STUDY OF
A VALUE STREAM MAP
ELABORATION AND ANALYSIS

Grau en Enginyeria en Tecnologies Industrials

Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

STUDENT'S FULL NAME: Xavier Gavarró Busquets

DIRECTOR'S FULL NAME: Neus Fradera Teixidor

DELIVERY DATE: October 13th, 2017

VOLUME'S CONTENT: Project Report
List of Contents

Introduction........................................................................................................................................... 3
The company – Maxion Wheels España S.L.U....................................................................................... 3
Six Sigma.................................................................................................................................................. 5
Lean Thinking ......................................................................................................................................... 7
   Value Stream Mapping ....................................................................................................................... 9
The process ........................................................................................................................................... 11
   Planning ............................................................................................................................................. 11
   Material acquisition and organization ............................................................................................... 12
   Wheel manufacture ............................................................................................................................. 13
   Packaging and storage ......................................................................................................................... 27
Value Stream Map Development ........................................................................................................... 29
   Tools used .......................................................................................................................................... 29
      Lead time ...................................................................................................................................... 29
      Cycle time ..................................................................................................................................... 30
      Work in Process (WIP) ..................................................................................................................... 30
      Takt time ...................................................................................................................................... 31
      Overall Equipment Efficiency (OEE) .............................................................................................. 32
      Actual Cycle Time ............................................................................................................................ 36
Document Creation ............................................................................................................................... 36
   Step 1: Establish customer demand .................................................................................................... 36
   Step 2: Define the process flow ........................................................................................................... 38
   Step 3: Gather data regarding the process .......................................................................................... 39
   Step 4: Gather inventory data ............................................................................................................ 48
   Step 5: Define the delivery rate (in and out) ...................................................................................... 49
   Step 6: Push or Pull? ............................................................................................................................ 50
   Step 7: Do the math ............................................................................................................................. 52
Conclusions .......................................................................................................................................... 54
References ............................................................................................................................................ 56
List of Figures

Figure 1 – Plant’s location .......................................................................................... 3
Figure 2 – Maxion Wheels España S.L.U. Organization Chart ............................. 4
Figure 3 – Normal distribution curve ...................................................................... 5
Figure 4 – Normal curve with acceptance range ..................................................... 6
Figure 5 – Finished Maxion Wheels’ VSM .............................................................. 9
Figure 6 – Steel wheels manufacturing process flowchart .................................... 11
Figure 7 – Line 413-7’s Production Planning ......................................................... 12
Figure 8 – Example of a rim with its lateral area outline ...................................... 14
Figure 9 – Rim manufacture process flow chart ..................................................... 14
Figure 10 – Layout of one of the biconical rim line ............................................... 16
Figure 11 – Disc process flowchart ........................................................................ 19
Figure 12 – Assembly process flowchart .............................................................. 23
Figure 13 – Paintshop process flowchart .............................................................. 26
Figure 14 – VSM Customers’ Graphic Depiction .................................................... 37
Figure 15 – VSM Warehouse and Consignment Added .......................................... 37
Figure 16 – VSM Blank Rim Area Sub-process ..................................................... 38
Figure 17 – VSM Blank Process Flow ................................................................. 39
Figure 18 – 413-74 Reference 1 Data Distribution vs Normal Curve ............... 42
Figure 19 – 413-74 Reference 2 Data Distribution vs Normal Curve ............... 43
Figure 20 – 413-74 Reference 2 Data Distribution vs Normal Curve ............... 44
Figure 21 – 413-74 Data Distribution vs Normal Curve ....................................... 45
Figure 22 – 413-74 OEE Sheet .............................................................................. 46
Figure 23 – OEE Data Addition ............................................................................. 47
Figure 24 – VSM Aspect After Step 3 .................................................. 48
Figure 25 – Inventory Data Standard Icon ........................................... 48
Figure 26 – Disc Area Inventory Data ................................................... 49
Figure 27 – VSM Flow Arrows ............................................................... 51
Figure 28 – VSM After Step 6 ............................................................... 52
Figure 29 – Process Lead and Processing Time ...................................... 53
Figure 30 – Finished Maxion Wheels VSM ........................................... 53

List of Tables
Table 1 – 413-74 Lead Time measurements ........................................ 41
Table 2 – 413-74 Reference 1 Lead Time Normal Distribution Values ........ 42
Table 3 – 413-74 Reference 2 Lead Time Normal Distribution Values ........ 43
Table 4 – 413-74 Reference 3 Lead Time Normal Distribution Values ........ 44
Table 5 – 413-74 Lead Time Normal Distribution Values ........................ 45
Table 6 – Inventory Data ................................................................. 49
Table 7 – Updated Inventory Data ....................................................... 50
Introduction

The company – Maxion Wheels España S.L.U.

IOCHPE-MAXION is an international investment group based in Brazil that manages a total of 32 industrial production plants scattered around 14 different countries. The group focuses mainly on the manufacturing of automotive products and components, as well as train rails and locomotive components.

Specifically, it is divided in 3 different divisions depending the type of product each one produces. *AmstedMaxion* manufactures all locomotive related products and amounts to around 1% of the group’s total billing. *Maxion Structural Components* is responsible of the production and distribution of chassis and other light vehicles structural components, division corresponding to 21% of the group’s business volume. Finally, *Maxion Wheels* manufactures both steel and aluminium wheels for both light vehicles and heavy machinery and its business volume amounts to the remaining 78% of the group.

The division Maxion Wheels supplies approximately 16.5% of the original wheels worldwide (around 60 million wheels this past 2014) which promotes them to the 3rd wheels producer. The division has production plants in 12 different countries with a total workforce of more than 10 thousand workers.

Figure 1 – Plant’s location
Manresa’s plant is a part of this last division and this is why it receives its name, *Maxion Wheels España S.L.U.* This factory, though, has not always been under Maxion Wheels’ control. In fact, it has a history of more than one hundred years. Founded at the start of the Nineteenth Century by the Casals’ family, it was originally dedicated to steel sheets forming. On 1929, the company OCOMESA was created with this factory as its only asset, and it became one of the main local economy drivers during the dictatorship first years.

On 1932 the first metallic wheels for both trucks and cars were manufactured, which some time later propitiated Lemmerz’s interest in acquiring OCOMESA in 1960. Lemmerz was a German wheel producer that in 1997 merged together with the Nord-American investment group Hayes, resulting in the company Hayes & Lemmerz. Finally, on 2012 IOCHPE-MAXION decided to acquire the Nord-American group and annex it to its *Maxion Wheels* division, becoming one of the most important wheel producers worldwide.

Currently, the factory has around 230 workers between operators and administration with a maximum capacity of 6 million wheels a year, 4.8 for commercial cars and 1.2 for light trucks.

![Maxion Wheels España S.L.U. Organization Chart](image-url)
The plant follows the previous organizational chart (*Figure 2*) and this concrete project has been conducted in the OPEX department under the current OPEX Manager supervision. The OPEX department is responsible for the application of the Lean manufacturing and Six Sigma methodologies throughout the plant, which means it has to maintain a close relation with each and every other departments, thus making it the most suitable to develop a Value Stream Map.

**Six Sigma**

*“Six Sigma is a quality program that, when all is said and done, improves your customer’s experience, lowers your costs, and builds better leaders.” — Jack Welch*

Six Sigma is a data-driven approach and methodology for eliminating defects in any given process, with the aim of increasing the benefits it generates. Its name and principles derive from a well-known statistical curve, the normal curve, a concept first introduced by Carl Friedrich Gauss in 1809. When drawing the normal distribution probability curve, it forms a very distinctive shape resembling a bell. From this curve we can highlight 2 different concepts: the mean and the variance.

The mean ($\mu$) is the average value of all the measures in the distribution curve and it always matches with the centre of this bell. The variance ($\sigma^2$) is a value used to measure how much does the value deviate from the mean, which is in turn considered the square of the standard deviation ($\sigma$): the higher these values, the further the measurement is from the mean.

*Figure 3 – Normal distribution curve*
As seen in the previous figure (Figure 3 – Normal distribution curve), it is very common to measure the distance between the mean and the value measured with units of “sigma” (1σ; 2σ; 3σ). This curve is used to estimate the probability of any given measure being higher or lower than a reference value.

