STUDY OF A LEAN MANUFACTURING LABORATORY: IMPROVEMENTS TOWARDS AUTOMATION

Master thesis – Kungliga Tekniska Högskolan (KTH)

Herrero Cuesta, José Manuel

Molina Gil, Bernat

ABSTRACT

The intention of the Master thesis is to suggest and provide a comprehensive picture of the improvements of a lean manufacturing laboratory installed in Kungliga Tekniska Högskolan (KTH) previously located in Atlas Copco's facilities.

This study is initiated with a solid literature review about learning factories, lean philosophy and automated manufacturing. This information, gathered in the literature review section, has allowed the acquisition of the necessary knowledge to first understand the functioning and design of lean laboratories, as well as to internalize the important role that these learning modules play in the development and research of companies. Corporations need these tools to smooth the transition to new, more competitive and efficient production systems. In the same way, as it has been commented, the thesis has the purpose of bringing the lean philosophy closer to the students. For this purpose, some of the most important tools that make up this philosophy have been studied and analyzed, seeking the best way to present it and implement it in the laboratory. Finally, the search for information has focused on the automated manufacturing; the advances in this technology together with the lean philosophy allow reaching higher levels of efficiency on the production and assembly lines. As it has been proven in several articles, automation is the ideal and necessary complement to the lean philosophy, as a preliminary step to industry 4.0. For this reason, automation solutions have also been sought to help the lean lab reaching a higher production stage.

In the second stage of this work there is an inquiry of the current assembly line, identifying the source of waste in time and resources. In this section the focus is on what the lean laboratory consists of, explaining how it is ran and what is the purpose of it. A detailed explanation of the components of the laboratory is presented along with, the disposition of it and the operations at each workstation. After this analysis, the results of the lean laboratory are shown and there is a following discussion about the results the students got in each stage, what aspects of the assembly were causing wastes and how improve them.

Finally, after the analysis phase, a proposal of improvements and a posterior discussion of their advantages and drawbacks are discussed, deciding which of the improvements should be put in place in the line. The improvements that are proposed in this work will aim to improve the line in 2 directions: the automation of the line and the inclusion of new lean manufacturing techniques that help the students to understand production and control.

Sammanfattning

Intentionen med denna masteruppsats är att föreslå och förse en omfattande bild av förbättringarna av ett "lean manufacturing" laboratorium är installerat på Kungliga Tekniska Högskolan (KTH), tidigare beläget i Atlas Copco anordningar.

Denna studie inleds med en omfattande litterär genomgång om "learning factories", "lean philosophy" och automatiserad tillverkning. Denna information, som är samlad i den litterära genomgångsdelen, har tillåtit förvärvningen av nödvändig kunskap för att kunna förstå funktionen och designen av "lean laboratories", så väl som att poängtera den viktiga rollen som dessa lärande moduler spelar i utvecklingen och forskningen av företag. Företag behöver dessa verktyg för att jämna övergången till nya, mer konkurrenskraftiga och effektiva produktionssystem. På samma sätt som den har blivit kommenterad, har uppsatsen ändamålet att bringa "lean philosophy" närmare studenterna. För detta syfte har vissa av de viktigaste verktyg som utgör denna filosofi blivit studerade och analyserade, för att hitta den bästa vägen till att implementera dem i laboratoriet. I slutändan, har sökningen efter information varit fokuserad på automatiserad tillverkning, framstegen i denna teknologi tillsammans med "lean philosophy". Dessa har tillåtit att nå högre höjder av effektivitet för produktion- och hopsättningslinjerna. Som det har bevisats i flera artiklar, är automatisering idealet och ett nödvändigt komplement till "lean philosophy", som ett priluminärt steg till "industry 4.0". På grund av detta, har automatiserade lösningar också eftersträvats för att hjälpa "lean" laboratoriet nå ett högre tillverkningsstadium.

I den andra delen av detta arbete finns det att en utredning av den nuvanrande hopsättningslinjen och en indentifiering av källan till slöseri av tid resurser. I denna del läggs fokus på vad "leanproduction" innebär, hur den används och syftet med den. En detaljerad beskrivning av komponenterna av laboratoriet, dispositionen av dem och operationen vid varje arbetsstation. Efter denna analys, kommer resultaten av "lean laboratory" att visas och de följs av en diskussion om resultaten eleverna fick fram i varje stadium, vilka aspekter av hopsättningen som orsakade slöseri och hur man kan förbättra dem.

Till sist, efter analysfasen presenteras förslag om förbättringar och en senare diskussion om deras för- och nackdelar som leder fram till vilken av förbättringarna som ska sättas på plats i linjen. Förbättringarna som presenteras under detta arbete kommer att sträva efter att förbättra linjen åt två håll: automatiseringen av linjen och inkluderingen av nya "lean manufacturing" tekniker som hjälper studenter att förstå produktion och kontroll.

