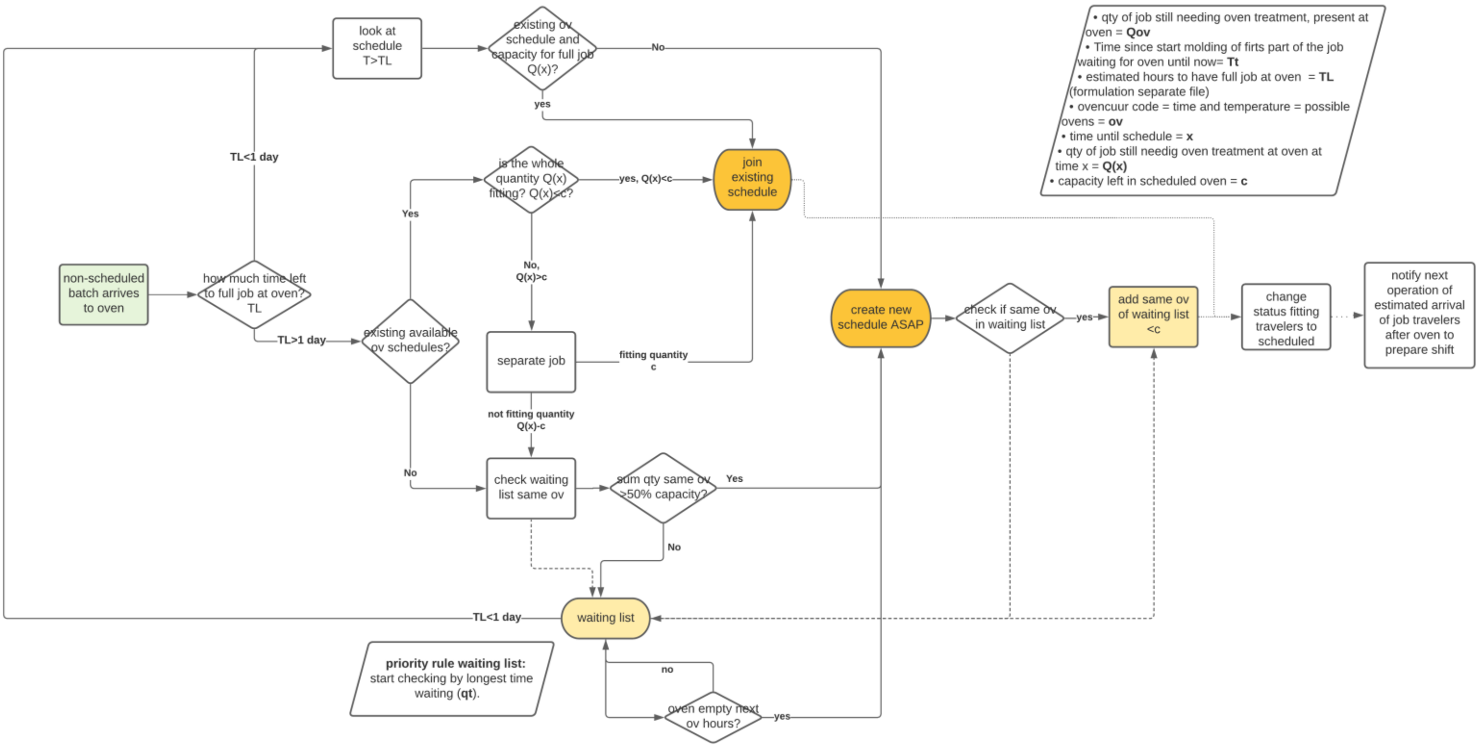


Figure 32. Oven scheduling rule conceptual map

6.2.4 External sorting

The given recommendation, and the key to solve this problem, shortening the total time and at the same time making more predictable and stable, is to improve the communication.

First, to have communication inside the plant, between operations and logistics, so they can plan in advance the transport to Poland. This is not simple to plan as logistics have to optimize the transport, they can't make a shipment for only one job, so there has to be an acceptable quantity to reduce the transport cost. Then, it is essential to know when are jobs going to arrive in advance, so the optimal shipment time can be set, and reduce the waiting time.

Secondly, communication between Vernay and the subcontractor company. If they know when they are going to receive jobs, they will be able to plan the resources needed for performing the work, and then, they will be more constant in output time.

Finally, the digital traveler, discussed in *Section 6.2.1*, will help to track the whole process better, and to take better decisions based on performance. My conclusions were made comparing reports and tracked times, which is not a very straightforward way, and very time consuming, to analyze this process. With the digital traveler, it will be possible to track when the job arrives to logistics, when the job is shipped, when it arrives to the subcontractor, when they send it back, and when it arrives, as mentioned in *6.2.1*. At the moment the shipping and receiving date is not tracked anywhere, and the process in between has a very poor transparency. The same case is for the 'subcontract processing' operation, which is even worse, as it doesn't even count with reports to analyze.

6.2.5 Punching (OD and ID/slitting)

The main recommendation for punching is to change the priority rule. The system has to be changed from push to pull. Right now, as already commented in *Section 5.2*, punching gives priority to the normal birth-giver punching, while forgets about the other types. This means that jobs are starting to be produced (push), while already opened jobs, are not getting finished. The standard lead time (SLT), set as target due date, should be used in order to pull the jobs in the operation depending on the time left for estimated completion. By having a pull system, the final completion date of the work will be more predictable, and then, the lead time more stable, by reducing peaks in waiting times. The problem is that the whole production is organized to push the jobs, by only controlling the birth-giving operations, while not caring about when those opened jobs are closed.

In addition, for slitting/ID punching type, there should be a direct connection between this and dipping, so that if materials need to be dipped again, because more than four hours passed, it is not needed to wait long. This could be done by reserving a dipping container just for jobs that are coming back from punching, not for the ones that haven't still been in dipping. This is part of the future research.

Besides, the operation's tracking should also be divided in two different ones, so that operators can track slitting and ID punching separately, by introducing the right quantity, and then increasing the control on performance.

6.2.6 Standard lead times and BI dashboard

My recommendation for the usage of the SLTs and the dashboard is divided in three steps.