Since almost all (if not all) of the industrial processes follow a normal distribution, the products are designed with a margin for each and every of their dimensions and/or properties. And here is where the standard deviation comes into play.

At the designing stage, a customer establishes an acceptance range for a given dimension or property which all the products supplied have to fulfill. Inside this range, the product performance and quality is guaranteed, while the ones with values outside of it have to be discarded or thrown away due to not satisfying the specifications.

Using the previous figure as a reference (Figure 4 - Normal curve with acceptance range) and supposing the distribution curve represents an industrial process while the red lines mark the acceptance range limits established by the customer, all the values on the outer ends of the curve would have to be discarded. To calculate the percentage of “scrap” products that stem from the process, a bit of statistical analysis is done.

In this case, the process would be considered a 2.3σ process, approximately, which means that around 1.07% of the products generated would not be accepted by the client and, thus, wasted.
During most part of the 20th Century, a 3σ process (≈0.13% of defective parts) was the limit considered as good as established and demonstrated by Walter Shewart around the 1920s. Anything lower than that demanded some sort of correction. This was considered the standard until the 1980s, where an engineering team in Motorola decided the traditional standards were too low.

This team set their goal on reaching a 6σ process (≈3.4ppm or ≈0.00034% of scrap parts) and started to develop a series of tools and methodologies to achieve this goal, hence the name Six Sigma. This new standard, though, apart from demanding an evolution and modernization of the process, requires a cultural change from all the workers, which is probably its hardest aspect to accomplish.

Since the principles followed by the Six Sigma philosophy are not exclusive to industrial processes, it rapidly started to expand to other sectors and it is currently widely used.

**Lean Thinking**

Although really similar in their core, as both aim on improving a process capability and quality, Lean manufacturing and Six Sigma have slight differences that make them distinctive. The main one is that while Six Sigma focuses on reducing defects in general, the Lean philosophy looks to eliminate all waste generation.

As can be seen from their goals, both methodologies are quite similar and, in fact, are complimentary with each other: using one helps reaching the other’s objectives and vice versa. This means that most of the tools and projects from any of the methodologies can be used by both. And a clear example of that is the Value Stream Map.

But, where does the Lean philosophy come from? Lean thinking was developed in the 1990’s by researcher James Womack at the Institute of Technology (MIT). It is a corporative program which consists of a set of tools and techniques focused on improving an organization’s performance through an increase of its quality and productivity.
It tries to reach its goal by identifying which aspects of the process generate value for the customer and which don’t, to then improve the value-adding ones and eliminate the rest. All these non-value-adding aspects are seen as waste that have to be disposed of.

**Waste** /ˌwɜːst/ n. extravagance; residue which is not easy to use or is not used due to careless attitude; action or effect of wasting.

Lean thinking sees waste as the difference between the ways things are done now and the way they could be done if everything was perfect – no mistakes, concerns, problems or complexities. In other words, waste is every activity which does not add value.

On the other side, generating value is considered transforming the product in a way customers are willing to pay for it. To produce the perfect product one must: produce with perfect Quality, in the right Volume, at the right Place, at the right Time and at a minimum Cost. Anything other than that is waste or non-value-adding activities. These activities are classified in 8 different kinds:

- **Overproduction waste**: Producing more than necessary; producing before the necessary moment; high in-process inventory.
- **Correction waste**: Repeating work or information to understand customer requirements.
- **Information flow waste**: Inefficient information flow (losses, misunderstandings, complex management).
- **Processing waste**: Effort which does not add value to service or information; extra costs with insignificant impact on the customer requirements.
- **Inventory waste**: Any supply in excess beyond customers’ requirements, process needs or just-in-time services.
- **Waiting waste**: Idle time created when two or more activities, people or dependent events are not completely synchronized.
- **Motion waste**: Any motion people, machines or material which does not add value to service or information.
- **Lack of commitment by Employees**: Non-committed employees do not perform as well as committed ones due to lack of motivation.
In order to identify these kinds of waste, the Lean methodology developed a tool called Material and Information Flow Analysis (MIFA). A MIFA is all the actions (both value-adding and non-value adding) currently required to bring a product to the customer through the main flows essential to every process: the design flow from the concept to the launching and the production flow from raw material to the customer, also called Value Stream Map.

This MIFA tool was first introduced by Lean thinking and later on also adopted by Six Sigma due to its high improvement potential while adding other aspects to it. Nowadays it is considered a Lean Six Sigma tool, a mix between the two methodologies.

**Value Stream Mapping**

As previously defined, the goal of this project is to develop a VSM of the wheel manufacturing process carried out in Maxion Wheels España S.L.U. In a rough way, it is a “big picture” approach to the current production system that intends to highlight where the flow discontinuities occur, demonstrate interaction between material and information flows, and highlight areas of waste as well as other improvement opportunities.
Value Stream Mapping helps in the understanding of the material production process answering:

**What**  Happens to the material at any given point

**Who**   Does what to the material.

**When**  Does the person know what to do.

**Where** Does the material come from.
               Does the material go to.

**Why**    Does the activity happen.

**How**    Does the person know what to do.

As well as well as the information flow:

**What**  Information is being conveyed.
           Is done with this information.

**Who**   Sends the information.
           Receives the information.

**When**  Is the information received.

**Where** Does the information come from.
            Does the information go to.

**Why**   Is the information conveyed

**How**   Is the information used
           Is the information transmitted.

In order to elaborate this project, then, having an extensive knowledge of the process is vital and especially of its different stages.
The process

The process itself (Figure 6) can be divided in three main phases: planning, material acquisition and organization, wheel manufacture and storage.

From this report's academic point of view, the main stage is the fabrication of the wheels per se, but since the other three have to be included in the VSM too, it is compelling to also incorporate a brief description.

**Planning**

The process begins with the contact between the different clients with the Purchasing department. These communications occur at least once a week, but sometimes they can be as frequent as once a day. These are done telephonically, although in some cases are through e-mailing, always depending on the client.

From these communications arise the different orders, usually with medium and long term deadlines, since the global planning is done at least 6 months prior. With these orders, a sales prediction algorithm is developed which is later used by the Logistics department to create the Production Planning. The aforementioned program uses data that will be implemented to the VSM later on, such as cycle and takt times, lines efficiency or inventory levels, and it is the guide followed by the whole plant.
The Production Planning indicates which reference has to be produced in each and every line, the amount to be manufactured in each series as well as the approximate times every step should take, either set-ups or production. The set-ups are all the actions and adjustments to be made in a given line to be able to manufacture a given reference; while the production is, as its name says, the series’ actual production time.

Were it to be necessary, the production planning also shows which days or shifts the machine will not work, although this condition only occurs on the least used lines due to low demand. The usual production plan is similar to the one seen in Figure 7. Every working day is divided in 3 shifts and, next to every planned reference, the shift is either painted grey for the producing intervals or black for the set-up procedures.

This production plan generation is one of the critical stages of the process since, along with other things, the raw material purchasing is done following the timing set by Logistics. Were the plan not be precise enough, there would be either excess or scarcity of steel since its purchasing is as precise as possible in order to avoid its corrosion or having to stop producing due to lack of it.

Material acquisition and organization

Once the production planning is over the following step is acquiring the materials needed to carry it out. The purchasing is performed by the Purchasing Department following Logistics needs, and the orders are sent daily to two different suppliers following the company’s dual-provider philosophy, a philosophy aiming at reducing the steel overall cost by creating competition between the 2 suppliers.
Apart from having multiple references with different width, thickness and steel quality specifications, the raw material can be divided in two main categories depending on its purpose, which are either disc or rim rolls. Since the production process of these two wheel components are radically different, the quality and specifications for the steel are bound to be distinctive as well, while different references for the same process raw materials have quite a bit of similarities between each other.

Independently of their destination, though, the purchasing orders are created daily, and between seven and ten trucks with approximately 1500 tons of steel are received in the plant every day. The steel comes in the shape of coils and, once it arrives at the factory, it is stored for around 5 dies in average, during which the material is subjected to various quality tests in order to ensure it complies with the specifications asked for.

Once the material passed these tests, it is sent to its appropriate area for its processing.

**Wheel manufacture**

The manufacturing process is divided in 4 different and independent sub-processes and assigned to one of the four production areas: the Rim Area, the Disc Area, the Assembly Area and the Paintshop.