INDEX

FIGURES AND TABLES INDEX

1. Introduction

The intention of the Master thesis is the improvement of a lean manufacturing laboratory placed in Kungliga Tekniska Högskolan (KTH) granted by Atlas Copco. The lean laboratory was being used in the "Production Engineering – Planning and Control" the previous years in Atlas Copco installations and this year was acquired by the KTH. Now that KTH owns the assembly line, some improvements are required in order to be able to increase the concepts taught in the course laboratory.

During the master thesis there will be an inquiry of the assembly line, locating the source of waste in time and resources. After the analysis phase, there will be a proposal of improvements and a posterior discussion of their advantages and drawbacks, deciding which of the improvements should be put in place in the line. The improvements that will be proposed along this master thesis will aim to improve the line in 2 directions: the automation of the line and the inclusion of new lean manufacturing techniques that help the students to understand production and control.

During this section there will be a description of what the lean laboratory consists of, explaining how the students run it and what is the purpose of it. There will be also a detailed explanation of the components of the laboratory, the disposition of it and the operations of each workplace. After this analysis is made, the results of the lean laboratory will be shown and there will be a following discussion about the results the students got in every stage, what aspects of the production were causing waste and how improve them.

1.1. Lean Manufacturing laboratory

The lean manufacturing laboratory consists in an assembly line where the students will play the role of operators and will have to produce an output screwing pieces and plates; other students will play the role of logistics, replenishing the materials needed. The line is divided in 6 stations and 1 quality station where the operators have to work in shifts of 10 minutes to deliver the pieces to the client. After one product is finished it will be inspected by a quality operator who will check the position of the pieces and plates and the tightening torque of the screws. The aim of this laboratory is to make the students realize, based on their own experience, the lack of efficiency and the waste focuses in the line, applying lean techniques to reduce them.

The product the line has to make is shown in picture 1, it is “the house of lean” made of 11 blocks, 36 screws and 11 plaques, showing the lean principles applied during the laboratory. The final product has 2 variants, in where the upper block below the “ceiling” is blue and another one witch is transparent. These variants will not be taken into account until the last stage, where the customer will give information of which variant wants and when does he want it.

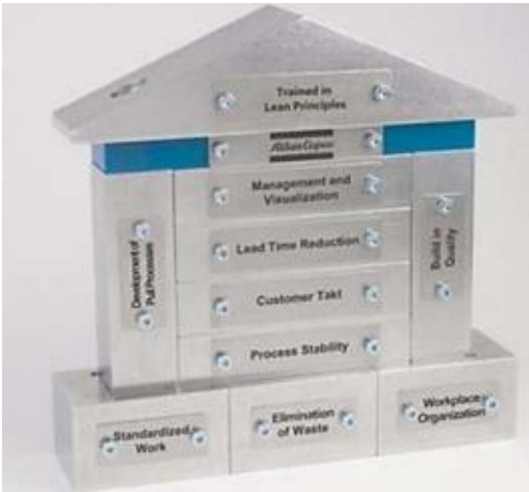


Figure 1: Final product of the lean manufacturing line

The operators will have to assembly all the pieces with a screwdriver that has 3 different heads, every time the operators changes the screws he is tightening he will have to change the screwdriver head by his own.

The objective of every running cycle is to produce 5 complete pieces without any defects during 10 minutes of production.

$$Takt\ time = \frac{Available\ time}{Number\ of\ items\ to\ deliver} = \frac{600s}{5} = 120s$$

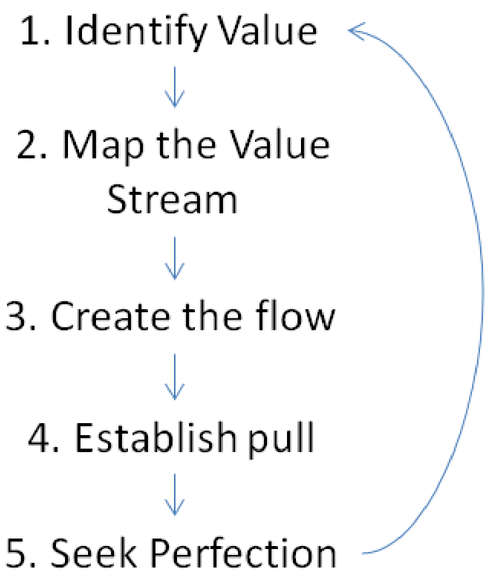
The Takt time is marked by the customer and indicates how often a new product must be produced to meet the customer's demands. Therefore, the Takt time gives valuable information to know the rhythm at which the line must work, that is to say the cycle time, which must be lower than the Takt time.