First, the SLT should be set as a target when a job is released to production. The total lead time of the job is registered. And then, in the weekly meeting between planners and production shift leaders, instead of just discussing the performance of birth-giver operations; examine also the performance of A parts, with jobs finished that week, in terms of SLT completion. Then, it can be seen which are the parts that are achieving the set SLT, and the parts which aren't, so the reasons for these late completions can argued with the use of the dashboard as a reference for evaluation, and decisions for improvement can be taken.

Secondly, after some weeks analysing the SLT completion rate performances of A parts and decisions have been taken to make changes on the troublesome operations that were not allowing jobs to be on time, and reach a point where SLTs are completed by most of jobs. Afterwards, if some parts still can't reach the SLT, this can be adjusted. Then, the SLTs and the expected cycle times per 'tracking groups' to achieve this, can be included in the job traveller, so that priorities for operations processing can be based on the remaining time and operators can see if the job is going ahead of schedule or, by the contrary, behind, so the job is prioritized differently. This provokes a transition in the system, moving from push to pull, as jobs are processed in order to get to a stated due date. The pull system makes that lead times are more stable, since they are intended to be finished on a determined day, and in case there is a problem, this could be delayed slightly, but the fluctuations would be tremendously reduced.

Lastly, once the whole production system is using this method, achieving the SLT and stabilizing the LT of parts, the entire flow becomes more predictable. Then, the logistics department can use the SLT and the dashboard to know how long it is expected to take until each job arrives to their centre, so transport and the warehouse stock can be planned in advanced and optimized.

6.3 Contributions

Theoretical contribution

As discussed in *Chapter 3*, each manufacturing plant is a whole different world, and it can't be analyzed the exact same way. Many literature methods are analyzed, and insights were extracted for the standard lead time calculation, however, it is complex to find a tool that fits perfectly for the actual circumstances. Actual circumstances are: the high variety of parts to analyze and flowing through the plant, the uncommon and difficult to analyze mix between job-shop cellular manufacturing system, the bad and unprecise tracking of production, the lack of standards, the presence of external unstable processes, and the reduced internship research time of twelve weeks.

Therefore, a new methodology was designed for setting a standard production lead time for every A part (46), based on the two research scopes: lean manufacturing and statistics. Lean manufacturing value-stream mapping, is a flexible tool to any manufacturing system, not as specific as other methodologies, which allows to estimate a lead time based on summing processes composed by VA and NVA activities. Moreover, in order to adapt this estimated LT to the historical records tracked, this previously calculated value is combined with central tendency and density indicators derived from statistical methods and theories.

Then, this research technique for calculating the standard production lead time is unique and can contribute to the existing literature, as it can be used in any scenario, with any manufacturing system, and any level of transparency and tracking of production, for setting the standard lead time and optimizing production.

Practical contribution

The practical contribution of this research to Vernay Oldenzaal is the setting of the standard lead times for each of their A parts (visible in *Section 4.4*), as well as a BI dashboard, where they can be consulted next to other performance indicators and data, presented by mean of BI tools (*Section 5.1*). From the BI dashboard data, another file is created stating the summarized performance of parts, as well as a summary table which can be sorted for seeing the best/worst performers based on different indicators (*Section 5.1*). Moreover, bottlenecks are found and analyzed in *Section 5.2*, and recommendations are given as possible solutions for it in *Section 6.2*.

All these stated contributions to the company will be able to be used in many aspects: for planning and estimation of due dates for parts, for taking decisions on presented bottlenecks, and for assessing the production performance themselves by the use of the dashboard and other files. With this research I uncovered production problems the company was not aware of and opened discussions, leading to future actions, in order to progress and fix different issues.

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Appendices

Appendix A: Product examples per category

Poppets

- V450310700

Guiding non-return valve

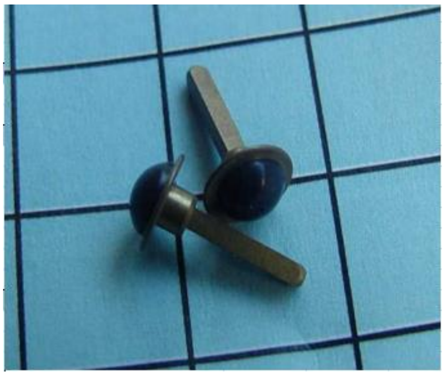
- V559810300

Component functions in an electromagnetically controlled pneumatic valve used in air suspension systems for passenger cars. Depending on load and driving conditions, this system can automatically adjust damping and spring characteristics. Part functions in conjunction with the V559810100.

- V115013300

Poppet in fuel pump. Part allows the fuel system to flow from the tank until the motor does not run empty when the pump (motor) is turned off.

A spring presses the doll onto its seat



Inserted Diaphragms

- V559810400

A system in which a small tank of compressed air is placed next to the engine. When the gas is depressed deeply, this air is sent through a valve directly to the exhaust manifold, causing the turbocharger to spin. According to the theory, you are immediately busy without having to wait for the first exhaust gases that give the paddle wheel a pendulum.

V037611400

Crankcase ventilation system. This diaphragm regulates that under all engine conditions the gases, which end up in the crankcase along the piston rings, are extracted to the intake manifold. The vacuum pressure required for this is controlled by this membrane.

Inserted seals

- V140414600

Tank valve in and outlet. Controls the aeration of the tank if underpressure is created. If the tank is full during refueling, close the valve. This will cause the pressure to build up in the tank, causing the fuel nozzle to shut off.

- V140414200

Tank valve in and outlet. Controls the aeration of the tank if underpressure is created. If the tank is full during refueling, close the valve. This will cause the pressure to build up in the tank, causing the fuel nozzle to shut off.

- V559810100

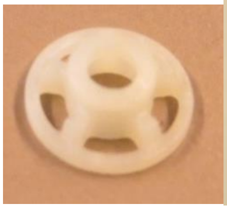
Part functions in an electromagnetically controlled pneumatic valve used in air suspension systems for passenger cars. Depending on load and driving conditions, this system can automatically adjust damping and spring characteristics. Part functions in conjunction with the V559810300

Assembly

- V115015900

High pressure valve.