Roughly, the first two (rim and disc areas) are in charge of manufacturing the wheel’s main components, the rim and the disc. The assembly lines fit the discs inside the rims with their subsequent fixing through welding, while the painting chain is responsible of painting and polishing the wheel, as well as packing the finished product.

Before diving into the manufacturing process, though, there is a couple misconceptions that have to be addressed in order to avoid future confusions. The car rim is a concept that, generally, is confused in the current society and is oftenly mistaken by the disc concept. Usually, when speaking of the “rim” of the car what is meant by “rim” is the visible metallic part of a wheel. This part is, in fact, the disc of the wheel; while the rim is the cylinder supporting the tire, the area contacting the rubber case.
Rim Area

As mentioned just above, the rim is a cylinder (approximately) designed to hold the rubber case of the tire, with an outline similar to Figure 8 to maximize the structural strength and hold the tire without it slipping off.

![Figure 8 – Example of a rim with its lateral area outline](image)

In order to obtain the rim, the material comes rolled in a coil with dimensions that range from 3 to 5 mm thick and 300 to 400 mm wide, depending on the reference it is intended for. The coil length is much more variable because it depends mainly on the supplier, and since the material is paid for its weight there is no control in place.

The coils are placed manually (with the help of a crane as the lightest coils weigh around 600kg) at the line beginning and this is about all the manual work that has to be done, since the rest of the process is completely automated.

![Figure 9 – Rim manufacture process flow chart](image)
Since the material always comes rolled into a coil and the curvature radius is a parameter impossible to control, the first step taken is to flatten the steel so the initial conditions are as similar as possible. This process is carried by three cylinders that, at the same time, put the steel in route to the next station, the cutting press.

This press contains a length sensor, adjusted at the beginning of each series, which measures the distance between cuts, or in other words, the blank length. In this stage the traceability code is also printed onto the steel. This code contains information such as the material quality, the manufacturing line and the date and shift it was cut.

Once the material is cut, a security sensor controls its flatness in order to carry on the process, since a not levelled enough template could propitiate a breakdown on one of the following stations. Were the blank deemed as defective or NOK (no OK), it is automatically discarded and separated from the rest.

Once the cut has been verified the material has two possible courses. The first one and also the most common is to keep forward with the manufacturing to the next process. Sometimes, though, advancing is not possible. In these cases the blanks are isolated and stacked on top of each other, storing them for future usage.

This situation occurs due to two main reasons. On the one hand the cutting press works slightly faster than the rest of the line, which means that every 4 templates the line can absorb the press cuts and this excess has to be stored. On the other hand there are the line stoppages. Eventually the line has to be stopped, but during these discontinuities the cutter does not halt and keeps generating blank stock to optimize energy and time usage.

The reason this blank stock is stored because the press cannot be working nonstop all the time. Be it to change the material coil, readjustments or plain breakdowns, sooner or later the press will have to stop. When the cutting press is not working is when the stock is used in order to keep feeding the line and increasing its productivity.
The next stage in the rim production process is the first blank deformation to begin shaping its final form. From this point onwards, the material is constantly wet with an oil with water emulsions called “taladrina” (and referred as such from this point forwards) that ensures there is lower friction between the steel and the tools, avoiding scratches and extending the tooling and matrix working life.

For this first shaping, the lines uses a machine with two pincers that hold the template by its both ends that, with the help of a mould, gives it a cylindrical shape. This cylinder, though, is not totally round. On the edges there is a short flat segment to facilitate its posterior welding. From this stage on, the piece receives the name of “birolla”, that literally means “scroll”.

Once this birolla is obtained, another group of pincers take it from the mould and put it the welding zone, a stage that can be divided in two segments: the welding itself and the deburring and smoothing.

In the first welding stage the same transporting pincers ensure the ends of the birolla are aligned to each other so the high intensity welding machine can join them in a matter of a couple tenths of a second. This initial weld is really irregular and its ends lightly stick out, thus, the following 4 stages are designed to polish it.

The first process is the deburring, that is basically two blades slicing the weld surface cutting all the “excess” taking advantage the material is still hot, making the birolla flat again. In the second one, the weld surface is polished in order to obtain a smooth touch.
The next process cuts the weld sides that form a little bulge in both fronts of the piece, which in turn can cause its edges to be sharpened. That is why the fourth and last welding stage pressures both edges of the weld line in order to round them off.

Once the welding is finished, the piece is subjected to a quality control to detect defects on the unions. This control consists of a really strong flash of light aiming to a photo camera going through the welding. If this camera detects a lighter than usual zone in the union, it means the weld is not strong enough and will most likely break when being bended.

Once the birolla succeeds, it is taken to the expander, a tool that, as its name implies, expands the piece to more desirable dimensions as well as rounding the still flat zone mentioned previously. In this step is where most of the welding breakings happen, since it is the point where it experiences the most tension out of the process.

For this station, though, there are two different approaches: the classic one where the birolla is simply expanded without accounting its thickness, that stays pretty much uniform throughout all the piece; and the newest one called biconical, where the thickness of the rim is slimmed wherever it is structurally possible. The biconical approach manages to save up quite a bit of material in the manufacturing, but its scrap ratio and difficulty rating is also higher than its counterpart.

The following stage is the shaping of the rim. This process is divided in 3 different steps since, as it can be seen in Figure 8, the contour is pretty complex and cannot be done in one go. Trying to do it in one single shaping will most likely exert too much tension to the steel and degrade its properties/break the welding.

This particular stage is known in the plant as the “cylinders” due to the tooling aspect. These matrix are formed by three different cylinders each: one supports the birolla while the other two rotate rapidly making the rim roll and shaping it at the same time.
Once the outlining is finished the piece is already considered a rim, although it is not yet a complete product. What is still missing is the rim calibration, a process where the rim is expanded (again) to obtain the desired diameter and concentricity in order to be able to assemble it with its disc later on.

Following the calibration comes the “leak test”, a quality control where the existence of “leaks” is checked. These leaks are actually wholes on the rim surface, that were the wheel be mounted to a tire and inflated would allow the air to escape. In order to find these, the rim is placed in a bell shaped tool that applies air pressure on the inside. Then, with the help of some microphones, the leakages are found by “listening” the air flow through the cracks.

And finally, the last stage of the process is the cutting of the valve whole and marking the rim traceability (as opposed to the blank traceability marked earlier). Similarly as the welding stage, this whole has to be deburred to prevent tearing the tire valve when introducing it.

After that, the rim has to pass a last visual control carried by a worker to check for major faults undetected by the previous automated controls. If nothing is found, the rim passes to the undergrown transportation system leading to the assembly area.

**Disc Area**

The disc is the other component of the wheel, the visible part when mounted and commonly confused as the rim. Its production process is completely different from the rim one too this one is all about cutting and shaping through a vertical press, making the process much more aggressive than the former.

Much like with the rim area, the material comes rolled in a coil with similar widths (between 3-5mm) but slightly wider (usually around 400-500mm). Since the discs are also made of steel, although the properties differ in order to adapt to the different process, the material coming out from the coil is curved.
Thus, the first step in the process has to be the flattening of the material for the same reasons: starting off with the most similar conditions every time to reduce variability in the process.

In fact, the first two stages are almost the same as the rim ones, one being the flattener and the other the cutting press. This cutting press, though, has a semi-circular shape that allows for a bit of material savings since the blank can be slightly smaller. The press also leaves a mark in the material with information of its quality, the line and date of its cut, and the disc reference. In this process a blank stock is also generated that functions exactly as the rim one.

Up to this point, the process has been almost identical to the rim’s manufacture, but their similarities end right now. For the rim production, the lines are actually multiple machines connected between each other, where each step involves, at least, one unique machine. In the discs case, though, it is all condensed into one single press with 9 different stations.
The press moves as a unit every cycle and applies a force of around 50000N every time it comes downwards, which means that every single one of the nine work stations exerts a strength of around 5000N onto the steel. Due to the machines structure there are 3 extra stations that do not exert any kind of pressure: two of them are simply meant for transportation while the third is a holder where an automated mechanical arm picks the finished product and puts it into a conveyor belt.

The process, thus, can be divided into 9 different steps corresponding to each one of the press stations, and all of them are based around exerting pressure to either cut or shape the material into the desirable form. This process is the main reason steel wheels are so much simpler structurally wise than their aluminium counterparts: cold processed steel cannot be cut into complex patterns because it will not hold on, whereas the aluminium wheels are manufactured through fusion and moulding allowing for much more advanced structures without jeopardizing its structural resistance.