2. Literature Review

2.1. Lean Manufacturing

Before explaining what is a lean learning laboratory and what it is its purpose, it is important to explain what lean manufacturing is. Lean manufacturing is a production method that provides a way to specify value, line up value creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively. Lean manufacturing is a philosophy developed in Japan, when the Toyota main executives focused on reduce the waste in the manufacturing systems; Taiichi Ohno defined the first seven types of waste in an assembly line, which will be explained above. To eliminate this waste and convert it into value creation they started to implement the lean thinking into all the activities related to the production, trying to create more value with less resources and getting closer to provide to the customers what they really need.

Lean manufacturing is a management model that focuses on minimizing the losses of the manufacturing systems at the same time it maximizes the value creation for the ending customer. It should not be mistaken with a cost reduction method, applying lean manufacturing means transform waste into value to the customer, not only reduce waste. There are 5 main principles (Fig 2) to establish lean manufacturing [1]:



1. Identify value from the standpoint of the end customer by product family.

2. Identify all the steps in the value stream for each product family

3. Make value flow continuously

4. Let customers pull value from the next upstream activity

5. Pursue perfection: Pursue continuous process of improvement striving for perfection

Figure 2: Fundamental lean principles [1]

2.1.1. Define Value

Define the value is often one of the most difficult task during the lean implementation. Most manufacturers want to produce what they already are making and when they decide to redefine value, they usually fall back on the same ideas: Cost reduction [2]. Same happens with the customers, who only know to ask for variants of what they are already getting. Another reason of why the companies find difficult to identify value is because the value flow usually goes through different areas. Each area defines the value to suit their own needs but the addition of them is not the value of the entire production. This may be an example of how the individual operations can be optimized but the complete production system is wasting resources. Identify the value requires producers to talk with the customers, not only outside the company but with the different operations upstream and downstream. It is vital to accept the challenge of redefinition because it is often the key to attract more customers, and this is very important. As one of the lean principles is to assure the assets of the company, such as the employees, if they reduce the waste and produce more with less, the company will have to find quickly more customers and sales. The most important phase in defining the value, once the product is defined, is to determine a target cost based on the resources available, doing this is the key to reduce the waste.

2.1.2. Value Stream Mapping

The first step towards the lean implementation is to identify the value creation of the manufacturing process. It is important to define which processes are creating value to the costumer, which ones are non-value adding but necessary and which ones are non-value adding. One tool used to identify this value flows is the Value Stream Mapping (VSM), the VSM helps the companies to identify the value creating activities and highlights where the improvements can be made in a specific workflow or process [1]. The method is based in one simple premise: the activities must be measurable and they have to be well defined (they have to have a clear beginning and end) in order to be able to improve them and eliminate the waste.

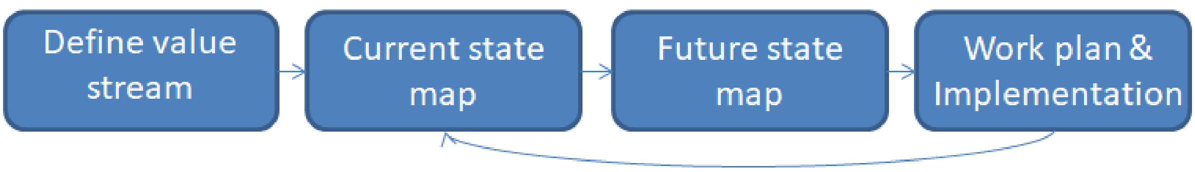


Figure 3: VSM process [1]

Besides the non-value activities the waste in the production system has to be detected. Waste is anything other than the minimum amount of equipment, materials, parts and working time which is absolutely essential to add value to the product or service [2]. The creation flow is focused on 8 types of waste:

Overproduction: It results from producing more than the actual demand or producing earlier than it is needed. I.e. Unbalanced line, unstable schedules, unreliable process.

Waiting time: Waste of being idle when two interdependent processes are not completely synchronized. I.e. Long set up times, batch production.

Motion: Waste of motion is any motion of a resource (can be both operator or equipment) that does not add value to the product or service. I.e. Poor method design, poor workplace organization.

Transportation: Transporting products from one location to another, is a cost incursion which adds no value to the product. I.e. Poor lay-out, large batch sizes.

Overprocessing: Overprocessing is adding more value to a product than the customer actually needs.

Inventory: Carrying stock attracts cost & storage problems. Storage leads to stacking, racking, sophisticated computers, bar coding & automation, all for an activity that adds no value to the product. I.e. Unbalanced work flow, large batch sizes, unstandardized processes.