Inserts:

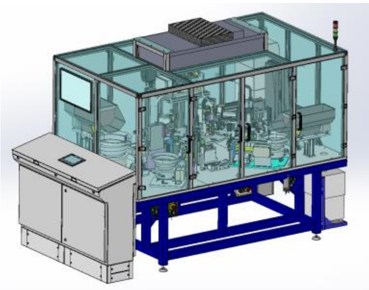


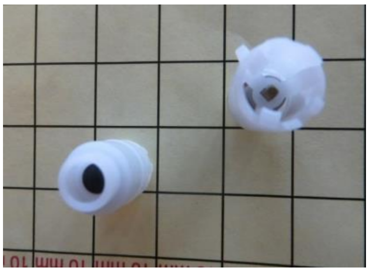
- V295716700

A check valve to maintain vacuum in the brake booster and prevent oil from flowing from the vacuum pump to the booster.

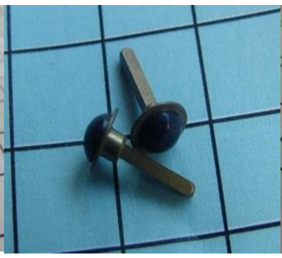
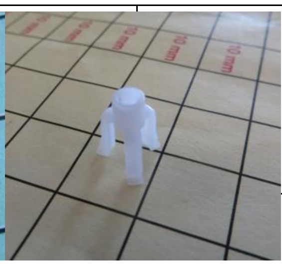
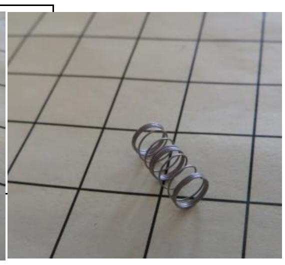
Vacuum pump for brake booster

- V115015500






A check valve to maintain pressure in the fuel supply line.

- V295716000

- V295715700

Check valve to maintain vacuum in the brake booster and prevent oil from leaking/from the vacuum, pump to the booster

- V295711000

Geraldo machine

The assembly is used in a vacuum system for, among other things, the power brakes in a car. The assembly prevents oil from flowing from the vacuum pump to the other parts in the vacuum system. In addition, the assembly maintains the vacuum for some time after the engine is turned off. The assembly is supplied in a plastic housing.

SPP (small platform project)

- V081619100

Dumpvalve.

Compressor size turbo.

Insert: 

- V115018300

Suction diaphragm for the return line of an Ad Blue pump.

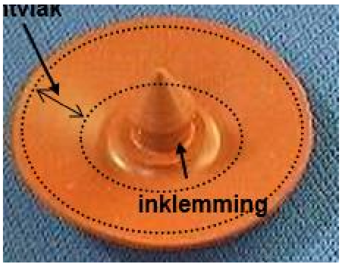
 

Full Rubber

- V194010500

Umbrella

- V470910300



Crankcase ventilation system. This valve regulates that under all engine conditions the gases, which end up in the crank case along the piston rings, are extracted to the intake manifold.

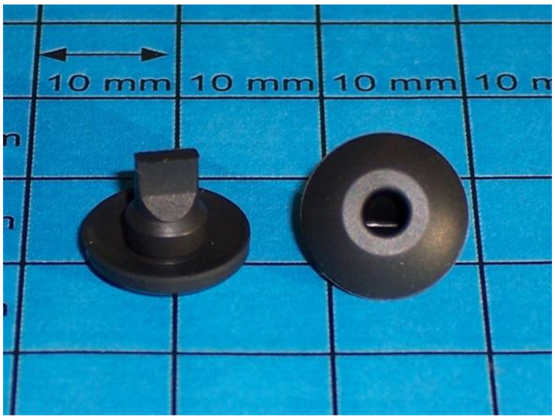
Application: trucks

- V072810900

Duckbill full rubber

Combination Valve

When fuel pump pumps gasoline to the engine, the duckbill ensures the air can flow in from outside, and the overpressure that can arise in the tank is limited, s valve ensures that excess air can scape from the tank



Discs

- V194012600

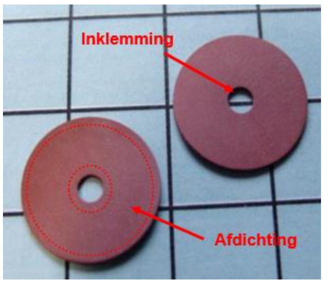
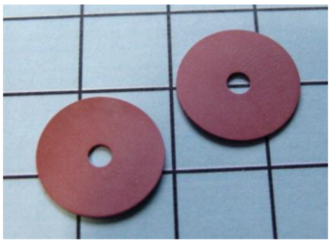


Figure 34. V194012600

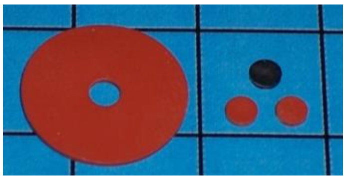
- V455110900



Brake systems have a system of vacuum amplification.(power brakes) For this there is in every car a large vacuum pot. The vacuum of the inlet is passed through pulled the valve with valve disc into the vacuum pot. When the vacuum in the inlet is lost, the valve disc closes the vacuum in the jar so that there is vacuum at all times remains available for the power brakes.

- V455110800

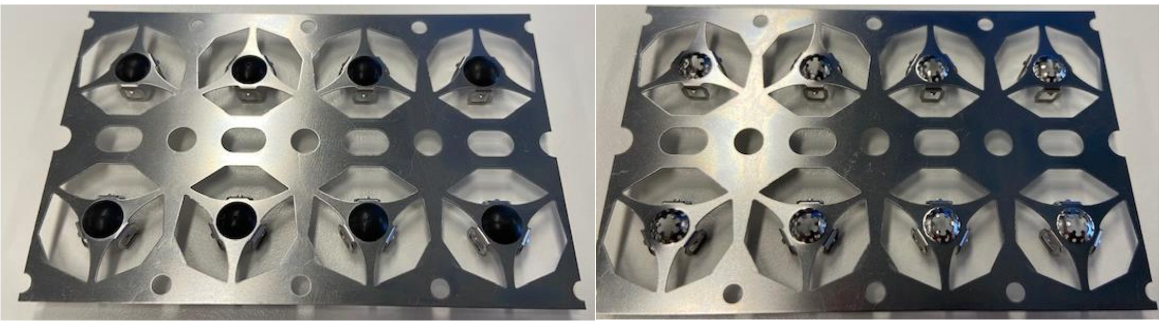
used in fuel tanks, behind the carbon filter a three way valve that can switch from flow to the air filter of the engine or floe to the inlet side of the turbo. The three way valve contains 2 of these discs