The first station consists of an initial encasing of the blank in a mould to obtain a first simple shape where the end result resembles quite a bit to a soup plate, preparing it for the second stage, one of the most critical steps of the entire process.

This second step is the punching of the central hole. It is critical because it determines the disc concentricity and, consequently, of the wheel. It is vital to maintain the concentricity in a really low level (which means centred) in order to ensure the wheel will function correctly, wasting as little energy as possible, ensuring structure stability and allowing the rest of the car components to work properly, axis, suspensions and high speed safety among others.

In order to maximize the precision in this station, the template is hold by pincers in its four edges, aligning it with the tooling, and then punching through the material leaving a hole behind. From this point onwards the disc will be subjected and adjusted through its central hole so any slight deviance is not carried to the following stations.
On stage three of the disc production process, the template is once again fit into a mould and then stamped to obtain its definitive structural shape, as well as the folding (or skirts) needed to weld the disc to the rim in the future. Furthermore, this station is also used to print the product with the vehicle brand and internal reference along with some information about the plant. This labelling is always on the inside of the disc so it is not visible from the outside when mounted on a car.

Then the fastening holes are cut. These are the future holding points between the wheel and the car transmission axis and are placed around the central hole. This process has to be really precise too, since the axis are made by another company and both parts’ holes have to be aligned.

Following this step, the fifth station flattens the holding holes surface to ensure the wheel and car axis contact area is the maximum possible, and calibrates the disc structure, especially the skirts’ width and depth.

The sixth and seventh stages following this first calibration are probably the most sensitive of the entire process since they are the most related to the disc structural resistance. In fact, it is this process that limits the steel wheels structure complexity, which is the disc windows piercing. Since it is a cold process, exerting this kind of pressure onto the steel makes it very likely to break, thus the design of both the disc and the matrixes are really restricted in terms of complexity.

Ideally, the windows would have to be as large as possible since it would reduce the amount of material used and therefore, weight. In reality, though, the stress the process exerts onto the material does not allow for many wonders. Although during this last years the designs have evolved a lot, obtaining larger windows every time, when comparing them to their aluminium counterparts, they fall really short in the visuals and structural resistance.

As mentioned previously, the window cutting process is divided in two stages, basically due to the press. Since it applies the pressure vertically, it is impossible to perforate in multiple directions in a single step. Therefore, the press first punches the vertical holes and then the horizontal ones, assigned to the sixth and seventh stations respectively.
As with all cuts and holes made in cold on a metal, the edges end up being really sharp, unsafe from later human manipulation. This issue is redressed in the step number eight, where the different holes and cuts are polished by being pressured.

Finally, the ninth and final step flattens again the central zone (which as explained previously is crucial for the car’s security and performance) to avoid any possible distortion provoked by the process. During this flattening, the central hole is also calibrated to redress slight concentricity deviations, which is the other critical measurement.

Once the disc has gone through this nine stations, a robotic arm picks them from the line and stores them in their designated cages that will be transported by a pallet truck driver to the Assembly Area, since, unlike the Rim Area, they are not connected.

**Assembly Area**

As its name implies, the Assembly Area is in charge of assembling the wheels per se. Using the rims and discs produced in the other areas, in this area both components are pieced together, welded and calibrated to obtain the final dimensions the client specified.

The rims get to the lines automatically through the underground connections. Once they are on the conveyer belt a robotic arm picks them up and positions them in a certain direction using a contrasting photographic system that takes the valve hole and weld line as reference. This way, the same conditions are ensure on every piece.

As for the discs, they are transported manually with a pallet truck to the beginning of the line, where another robotic arm plucks them from their cages and places them into the rim, also in a certain direction using a similar system as its counterparts. This particular positioning of the pieces is defined by the client specifications and is designed to ensure the wheel will lose the least structural resistance possible during the process.
Apart from being a requisition from the client, this particular orientation of the parts means the starting point of the process has the least variance possible, thus increasing the odds of obtaining wheels with lesser deviations. And, above all, standardizing any given process facilitates its later analysis and adjustment, therefore, its improvement.

Once the disc is placed inside the rim the fact that the former is slightly larger and it does not exactly fit in. This is done on purpose so when the disc is wedged inside the rim the material itself applies pressure, sticking it in its spot. Then the skirts depth is measured to ensure the positioning of the disc is optimal, both its vertical position and horizontality. Were it not to comply with the specifications, the wheel is pulled apart and marked as “to be reworked” (or just rework), wheels that will be readjusted at the end of the series.

The next step of the process and the most important is the welding. The welding machines possesses eight different nozzles that are used to bond the four skirts of the disc and the rim, ending up with eight different weld lines. These eight lines are then polished with their respective metal brush to eliminate possible irregularities.
The final station consists of an expander. This machine tries to give the finished wheel a more rounded shape that might have been lost during the disc fitting, while also increasing its diameter to comply with the final dimension specifications issued by the client.

All these dimensions are then checked through a quality control that also tests the welding. This automated examination deems the wheel as either OK, REWORK or NOK.

The NOK wheels are products that cannot be restored anymore, usually due to a bad welding. The REWORK ones can either be because the expander did not give it the proper dimensions, wheels that will be processed again at the end of the series; or as a result of a bad welding that can be recovered, process that is done by an operator manually. The good ones (or OK) just keep going to the next process, which is the painting, whose first station is right beside the assembly lines and is, for the most part, completely automated.

Although this process is, a priori, much simpler than the previous two, it is actually the most complex one since the variance on both the disc and the rim have influence and their effects are much more notable on the final product. This makes obtaining wheels inside the specifications and adjusting the different machines much more difficult than it is for the rim and disc operators, as well as producing a lot more scrap.

Paintshop

And finally, the last process the wheel has to go through before being ready to send to the client is the painting. The paintshop itself, though, can be divided in four distinctive stages: the hanging, chemical treatment, painting and final inspection.

This process is completely automated in almost its entirety: the wheels only have to be manipulated manually right before the hanging and depending on the situation. Most of the time, though, it is not necessary.
Furthermore, the paintshop is the largest area in terms of surface, since it occupies three different zones distributed around the shop floor, making the wheel transporting system travel across the plant. This transport is made up of hangers where the wheels are placed attached to a mechanical chain travelling in a constant speed around the plant.

Each of this hangers can hold up to three wheels, and to control what references are hung and where are they at the moment, each hanger has a small plate with a numerical code pierced in it. When the wheels are placed on the chain, the computer just reads and records the plate code as well as the row the wheel is hung on.

The wheels are hung up with a series of robots. These grab the wheels coming from the assembling and either puts them on their correspondent hanger, or places them on a pallet, depending on the situation. Most of the time, as soon as the wheels come out from the assembly line, they are automatically sent to painting and, thus, hung. When the robot hangs a wheel, it records its hanger code and row, information that will later be useful for the robots situated at the end of the line.

Sometimes, though, whether that reference is not scheduled for painting yet or the wheels come out of assembling faster than the chain can absorb them, the robot has to leave some on a pallet that slowly fills up. When it is full, a pallet truck has to come retrieve it and store it in a designed zone until it can be hung.

Once hung, the wheels follow the chain, going through all the other stages of the process, the first one of which is the chemical treatment. Before that, though, there is an initial visual inspection done by three operators at the same time (on for each row) that make sure the wheels coming through don’t have any major fault, either structural or visual. Were any of them be defective, it is pulled apart and most likely discarded since it is pretty difficult to amend any defect at this point.
After this inspection, the wheels start their chemical treatment or cataphoresis. In this stage the wheel is cleaned up and covered with a black paint coat that make the wheel more resistant to the typical steel corrosive effects, specially to oxidation due to air contact. In order to ensure the paint is adequately stuck, the wheel goes through ten different phases.

Before applying the painting, it is really important for the wheel to be as clean as possible: free of grease and particles. So much so more than half of the baths are meant to clean the wheels.

The first thing to be cleaned is the drill lubricant, the “taladrina”, an oil used to avoid scraping the steel when in contact with the different metal tooling. This is done through two steps. The first is a bathing on a neutral substance that peels off most of it, and then the wheels are subjected to an alkaline degrease that eliminates the rest of it using a low electrical tension.