Star seal

- V450612400

Products are later punched out of the strip. Single product is a poppet that is clicked on a holder (by means of the 3 click legs)



Appendix B: Operations and production machines

Figure 35. General ovens room

Figure 36. Oven car

Figure 37. Punching machine

Figure 38. waiting products for punching

Figure 39. Assembly machine

Figure 40. Assembly machine 2

Figure 41. Logistics center

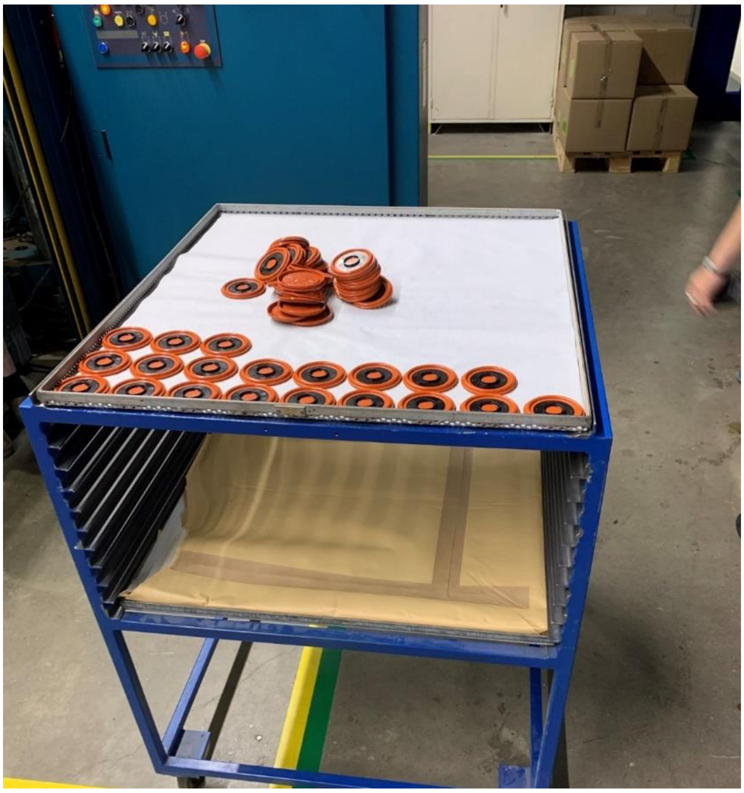


Figure 42. Inserted diaphragm after molding

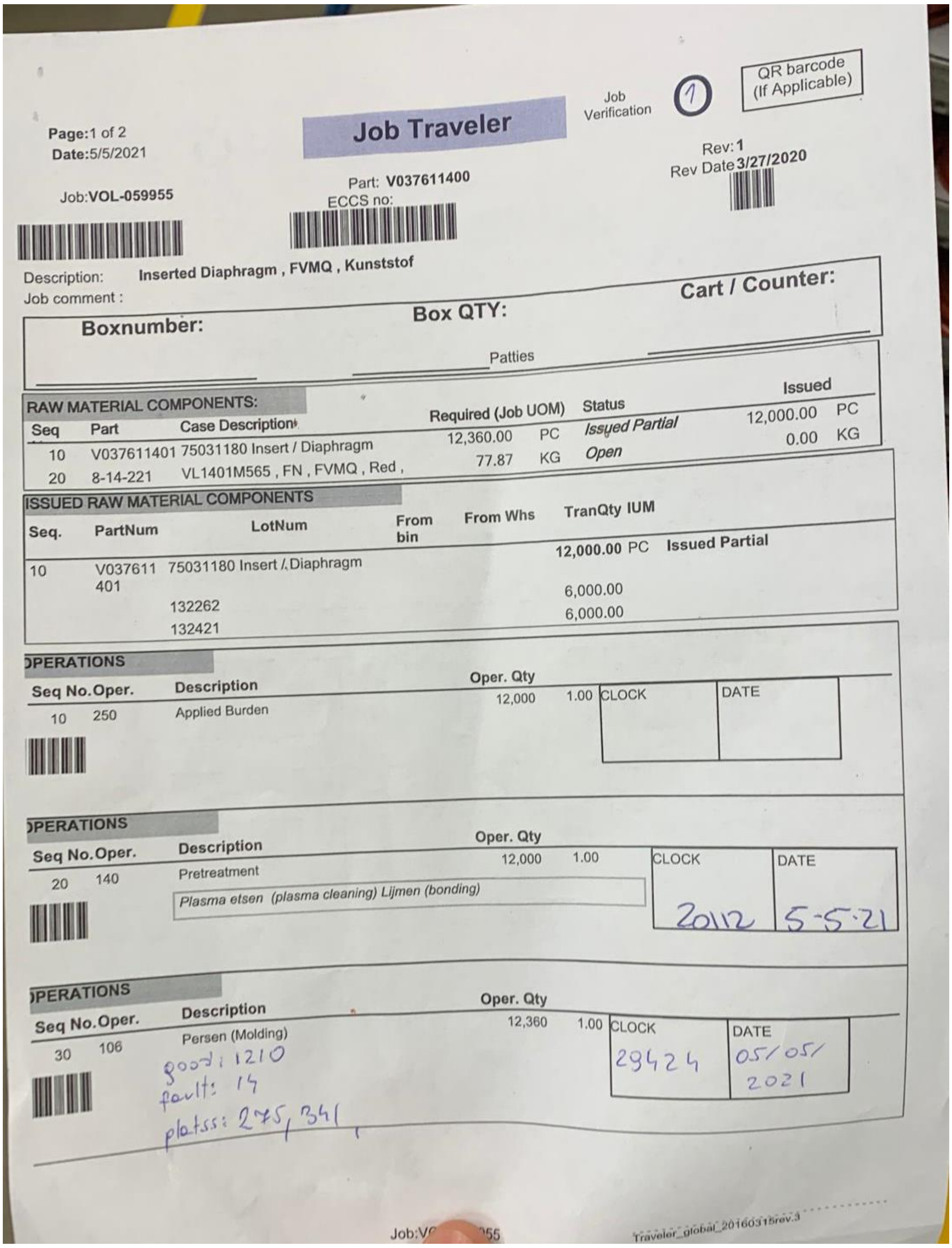
Figure 43. molding machine

Figure 44. Visual inspection workplace with loupe

Figure 45. Moly-coat vibrating drum

Figure 46. Small ovens

Appendix C: Job traveler


Page:1 of 2
Date:5/5/2021

Job:VOL-059955

Job Traveler

Part: V037611400
ECCS no:

Job Verification

1

QR barcode (If Applicable)

Rev: 1
Rev Date 3/27/2020

Description: Inserted Diaphragm , FVMQ , Kunststof
Job comment :

Boxnumber: Box QTY: Cart / Counter:

Patties

RAW MATERIAL COMPONENTS:

Seq	Part	Case Description	Required (Job UOM)		Status	Issued	
10	V037611401	75031180 Insert / Diaphragm	12,360.00	PC	Issued Partial	12,000.00	PC
20	8-14-221	VL1401M565 , FN , FVMQ , Red ,	77.87	KG	Open	0.00	KG

ISSUED RAW MATERIAL COMPONENTS

Seq.	PartNum	LotNum	From bin	From Whs	TranQty IUM	
10	V037611 401	75031180 Insert / Diaphragm			12,000.00 PC	Issued Partial
		132262			6,000.00	
		132421			6,000.00	

OPERATIONS

Seq	No.Oper.	Description	Oper. Qty		CLOCK	DATE
10	250	Applied Burden	12,000	1.00		

OPERATIONS

Seq	No.Oper.	Description	Oper. Qty		CLOCK	DATE
20	140	Pretreatment Plasma etsen (plasma cleaning) Lijmen (bonding)	12,000	1.00	20112	5-5-21

OPERATIONS

Seq	No.Oper.	Description	Oper. Qty		CLOCK	DATE
30	106	Persen (Molding) good: 1210 fault: 14 platss: 275, 341	12,360	1.00	29424	05/05/2021

Job:V 55

Traveler_global_20160315rev.3

Figure 47. Job traveler

Appendix D: External sorting tracking

External sorting counts with some transactions in the system, registered during its stance at the sorting company in Poland, but these transactions are not taken in specific moments, so it is not known exactly what they indicate. However, external sorting is a key step to track and to take into account, as it is the largest and the most difficult to control. Some parts have a large number of operations between the first operation tracked and the next one, as for example V081617400, which has its first operation, Molding, tracked, but since then, there are five operations (postcuring, external sorting, final audit, subcontract processing and testing) that are not tracked, until the end, packaging. Therefore, there are around twenty days lapsing, without any notice and five operations in between. Then, in order to have a more concrete idea, of how these twenty days are distributed over the five processes, reports sent by SGP and ESP (the external sorting companies) were analyzed and compared to the registered transactions in order to get a correlation with some point of the process and the last registered transactions. Hence, it was found a relation between the last transaction and the shipping back date (from Poland to VOL), and consequently, those transactions, adding 1.5 days of transport will be used as estimate for the arrival to the plant. The transaction indicating an approximation of the shipment date was in some cases registered as quantity equal to zero, and, as those were removed from the database, they had to be included again for the external sorting operations, as in this case they are relevant.

Appendix E: calculation of estimated production standards lead times

Part	opr	Operation	OpDesc	prod. standard PH	standard quantity	standard working h (Qty/ProdSt)	acceptable/standardized waiting time before starting operation (days)	total operation time (days)	LT (working days, calendar days)
V037611400	10	250	Applied Burden				0	0.00	**6.35**
V037611400	20	140	Pretreatment				0	0.00	8.35
V037611400	30	106	Persen (Molding)	300	12000	40.0	0	1.67	
V037611400	40	109	Ovenkuur (Postcuring)			8.0	2	2.33	
V037611400	50	103	Controleren (Testing)	0	12000	0.0	0.5	0.50	
V037611400	60	131	Eindcontrole (Final Audit)	30000	12000	0.4	1	1.02	
V037611400	70	132	Inpakken (Packaging)	1500	12000	8.0	0.5	0.83	
V039310300	10	250	Applied Burden				0	0.00	**20.74**
V039310300	20	140	Pretreatment				0	0.00	27.74
V039310300	30	106	Persen (Molding)	930	30000	32.3	0	1.34	
V039310300	40	109	Ovenkuur (Postcuring)			8.0	2	2.33	
V039310300	50	131	Eindcontrole (Final Audit)	30000	30000	1.0	1	1.04	
V039310300	60	121	Subcontract Processing			360.0	0.5	15.50	
V039310300	80	132	Inpakken (Packaging)	50000	30000	0.6	0.5	0.53	
V039310600	10	250	Applied Burden				0	0.00	**13.99**
V039310600	20	140	Pretreatment				0	0.00	17.99
V039310600	30	106	Persen (Molding)	1351	50000	37.0	0	1.54	
V039310600	40	109	Ovenkuur (Postcuring)			8.0	2	2.33	
V039310600	50	142	External Sorting			192.0	0.5	8.50	
V039310600	60	131	Eindcontrole (Final Audit)	30000	50000	1.7	1	1.07	
V039310600	70	132	Inpakken (Packaging)	50000	50000	1.0	0.5	0.54	
V072810900	10	250	Applied Burden				0	0.00	**11.67**
V072810900	20	106	Persen (Molding)	891	30000	33.7	0	1.40	15.67
V072810900	30	109	Ovenkuur (Postcuring)			7.0	2	2.29	
V072810900	40	145	Dipping	100000	30000	0.3	0.5	0.51	
V072810900	50	108	Slitten (ID Punching/Slitting)	1587	30000	18.9	4	4.79	
V072810900	60	120	Antistickbehandeling (Coating)	10000	30000	3.0	1	1.13	
V072810900	70	131	Eindcontrole (Final Audit)	33333	30000	0.9	1	1.04	
V072810900	80	132	Inpakken (Packaging)	100000	30000	0.3	0.5	0.51	