Then the wheels go through four straight water bathes, the first one being form the public water network and the following three being demineralized. This way, it is ensured no impurity is left on the wheel, such as rests of oil or calcium and other public water impurities. All of this water is later reused after being filtered and cleaned.

---

**Figure 13 – Paintshop process flowchart**

---

26
Following this the wheels are exposed to hot air fluxes to dry them up so they can be inserted to the cataphoresis tank itself. This painting is done by applying a tension between the anodes submerged in the paint solution and the wheel that acts as the cathode, which makes it easier for the paint to stick to the steel.

Once the wheel is painted, another three stations where the wheels are filtered and cleaned again with demineralized water so there are no impurities or lumps left on the surface.

Finally there is an oven where the pieces are exposed to a hot and dry atmosphere and are “cured” so the paint is dried. Once the wheel is out, it can be considered as being finished, and most of them are sent to the customer like this, painted in black.

Sometimes, though, the client wants the wheels to be finished with another colour, usually a metallic one. In these cases, these given references are taken through a specialized cabin where a final coat is applied on top of the cataphoresis. This process is known as “top coating”.

Once with the desired finishing, the wheels go through a last visual inspection, very similar to the one right after the hanging, and finally get to the packaging area.

Packaging and storage

Once the wheel passes the final inspection the only remaining step is to unhang them and pack them up as per the client demand. The options are: wooden or metallic pallet and covered with a plastic film or not. Every pallet is then identified with a sticker and ready to be stored while waiting to be sent.

The unhanging and packaging is done by two different sets of robots. The first ones simply take the wheels from the chain and put them onto a small conveyor belt after reading the hanger code and identifying the desired reference, while the second ones pick them up from the belt and put them on the pallet in a designed fashion to ensure its stability when moving.
In total, the whole painting and packaging process takes around one hour per wheel, but since it is a linear process and wheels are coming in constantly the actual cycle time is way lower. In fact, it takes around 21000 wheels a day on average.

Once packed, the pallets are taken to the storage area to wait for the order to be finished and then sent. On average there are 176000 finished wheels, and each one spends 8 days waiting to be sent, while around 49000 are stored as consignment (not payed until used), averaging 2.3 days in storage each. In total, the manufacture of a single wheel, with all waiting taking into account, takes 17 days approximately from the material arrival to its shipment.
Value Stream Map Development

As stated in its aim, the goal of this project is to study the development of a Value Stream Map of the Maxion Wheels España S.L.U. wheel manufacture process. The project development can be divided in two different steps or phases.

On the one hand and in order to work in this kind of project one must be familiarized with the manufacture and its different processes as well as the ideologies behind (Lean and Six Sigma). This was the goal of the previous section, where their main aspects have been introduced and explained superficially.

And on the other hand there is the Material and Information Flow Analysis (also known as VSM) development itself which would be the main aspect and the final purpose of this project. This second phase is what this section will cover, going through all the different steps followed and tools used during the study.

In order to follow an easy-to-understand order, the development will be presented following the final document creation steps, even though most of the information gathering and studies were not made in this sequence.

Before anything else, though, and in order to avoid any kind of confusion later on, it is essential to have some sort of knowledge on the various tools and statistics used throughout the VSM, which will be referred to several times.

Tools used

Lead time

Lead time is “the amount of time, defined by the supplier, which is required to meet a customer request or demand.”

To put it plainly, it is the time it takes a single unit to complete a whole process, from the beginning until the end. This is measured by elapsed time, usually seconds, minutes or hours, depending on the length of the process.
This is a concept that is often misunderstood as cycle time and vice versa and in fact many people use them interchangeably, when they are actually two different and very important metrics in Lean and process improvement in general, and this can often lead to issues when detecting true problems.

**Cycle time**

“Cycle time is the total time from the beginning to the end of your process, as defined by you and your customer. Cycle time includes process time, during which a unit is acted upon to bring it closer to an output, and delay time, during which a unit of work is spent waiting to take the next action.”

As seen by the definition it is no wonder both cycle and lead time are confused between each other, since they are really similar when expressed in words. Actually, the Cycle time is the time it takes to a process to produce a unit, in other words, the inverse of the amount of units produced per time unit (or Throughput).

Put into equations,

\[
Throughput = \frac{\text{no of pieces produced}}{\Delta t}
\]

\[
Cycle time = \frac{1}{Throughput} = \frac{\Delta t}{\text{no of pieces produced}}
\]

It is important noting that this time is completely theoretical, since it assumes a perfect process. For most calculations, the value used is the *Actual Cycle Time*, which will be defined later.

These both concepts can also be related through another one, which is the Work in Process or WIP.

**Work in Process (WIP)**

The WIP is “the amount of work that has entered the process but has not been completed.”

The name itself is pretty self-explanatory, and it is simply the amount of pieces (or its material equivalent) between the first and last step of a process. It is also used in one of the methods to calculate the cycle time of any given process.
This method, which is in fact the one used later on, consists of measuring the average lead times for various pieces of the same reference and dividing it for the WIP of that process.

This means that, as mentioned previously, WIP is the metric that correlates Cycle time with Lead time and Throughput.

\[
\text{Lead time} = \frac{\text{Lead time}}{\text{WIP}}
\]

\[
\text{Lead time} = \text{Throughput} \cdot \text{WIP}
\]

**Takt time**

In German, *takt* is the word used to refer to the baton an orchestra director uses to regulate the tempo of the music. In Lean, it has a similar meaning, it “is the rate at which a finished product needs to be completed in order to meet customer demand”.

In other words, it is the maximum cycle time a process can have in order to meet with the quota agreed with the customers. If a process’ cycle time is lower than the takt time means it is working at a faster rate than what is needed, thus the demand can be fulfilled. On the opposite, if the cycle time is higher than the takt time, the demand will not be finished in time since it is going slower than what was agreed.

Unlike cycle and lead times, the takt time is not a fixed value. The first two are limited by the machine or process and have a limit depending on the performance of the process, meaning they cannot go lower than a certain amount. Whereas takt time varies depending on the order amount and deadline.

\[
\text{Takt time} = \frac{\text{Available time for production}}{\text{Required units of production}}
\]

In fact, adjusting the takt times efficiently is one of the main challenges the Logistics department have to face, since it has to take into account the various cycle times and efficiency of the sub-processes related to each reference. It has to be noted, though, that the cycle times used on these calculations has to be the actual cycle time.
Having a low takt time means having shorter deadlines, which means higher client satisfaction, but also risks not fulfilling the quota and losing said satisfaction. Having a high takt time, though, ensures the demands will be satisfied but also means longer deadlines which the client may not agree with. Either way it loses on efficiency. This is why organizing a process with an optimal takt time is one of the most crucial aspects of its success.

**Overall Equipment Efficiency (OEE)**

The OEE is a metric that combines different aspects of a manufacturing process that aims to identify the true percentage that is productive from a given process. In order to reach this percentage the OEE combines three different metrics such as Quality, Efficiency and Uptime. An OEE score of 100% would mean a process is manufacturing only good parts, as fast as possible, with no stops, or in other words a 100% on each of its three metrics.

\[
OEE = Quality \cdot Efficiency \cdot Uptime
\]

Measuring OEE is considered a manufacturing best practice, meaning it is one of the best considered metrics by the manufacturing experts. It is considered the single best metric for identifying losses, benchmarking progress and improving the productivity of manufacturing equipment.

There are five steps to follow to measure the OEE of any manufacturing equipment. To clarify, an example will be analysed throughout the five steps.

**Planned Production Time**

The first thing to determine is the amount of time the equipment is planned to work. This means subtracting all time where there is no intention of running the machine or Schedule Loss, be it because the plant is shut down, breaks and lunches or periods where there are no orders. This remaining time the Planned Production Time.

\[
Planned \ Production \ Time = All \ Time - Schedule \ Loss
\]
Example:

A manufacturing plant shift is 8 hours long (480 minutes). The demand right now is pretty high, so the equipment is scheduled to produce for as much time as possible. Since there are not enough machinists to make a full break rotation, there are 30 minutes scheduled for the operators to lunch. This means the Planned Production Time for this shift is 450 minutes.

**Uptime**

This metric takes into account the Availability Loss, which includes all the events that stop the planned production for a considerate amount of time, such as unplanned and planned stops. Unplanned stops include situations like equipment failures and material shortages, while planned stops are mostly changeovers.