Figure 48. Example of the excel file where EPS LT were calculated

Appendix F: Dashboard

Part	V140414200									
Job	**Opr**	**# Operation**	**Start operation**	**Min of start job**	**end operation**	**time since last operation until start**	**days until start operation**	**days until finish**	**tracke d LT operati on**	**since last tracked operation until finish**
VOL-054281	80	132	01/10/2020 08:39	14/09/2020 02:55	01/10/2020 08:39			17.24	0.00	
VOL-054285	10	250	01/10/2020 00:11	25/09/2020 01:28	02/10/2020 00:05		5.95	6.94	1.00	
	20	106	01/10/2020 06:03	25/09/2020 01:28	02/10/2020 04:02		0.00	7.11	0.92	**0.92**
	80	132	09/10/2020 13:51	25/09/2020 01:28	09/10/2020 13:51	7.4	14.52	14.52	0.00	**7.41**
VOL-054325	10	250	01/10/2020 04:26	01/10/2020 04:06	08/10/2020 00:05		0.01	6.83	6.82	
	20	106	01/10/2020 04:06	01/10/2020 04:06	08/10/2020 02:56		0.00	6.95	6.95	**6.95**
	80	132	14/10/2020 15:42	01/10/2020 04:06	14/10/2020 15:42	6.5	13.48	13.48	0.00	**6.53**
VOL-054440	80	132	02/10/2020 15:10	21/09/2020 05:12	05/10/2020 13:31		11.42	14.35	2.93	
VOL-054545	10	250	07/10/2020 03:46	07/10/2020 03:25	13/10/2020 12:06		0.01	6.36	6.35	
	20	106	07/10/2020 03:25	07/10/2020 03:25	13/10/2020 13:19		0.00	6.41	6.41	**6.41**
	80	132	16/10/2020 06:06	07/10/2020 03:25	16/10/2020 07:45	2.7	9.11	9.18	0.07	**2.77**
VOL-054546	10	250	13/10/2020 00:06	13/10/2020 14:09	18/10/2020 00:06		0.00	4.41	5.00	
	20	106	13/10/2020 14:09	13/10/2020 14:09	18/10/2020 00:43		0.00	4.44	4.44	**4.44**
	80	132	22/10/2020 21:43	13/10/2020 14:09	22/10/2020 21:43	4.9	9.32	9.32	0.00	**4.88**
VOL-054547	10	250	18/10/2020 07:39	18/10/2020 07:04	29/10/2020 10:04		0.02	11.13	11.10	
	20	106	18/10/2020 07:04	18/10/2020 07:04	28/10/2020 07:20		0.00	10.01	10.01	**10.01**
	80	132	05/11/2020 16:16	18/10/2020 07:04	05/11/2020 16:16	8.4	18.38	18.38	0.00	**8.37**
VOL-054647	10	250	19/10/2020 00:16	19/10/2020 06:18	23/10/2020 14:04		0.00	4.32	4.58	
	20	106	19/10/2020 06:18	19/10/2020 06:18	23/10/2020 13:36		0.00	4.30	4.30	**4.30**
	80	132	30/10/2020 10:31	19/10/2020 06:18	30/10/2020 10:31	6.9	11.18	11.18	0.00	**6.87**
VOL-054648	10	250	23/10/2020 14:27	23/10/2020 14:12	28/10/2020 20:04		0.01	5.25	5.23	
	20	106	23/10/2020 14:12	23/10/2020 14:12	28/10/2020 20:04		0.00	5.24	5.24	**5.24**
	80	132	02/11/2020 15:52	23/10/2020 14:12	02/11/2020 15:52	4.8	10.07	10.07	0.00	**4.82**
VOL-054649	10	250	28/10/2020 00:20	28/10/2020 20:16	02/11/2020 17:05		0.00	4.87	5.70	
	20	106	28/10/2020 20:16	28/10/2020 20:16	02/11/2020 16:27		0.00	4.84	4.84	**4.84**
	80	132	06/11/2020 21:22	28/10/2020 20:16	06/11/2020 21:22	4.2	9.05	9.05	0.00	**4.20**
VOL-054650	10	250	29/10/2020 00:26	29/10/2020 14:18	05/11/2020 10:04		0.00	6.82	7.40	
	20	106	29/10/2020 14:18	29/10/2020 14:18	05/11/2020 10:33		0.00	6.84	6.84	**6.84**
	80	132	12/11/2020 15:36	29/10/2020 14:18	12/11/2020 16:16	7.2	14.05	14.08	0.03	**7.24**
VOL-054651	10	250	02/11/2020 00:24	02/11/2020 17:03	06/11/2020 22:04		0.00	4.21	4.90	
	20	106	02/11/2020 17:03	02/11/2020 17:03	06/11/2020 21:50		0.00	4.20	4.20	**4.20**
	80	132	13/11/2020 14:01	02/11/2020 17:03	13/11/2020 14:01	6.7	10.87	10.87	0.00	**6.67**
VOL-055529	10	250	05/11/2020 00:57	05/11/2020 10:37	11/11/2020 13:08		0.00	6.11	6.51	
	20	106	05/11/2020 10:37	05/11/2020 10:37	11/11/2020 13:18		0.00	6.11	6.11	**6.11**
	80	132	18/11/2020 19:43	05/11/2020 10:37	18/11/2020 19:43	7.3	13.38	13.38	0.00	**7.27**
VOL-055744	10	250	11/11/2020 00:18	11/11/2020 05:52	18/11/2020 16:09		0.00	7.43	7.66	
	20	106	11/11/2020 05:52	11/11/2020 05:52	18/11/2020 13:46		0.00	7.33	7.33	**7.33**
	80	132	26/11/2020 12:19	11/11/2020 05:52	26/11/2020 12:19	7.9	15.27	15.27	0.00	**7.94**
VOL-055745	10	250	06/11/2020 00:27	06/11/2020 22:03	13/11/2020 00:11		0.00	6.09	6.99	
	20	106	06/11/2020 22:03	06/11/2020 22:03	13/11/2020 02:22		0.00	6.18	6.18	**6.18**
	80	132	20/11/2020 19:27	06/11/2020 22:03	20/11/2020 19:27	7.7	13.89	13.89	0.00	**7.71**
VOL-055914	10	250	12/11/2020 03:17	12/11/2020 02:40	19/11/2020 06:14		0.03	7.15	7.12	
	20	106	12/11/2020 02:40	12/11/2020 02:40	19/11/2020 05:49		0.00	7.13	7.13	**7.13**
	80	132	26/11/2020 12:22	12/11/2020 02:40	26/11/2020 12:31	7.3	14.40	14.41	0.01	**7.28**
VOL-056103	10	250	19/11/2020 00:39	19/11/2020 06:09	24/11/2020 00:16		0.00	4.76	4.98	
	20	106	19/11/2020 06:09	19/11/2020 06:09	24/11/2020 03:49		0.00	4.90	4.90	**4.90**
	80	132	02/12/2020 08:40	19/11/2020 06:09	02/12/2020 08:41	8.2	13.10	13.11	0.00	**8.20**
VOL-056104	10	250	25/11/2020 21:10	25/11/2020 20:54	01/12/2020 21:08		0.01	6.01	6.00	
	20	106	25/11/2020 20:54	25/11/2020 20:54	01/12/2020 20:28		0.00	5.98	5.98	**5.98**
	80	132	08/12/2020 00:36	25/11/2020 20:54	08/12/2020 00:37	6.2	12.15	12.15	0.00	**6.17**
VOL-056140	10	250	23/11/2020 04:36	23/11/2020 04:10	29/11/2020 11:05		0.02	6.29	6.27	
	20	106	23/11/2020 04:10	23/11/2020 04:10	29/11/2020 10:43		0.00	6.27	6.27	**6.27**
	80	132	07/12/2020 03:16	23/11/2020 04:10	07/12/2020 03:16	7.7	13.96	13.96	0.00	**7.69**
VOL-056141	10	250	01/12/2020 21:05	01/12/2020 20:39	08/12/2020 07:06		0.02	6.44	6.42	
	20	106	01/12/2020 20:39	01/12/2020 20:39	07/12/2020 06:47		0.00	5.42	5.42	**5.42**
	80	132	16/12/2020 15:55	01/12/2020 20:39	16/12/2020 15:55	9.4	14.80	14.80	0.00	**9.38**
VOL-056167	10	250	29/11/2020 11:21	29/11/2020 11:04	04/12/2020 20:10		0.01	5.38	5.37	
	20	106	29/11/2020 11:04	29/11/2020 11:04	04/12/2020 20:11		0.00	5.38	5.38	**5.38**
	80	132	14/12/2020 16:48	29/11/2020 11:04	14/12/2020 17:16	9.9	15.24	15.26	0.02	**9.88**
VOL-056364	10	250	04/12/2020 00:57	04/12/2020 22:00	10/12/2020 18:11		0.00	5.84	6.72	
	20	106	04/12/2020 22:00	04/12/2020 22:00	11/12/2020 04:10		0.00	6.26	6.26	**6.26**
	80	132	18/12/2020 16:01	04/12/2020 22:00	18/12/2020 16:01	7.5	13.75	13.75	0.00	**7.49**
VOL-056365	10	250	11/12/2020 02:31	11/12/2020 14:34	24/12/2020 00:04		0.00	12.40	12.90	
	20	106	11/12/2020 14:34	11/12/2020 14:34	24/12/2020 01:07		0.00	12.44	12.44	**12.44**