While it is true that changeovers are planned and the first impulse would be to include them as Schedule Loss, thus not affecting the OEE, it is time that could otherwise be used for manufacturing since decreasing their lengths would increase production time.

Recapitulating, the Uptime of an equipment is the percentage of time previously planned where it is working. When multiplied by the Planned Production Time results in the Run Time.

\[
\text{Run Time} = \text{Planned Production Time} - \text{Availability Loss}
\]

\[
\text{Uptime} = \frac{\text{Run time}}{\text{Planned Production Time}}
\]

Example:

The same manufacturing equipment from the previous example, with a Planned Production Time of 450 minutes, works through the whole shift during which there is a 90 minutes changeover as well as an accumulated 42 minutes of breakdowns and unjustified stops due to various reasons.

Thus,

\[
\text{Run Time} = 450 - 90 - 42 = 318 \text{ minutes}
\]

\[
\text{Uptime} = \frac{318 \text{ minutes}}{450 \text{ minutes}} = 0.7067 = 70.67\%
\]
Efficiency

Much like Uptime, Efficiency is also a percentage, but this one is based on a theoretical estimation. This metric takes into account anything that causes the equipment to run slower than its maximum possible speed, be it a Slow Cycle or a Small Stop. Both causes can be considered as slight production halts short enough to not be tracked as Stop Time. The difference between them is simply their length and they are really subjective to the process. In Maxion Wheels’ case, anything under than a second is considered a Slow Cycle, while under five seconds is deemed as a Small Stop.

The way it is computed in Manresa is by estimating the maximum amount of units an equipment can produce during its Run Time using the Cycle Time and comparing this value to the actual output. The issue with this system is the cycle times have some differences between references that, although small, cause some inaccuracy in the results.

There are other and probably better ways to calculate Efficiency, but in Maxion Wheels there are not enough tools or systems to do so automatically and this is why it is done this way.

\[
\text{Maximum Output} = \frac{\text{Run Time}}{\text{Cycle Time}}
\]

\[
\text{Efficiency} = \frac{\text{Actual Output}}{\text{Maximum Output}}
\]

Example:

Following with the example, the manufacturing equipment can work with a cycle time of up to 12 seconds and at the end of the ship manages to produce 1450 units.

\[
\text{Maximum Output} = \frac{318 \text{ min} \cdot 60 \text{ s/min}}{12 \text{ s/unit}} = 1590 \text{ units}
\]

\[
\text{Efficiency} = \frac{1450}{1590} = 0.9119 = 91.19\%
\]
Quality

This metric takes into account Quality Loss or Fallout, which is all the manufactured parts that do not meet the quality standards. They can either be scrap or parts that need rework since they will have to be processed again thus not count as acceptable.

In other words, Quality is the percentage of good parts out of all the manufactured.

\[
\text{Fallout} = \frac{\text{Scrap} + \text{Rework}}{\text{Produced Parts}}
\]

\[
\text{Quality} = 1 - \text{Fallout}
\]

Example:

The same equipment as previously managed to produce 1450 units. Out of these, 38 are scrap and another 51 have to be reworked.

\[
\text{Fallout} = \frac{37 + 51}{1450} = 0.0614 = 6.14\%
\]

\[
\text{Quality} = 1 - 0.0607 = 0.9386 \approx 93.86\%
\]

OEE

The last step to obtain the OEE of any equipment, is to simply multiply its three metrics to merge them into one.

\[
\text{OEE} = \text{Quality} \cdot \text{Efficiency} \cdot \text{Availability}
\]

Example:

In the example then, the OEE is the following:

\[
\text{OEE} = 0.9386 \cdot 0.9119 \cdot 0.7067 = 0.6049 = 60.49\%
\]

This means the fully productive time of the equipment is 60.49% of the planned.

\[
\text{Fully Productive Time} = 450 \cdot 0.6049 = 272.21 \text{ minutes}
\]
Actual Cycle Time

As mentioned previously, when doing calculations based on any equipment Cycle Time, the one that has to be used is the Actual Cycle Time since it takes into account its performance, not only its fastest cycle time.

Obtaining the Actual Cycle Time is done through dividing it by the equipment OEE.

\[
\text{Actual Cycle Time} = \frac{\text{Cycle Time}}{\text{OEE}}
\]

This way, all the aspects that may affect the manufacture process are taken into account and the estimations are much more accurate.

Document Creation

A Value Stream Map creation follows seven steps which will be followed to describe the project development, which also coincides with the importance order given by

Step 1: Establish customer demand

Since both Lean and Six Sigma methodologies put the most emphasis on customer’s satisfaction, it makes sense for it to be the first step of the Value Stream Map Creation. To do that the different customers have to be identified.

Most of the time, the ones represented in a VSM are the most important ones, the ones that correspond to the 80% of the company’s total volume sales. In Manresa these customers are five, the names of which will be hidden due to privacy policies.

Furthermore, to differentiate the different aspects of the process, the customers are represented by this icon.
Once the customers are defined and drawn into the file the demand has to be defined. In this case, it is counted as trucks per day, although it could also be wheels per day. The reason behind this is because in the company’s case trucks are more expensive than weight and this information is more useful for Logistics.

In this case, the average trucks sent per day is 11. The average wheel quantity will be specified later on with the rest of the process data gathering. Another action taken is also the drawing of both consignment and warehouse storages since these are where the sent wheels come from, whose stored amounts will also be determined on another step.
Step 2: Define the process flow.

In the Introduction the manufacturing process and its different areas and sub-processes was described. This same sub-processes have to be included in the VSM. The way to illustrate them is through a table similar to this:

![Figure 16 – VSM Blank Rim Area Sub-process](image)

This table is filled information regarding the area it belongs to and the manufacturing lines it contains. The remaining blank spaces are reserved for the process related data and metrics. In total there are five sub-processes in Manresa, which are the Disc Area, Rim Area, two Assembly Areas for both particular cars and light trucks, and Paintshop (or E-Coat) with the optional finishing Top Coat, that amounts to around 20% of the total produced volume.

The overall process looks like Figure 17. What comes after this is the data gathering, during which some studies were carried since some information was outdated.
Figure 17 – VSM Blank Process Flow

Step 3: Gather data regarding the process.

This step would be the most important of the project as well as the longest, since a couple studies were done regarding the different lines. During this step, an automated system has been put in place to refresh the data periodically.

The main metric to be determined is the OEE of every line since together with their Cycle Time will allow for the Actual Cycle Time estimation, which is the data Logistics use to develop the whole plant Production Plan.

The main issue presented here was most cycle times were outdated (except for the 418-36), thus a study to determine them was carried by, a study that took most of this project dedicated time.

Cycle Time Analysis

To define the different lines’ cycle times, the method used was to determine the average Lead Time for the main references (the three most manufactured ones for each line with some exceptions) and then dividing it by their Work in Process.
Time measurements

The Lead Time measurements were done manually with a stopwatch. The stopwatch had a 0.01s measurement error. Three different references were chosen for each line and later, using the Production Planning, the measurements were scheduled. In one particular case, though, the line is used so little, only two references could be covered in the span of two months.

For each reference, up to three different complete cycles for each material roll were measured (there is between three and seven rolls in every coil) when possible, one at its beginning, another on the middle and the third on its end; and also distributed between different shifts. This was made in order to account for both material and setup variance as well as measurement errors. At the end of the day the differences were pretty much minimal and no variance trends were detected, which led to believe human measuring errors were most likely the most impactful.

To illustrate the analysis process, the rim line 413-74 study will be used as an example. All timings, though, have been modified to comply with the company’s privacy policies, so the results shown at any times do not comply with the process reality, although the proportions between different lines have been more or less maintained.

413-74 Cycle Time Analysis

In this case in particular, the line 413-74 is one of the most active in the plant, so scheduling its measurements pose no problem at all. The fact the measures were distributed almost equally between shifts and different material coils and all in the exact same reference, makes it one of the most accurate.

It is important to specify they were all from the same reference since in some cases, be it because the line is not used that much or the reference series are not long enough, different product references had to be used. Albeit having different reference numbers, these pieces have very slight variations between each other. This leads to the hypothesis their Cycle Time variance is small enough it can be considered irrelevant.
In fact, the final conclusion was the same as previously: man-made measuring errors were most likely more influential since no remarkable variance trends were detected.

In the 413-74 case, the measurement took place in the span of three days for each reference, taking, on average, around 15 and 20 measures every day up to a total of 50. The method followed was to select any template coming off the cutting press and following it visually through the whole process. The stopwatch would be started when the blank was picked up right after its cut and stopped when the rim was put on the conveyor belt, before the man-made visual inspection.

The Lead Times measured for each of the three references were then written on an Excel table.

Table 1 – 413-74 Lead Time measurements

<table>
<thead>
<tr>
<th>Reference 1</th>
<th>Reference 2</th>
<th>Reference 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Time(s)</td>
<td>Lead Time(s)</td>
<td>Lead Time(s)</td>
</tr>
<tr>
<td>89.22</td>
<td>100.46</td>
<td>99.73</td>
</tr>
<tr>
<td>90.10</td>
<td>102.24</td>
<td>100.03</td>
</tr>
<tr>
<td>90.46</td>
<td>100.69</td>
<td>93.32</td>
</tr>
<tr>
<td>98.26</td>
<td>101.21</td>
<td>90.71</td>
</tr>
<tr>
<td>99.26</td>
<td>98.81</td>
<td>100.03</td>
</tr>
<tr>
<td>90.20</td>
<td>102.07</td>
<td>100.03</td>
</tr>
<tr>
<td>90.63</td>
<td>102.08</td>
<td>98.06</td>
</tr>
<tr>
<td>96.69</td>
<td>102.03</td>
<td>100.38</td>
</tr>
<tr>
<td>97.29</td>
<td>105.10</td>
<td>93.74</td>
</tr>
<tr>
<td>97.30</td>
<td>99.68</td>
<td>93.57</td>
</tr>
<tr>
<td>97.38</td>
<td>102.73</td>
<td>100.71</td>
</tr>
<tr>
<td>90.43</td>
<td>99.76</td>
<td>93.96</td>
</tr>
<tr>
<td>97.41</td>
<td>100.47</td>
<td>98.87</td>
</tr>
<tr>
<td>97.54</td>
<td>98.22</td>
<td>92.94</td>
</tr>
<tr>
<td>97.24</td>
<td>100.50</td>
<td>92.25</td>
</tr>
<tr>
<td>95.45</td>
<td>99.59</td>
<td>100.75</td>
</tr>
<tr>
<td>96.16</td>
<td>98.11</td>
<td>100.50</td>
</tr>
<tr>
<td>97.30</td>
<td>100.15</td>
<td>100.52</td>
</tr>
<tr>
<td>97.17</td>
<td>101.76</td>
<td>100.50</td>
</tr>
<tr>
<td>97.84</td>
<td>100.47</td>
<td>99.36</td>
</tr>
<tr>
<td>96.06</td>
<td>99.07</td>
<td>94.43</td>
</tr>
<tr>
<td>97.51</td>
<td>100.01</td>
<td>98.76</td>
</tr>
<tr>
<td>96.57</td>
<td>100.21</td>
<td>100.07</td>
</tr>
<tr>
<td>98.52</td>
<td>99.91</td>
<td>100.56</td>
</tr>
<tr>
<td>97.59</td>
<td>100.07</td>
<td>99.51</td>
</tr>
<tr>
<td>97.31</td>
<td>99.69</td>
<td>100.29</td>
</tr>
<tr>
<td>97.53</td>
<td>102.22</td>
<td>100.27</td>
</tr>
<tr>
<td>97.31</td>
<td>100.04</td>
<td>99.74</td>
</tr>
<tr>
<td>96.22</td>
<td>101.27</td>
<td>99.83</td>
</tr>
<tr>
<td>97.52</td>
<td>99.72</td>
<td>100.46</td>
</tr>
<tr>
<td>96.11</td>
<td>99.05</td>
<td>102.13</td>
</tr>
<tr>
<td>97.67</td>
<td>101.26</td>
<td>95.63</td>
</tr>
<tr>
<td>97.76</td>
<td>100.12</td>
<td>95.56</td>
</tr>
<tr>
<td>97.52</td>
<td>100.01</td>
<td>95.86</td>
</tr>
<tr>
<td>97.76</td>
<td>102.64</td>
<td>101.07</td>
</tr>
<tr>
<td>97.48</td>
<td>99.62</td>
<td>96.95</td>
</tr>
<tr>
<td>98.25</td>
<td>103.27</td>
<td>98.98</td>
</tr>
<tr>
<td>96.23</td>
<td>101.55</td>
<td>96.62</td>
</tr>
<tr>
<td>97.64</td>
<td>101.10</td>
<td>96.82</td>
</tr>
<tr>
<td>97.39</td>
<td>102.32</td>
<td>100.31</td>
</tr>
<tr>
<td>98.60</td>
<td>99.73</td>
<td>97.34</td>
</tr>
<tr>
<td>97.83</td>
<td>99.27</td>
<td>95.27</td>
</tr>
<tr>
<td>97.79</td>
<td>99.52</td>
<td>101.06</td>
</tr>
<tr>
<td>96.05</td>
<td>99.22</td>
<td>101.24</td>
</tr>
<tr>
<td>97.59</td>
<td>99.59</td>
<td>98.84</td>
</tr>
<tr>
<td>96.07</td>
<td>100.01</td>
<td>95.93</td>
</tr>
<tr>
<td>97.23</td>
<td>99.66</td>
<td>93.94</td>
</tr>
<tr>
<td>98.40</td>
<td>99.65</td>
<td>95.91</td>
</tr>
<tr>
<td>96.57</td>
<td>100.68</td>
<td>90.21</td>
</tr>
<tr>
<td>98.01</td>
<td>102.28</td>
<td>100.62</td>
</tr>
</tbody>
</table>
When analysing the different references, the most compelling aspect is the lead times follow a normal distribution, as expected in every industrial manufacturing process.

The distribution curve for each of the reference ended up like this:

**Reference 1**

![Reference 1 Lead Times](image)

*Figure 18 – 413-74 Reference 1 Data Distribution vs Normal Curve*

*Table 2 – 413-74 Reference 1 Lead Time Normal Distribution Values*

<table>
<thead>
<tr>
<th>Reference 1 Lead Time Normal Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
</tr>
<tr>
<td>97.83 s</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
</tr>
<tr>
<td>0.514 s</td>
</tr>
<tr>
<td><strong>WIP</strong></td>
</tr>
<tr>
<td>28 units</td>
</tr>
<tr>
<td><strong>Cycle Time</strong></td>
</tr>
<tr>
<td>3.49 s/unit</td>
</tr>
</tbody>
</table>
Figure 19 – 413-74 Reference 2 Data Distribution vs Normal Curve
Table 3 – 413-74 Reference 2 Lead Time Normal Distribution Values

Reference 2 Lead Time Normal Distribution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>100.21 s</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.709 s</td>
</tr>
<tr>
<td>WIP</td>
<td>28 units</td>
</tr>
<tr>
<td>Cycle Time</td>
<td>3.58 s/unit</td>
</tr>
</tbody>
</table>
As observed, the normal distribution (blue bars) is pretty clear in their respective graphs when compared to the normal curve. With the three superposed,
Although there is some noticeable dispersion, it is expected since three “different” processes are being studied together and the sample size is not big enough to obtain a smooth curve. And while this is true, since the value used for future calculations is the cycle time and a slight difference of 1 or 2 seconds of lead time translates into just a couple hundredths of a second, the values obtained are deemed as valid.

Nonetheless, the tendency is pretty clear: lead times are all around 100 seconds approximately, being 99.35s the mean. With a Work in Process of 28 units, this
leaves the Cycle time on around 3.54 seconds per rim that will end up rounded to 3.5 s/unit.

This same procedure has also been followed for the rest of the lines with the exception of the 415-10 disc line, where only two references were used due to lack of scheduled production; and the 418-35 light truck assembly line, where another study was made recently and the data was taken from there. The study for the lines other than the 413-74 will not be included in this memoir but as an annex.

**OEE Analysis**

As mentioned previously, an automatic data gathering system has been put in place to calculate the OEE. This system consists of an Excel file that take the raw production data from the SAP, a German software corporation, production control system and puts it into a dynamic table. This table is updated every time a “Refresh” button is pressed.