Part
V037611400
V039310300
V039310600
V072810900
V081615900
V081616200
V081617400

Part
sample size
st de
aver
average lowest-95th per
r
average lowest-70th perc
H
estimated prod. Std (EP
plann
EPS LT (working

Operation
106
109
131
132
250
103
107
108
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117
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120
124
134
140
142

part standard o

tracked operation

Figure 49. Tracked transactions pivot table

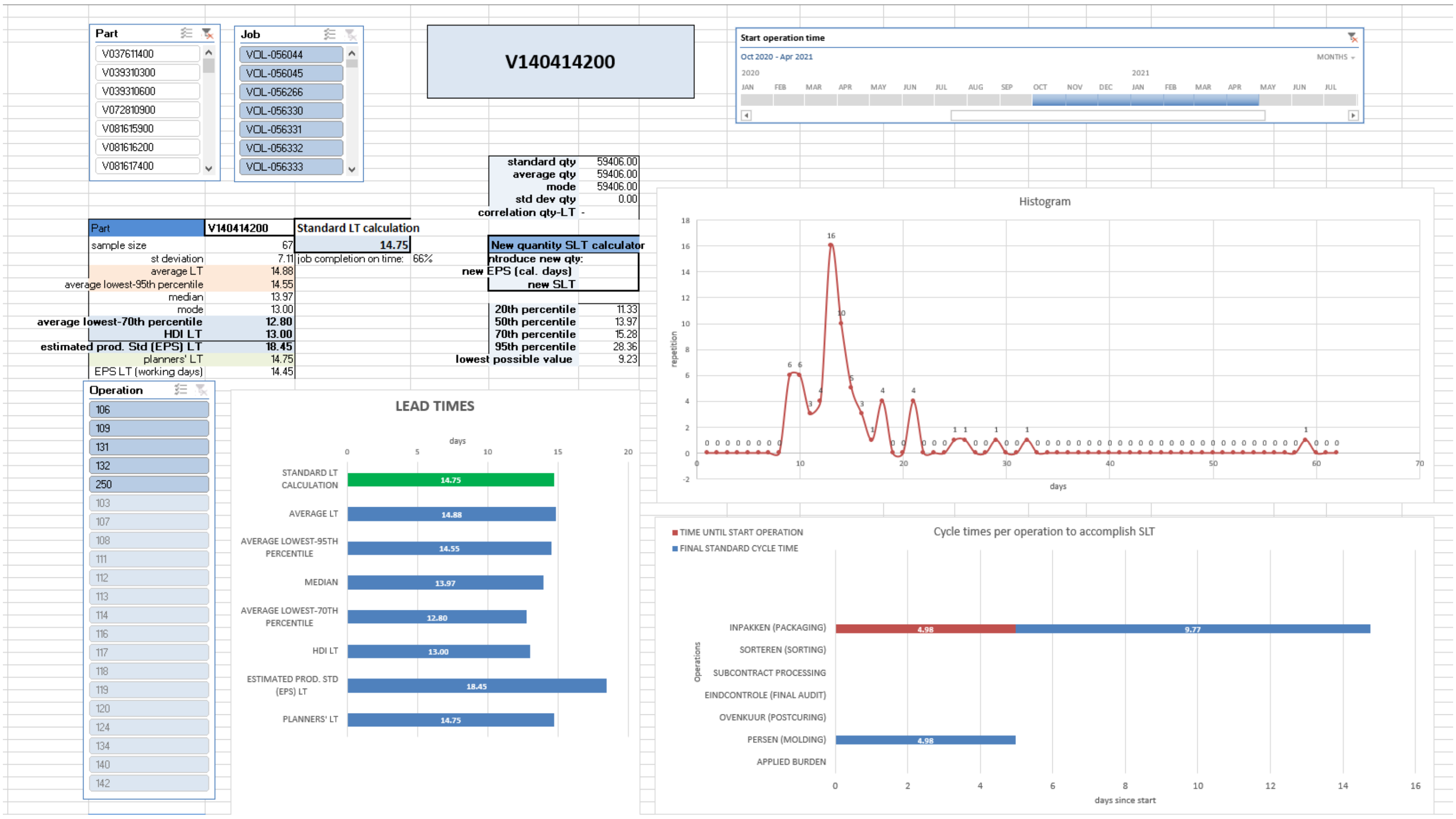

Figure 51. indicators, cycle times for SLT completion, filters , histogram and new quantity SLT calculator

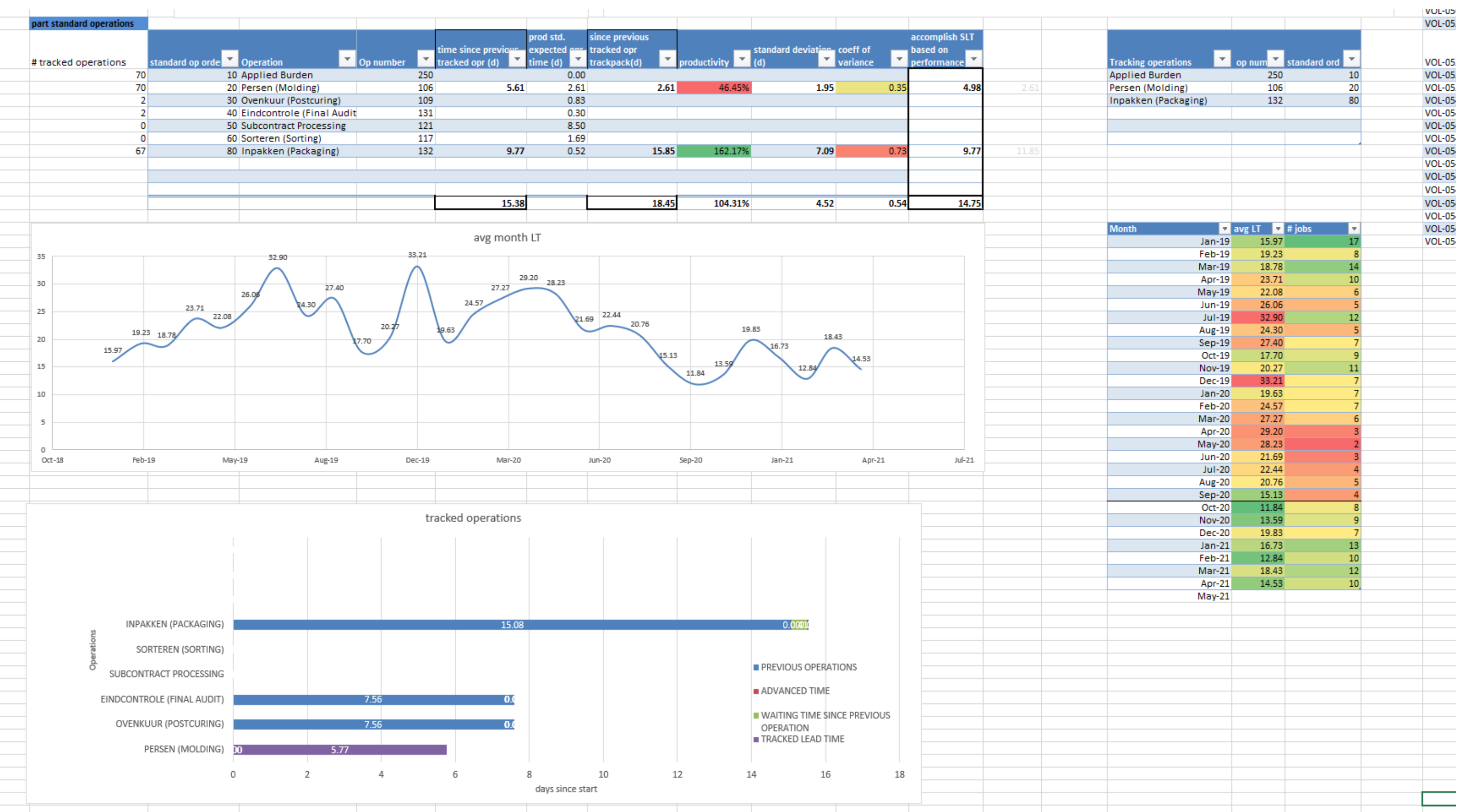

Figure 50. Performance table, tracking operations table, LTs change over time lines graph and table, and tracking graph

Appendix G: Oven scheduling

Estimation time left until full job at oven

Database information on job:

Q = total quantity
Qcompl = quantity that already had oven treatment
Qr = quantity registered in system (at least started molding) ; Qr ∈ (0,Q)
b = number of batches just/already arrived to oven
q(n) = batch n quantity   n ∈ (1 to b)
t(n) = total time batch n since start molding until arrived to oven
Tf = time first transaction n=1
Tnow = actual time

Calculated variables:

Tt = total time until now = Tnow – Tf

r(n) = production rate batch n = q(n)/t(n)

Qf = quantity finished with previous operation (already arrived to molding) = Σ q(n)

Qov = quantity needing oven at oven = Qf-Qcompl

Ql = quantity left to arrive = Q - Qf

Qm = quantity in molding = Qr – Qf

Qns = quantity not started = Ql - Qm

Ravg = average production rate p/h = Σ r(n)/b

Rcompl = total rate of production = Qf/Tt

TL = estimated total time left until full job in oven = **Qm/Ravg + Qns/Rcompl**

Figure 52. conceptual calculation for the estimation of time left until full job arrives to oven

Figure 53. Oven scheduling process