Then, each of the sheets for each line reads and takes their related information from the table and displays it, as well as calculating its monthly and yearly OEE using the method explained previously. This file is being used by various departments since it is quite useful to assess each process productivity monthly. In the VSM case the data used is the previous year’s.

<table>
<thead>
<tr>
<th>OEE Analysis</th>
<th>41374</th>
<th>OEE</th>
<th>Task Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 22 – 413-74 OEE Sheet*
This information is later used in the VSM main window in order to illustrate the general status. Next to the area and line boxes there have been added some buttons that will bring the user to that particular line or area sheet to examine closely the data (steps 3 and 4 of the following figure, bottom left and bottom right respectively).

![Figure 23 – OEE Data Addition](image)

Once the data is included for each process, Step 3 is considered finished.
Step 4: Gather inventory data.

Once the process data has been defined, the next natural step is gathering information regarding the inventory, which is the amount of product being stored in the plant. There are 7 different storing points throughout the process, which are: disc raw material, rim raw material, finished discs, finished rims, assembled wheels, warehouse and concealment.

The inventory icon gives two types of data: the average amount of inventory being stored and its production coverage, the amount of time it takes for this inventory to dry out. This coverage is determined by either dividing the inventory level by the average daily wheels sold or multiplying it by the process takt time.

\[ Coverage = \frac{Average \ Inventory \ Level}{Average \ Daily \ Wheels} = Average \ Inventory \ Level \cdot Takt \ Time \]

The inventory data is collected in this following Table 6. The coverage is not included since the tkt time is still missing, which is determined in the next step.
Table 6 – Inventory Data

<table>
<thead>
<tr>
<th>Inventory Level</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc Raw Material</td>
<td>900 tones</td>
</tr>
<tr>
<td>Rim Raw Material</td>
<td>600 tones</td>
</tr>
<tr>
<td>Finished Discs</td>
<td>30000 discs</td>
</tr>
<tr>
<td>Finished Rims</td>
<td>15000 rims</td>
</tr>
<tr>
<td>Assembled Wheels</td>
<td>10000 wheels</td>
</tr>
<tr>
<td>Concealment</td>
<td>49000 wheels</td>
</tr>
<tr>
<td>Warehouse</td>
<td>176000 wheels</td>
</tr>
</tbody>
</table>

**Step 5: Define the delivery rate (in and out)**

To determine the delivery rate, the Sales department is consulted. They make an estimation based on previous years’ data and the current’s forecast. In this case, the daily wheels sold amount to an average of 21000 wheels every day. Taking the disc area as an example, whose inventory level is 30000 finished discs, the label ended up looking like Figure 26.

![Disc Area Inventory Data](image)

**Figure 26 – Disc Area Inventory Data**

As for the material suppliers’ delivery rate, the Logistics department is in charge of this data. They have both the average daily trucks and the coverage of the material inventory, so no calculations had to be made. The updated inventory data is collected in Table 7.
### Table 7 – Updated Inventory Data

<table>
<thead>
<tr>
<th>Inventory Level</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc Raw Material</td>
<td>900 tones</td>
</tr>
<tr>
<td>Rim Raw Material</td>
<td>600 tones</td>
</tr>
<tr>
<td>Finished Discs</td>
<td>30000 discs</td>
</tr>
<tr>
<td>Finished Rims</td>
<td>15000 rims</td>
</tr>
<tr>
<td>Assembled Wheels</td>
<td>10000 wheels</td>
</tr>
<tr>
<td>Concealment</td>
<td>49000 wheels</td>
</tr>
<tr>
<td>Warehouse</td>
<td>176000 wheels</td>
</tr>
</tbody>
</table>

This information is useful because it highlights the sub processes that have less margin when it comes to their productivity, such as the rim and assembly areas. These two cannot allow themselves to spend too much time without working since, on average, their inventory level will reach zero in less than a day.

This, though, does not mean either one is a process bottleneck, it simply shows which areas should have priority when suffering a setback, mostly in the form of breakdowns. The process bottlenecks are analysed and detected differently.

#### Step 6: Push or Pull?

The second to last step consists of, basically, drawing arrows between the different stages showcasing both material (black) and information (red) flows, while at the same time classifying it. Information flow can be either manual or electronic while material is either pulled or pushed.

To clarify, since it can be very misleading, a pull production system is one that explicitly limits the amount of work in process that can be in the system while a push production system has no explicit limit for its WIP. It has nothing to do with the physical action of pulling or pushing, as the name can lead to believe.
These various material and information flows are indicated with their particular arrow shapes:

![VSM Flow Arrows](Figure 27 – VSM Flow Arrows)

The main information flows of the process are from customers to Sales and then to Logistics, all of them usually being electronic although sometimes via phone call; then Logistics generates the Production Planning which is later communicated to the different process areas and is used to make the material demands via phone call, which is considered a manual information flow.

As for the material ones, both customers’ and suppliers’ shipments are “pulled” since the amounts sent are limited to the demand and there is limited space in the material storing area, while the in-process flows are “pushed”.

There is also another arrow shape throughout the process with the acronym FIFO written in it which means First In, First Out. This means that the order of entrance of units in the inventory is also the order of departure. This is done to avoid possible defects due to corrosion that may affect the pieces since they have not been chemically treated yet, the lesser time stored the better.

Finally, the map with all the different flows looked like Figure 28.
Step 7: Do the math.

With all the information in hand, the only thing left to do is to calculate the global process Lead Time. These numbers are calculated by using the weighted Lead Time average for each process using the production volume percentage and the average coverage time for inventory.

There is one point where doubt may arise of which process should be used towards the total which is choosing between disc and rim. The final chosen in this case is the rim area since it is the process bottleneck.

The reason behind this decision is because of the evolution of the market, where flow forming rims are much more appreciated and have more demand than the classic ones. In Manresa, the only line capable of producing them is the 413-31, which is also the slowest of the three and the only one scheduled to work 24h a day. As for the other two rim lines, their rim types demand is not high enough to have them at full capacity.
This leads to the inevitable conclusion that to increase the plant’s productivity, the only way is to increase the productivity, making it the bottleneck. At the end of the day, though, the value displayed on the VSM is the weighted average of the whole rim process and its average coverage time.

There are two times to be calculated in the VSM. The first one is the time it takes for one single wheel to be manufactured from material arrival to its shipment or Lead Time; and the other is the Lead Time minus the waiting times of the different parts, called Processing Time.

![Figure 29 – Process Lead and Processing Time](image)

Once this information is determined it is included at the bottom of the VSM and it can be considered as finished.

![Figure 30 – Finished Maxion Wheels VSM](image)
Conclusions

A VSM is a complementary tool and by itself offers “only” the big picture (which is really important when analysing an industrial plant manufacturing process), which makes it really difficult to jump onto conclusions on how to improve the process. Nonetheless, there are a couple observations that can be made.

The first thing worth noticing from this VSM is Maxion Wheels Manresa’s plant manufacturing process is pretty short to medium term oriented. Both its scheduling, posted eight days prior to production, and its inventory have decently short coverages.

This aspect makes the process really sensible to deviations from the planning, be it machine breakdowns and especially material shortages, since it means the process will be more time pressed and even having to slow down its production which translates to losses for the company.

Another interesting aspect to analyse is the takt time prediction made for every line. When entering any line’s data sheet by clicking on its “DATA” button detailed information is presented in a table with a couple complementary graphs, as seen in Figure 22. On the bottom right there is the takt time analysis one.

This graph takes to current real cycle time and compares it to the theoretical monthly takt time were the customer demand be the same as last year’s month. This graph does take into account the number of available days for each month, meaning if there are less work days than previous year the takt time will also be lower, thus lowering the margin.

In the 413-74 case in Figure 31, we can conclude the production levels can be maintained both October and November, while in January it could be increased compared to last year. On the contrary, in both December and February this matter cannot be achieved since the theoretical takt time is lower than the cycle time.
These two are the most obvious conclusions that can be extracted from this file but, as already mentioned, this is just a support tool and it is meant to be used simultaneously with some others in order to properly analyse a process.

The file generated through this project is currently being used in the plant with the actual process data, and the fact it is updated automatically makes it likely to be used during a relatively long time, or at least until the process varies noticeably.

On a side note, for this project neither bid specifications, technical drawings nor environmental aspects are relevant and they will not be included in the report.
References