Defects: Defects are the products/services that deviate from what the customer actually asked for. I.e. Unskilled workers, excessive stocks, transportation.

Do not use people creativity: Failure to involve the workforce in the design and development of their workplace to incorporate practical solutions and build ownership leads to suboptimal performance.

2.1.3. Establish Flow

When you look to the majority of the processes along the production, the product spends most of the time waiting to be processed; it is just in a few moments when the product is actually acquiring value[2]. The amount of time waiting is a waste as seen previously, to avoid this waste it is necessary to establish a flow along the processes where the product spends the minimum time possible waiting and the maximum acquiring value. There are three techniques to establish flow. The first one is, once value is defined, maintain the idea of the product, and remember what is its specific design and order. The second task, which makes the first one possible, is to forget the traditional boundaries of the tasks and jobs so you can eliminate all the impediments of the continuous flow of a specific product or product family. The third one is to rethink the works and activities to reduce the waiting time, back lows and scrape along the production.

2.1.4. Pull System

Pull system is one of the foundations on which lean philosophy is based. In this system the clients are the ones that ask for the product. Instead of make the machines at maximum rate, they are producing to satisfy the demand of the client downstream. Therefore it is the downstream customers who launch the production order for their predecessor station[2]. With this system it is possible to reduce the amount of WIP present in the system, reaching the ideal of a one-piece flow. In order to implement these systems it is necessary to use for example Kanban cards. The Kanbans can be cards or signals of different kinds that indicate to the predecessor station when to start working, but in any case it is a way to pull the system to produce when necessary.

2.1.5. 5S

The typical second step towards the implementation of the lean approach is the workplace optimization; this optimization is described as housekeeping (5S) [2]. The 5S is a workplace organization method, based on Japanese terms which represent:

5S Term	Japanese Term	Summary
Sort	(整理) *Seiri*	Eliminate what is not useful
Set in order	(整頓) *Seiton*	Organize the workplace effectively
Shine	(清掃) *Seiso*	Increase the cleanness in the workplace
Standardize	(清潔) *Seiketsu*	Establish rules to prevent dirtiness and disorder
Sustain / Self-discipline	(躾) *Shitsuke*	Make all the “S” an habit and audit them

Table 1: 5S terms

Nowadays the companies have included another term:

5S Term	**Japanese Term**	**Summary**
Safety	(安全) Anzen	Keep the workplace safe

Table 2: 5S terms added recently

2.1.6. Seek Perfection

As a value is specified, value stream maps are identified, waste is removed and flow and pull is introduced into the processes. To reach a perfect state of 0 waste and 100% of value added, it is necessary to start all over again and repeat this processes continuously.

2.2 Lean Learning Factories

Learning factories create a reality-based production workplace as a learning environment. Here the trainees can experiment, test and discover the technology implemented as well as get used to the distribution and the performance of the workstation. The main objective of these training environments is to develop effectively the competency and ability of the participants into complex or unfamiliar situations. These trainings do not only focus on the production areas, learning factories create value by upgrading the skills of factory staff along the value chain at all hierarchical levels in different technological and organizational areas of action. Therefore, it can be say that the backdrop of the learning factories is mainly didactic but with a powerful real application. Each learning factory is unique: although the purpose of two learning factories is the same, i.e. they try to simulate a real environment of a particular workplace; each company´s laboratory will have their own characteristics.

In order to be able to measure the performance of a Lean Lab, as it is defended in the article [3], the 'Magic triangle' needs to be considered. The Lean philosophy has been presented previously as a methodology that allows achieving higher levels of efficiency of the assembly line through the reduction or elimination of the waste. As it can be observed in the figure 4, in this 'magic triangle' three main areas are going to be studied to be able to determine how effectively the implemented Lean Lab is helping our system to achieve its goals. These areas of study that compound the corners of the 'Magic triangle' are Quality, Costs and Time. As it has been explained before in the lean philosophy the capacity of the assembly line is one of the parameters that benefit directly from the introduction of the lean philosophy. The application of lean tools as 5s, standardization or automation brings to the assembly line a higher number of products obtained in a certain time. This makes it possible to achieve previously unattainable takt times imposed by the customer. At the same time the application of lean tools as pull systems, build in quality or Poka-Yoke instructions helps to push wastes and production defects to the surface. Making it possible for them to be solved, thereby making the machines currently on the line work more efficiently. This gives the system a reduction in costs or at least an increase in profits while keeping costs constant. And finally, significant improvements in production and system capacity lead to improvements in quality. An example of achieving the three objectives presented in this 'magic triangle' is that you get the number of products the client wants in less time, with less expense and with the quality you want at the first time. In other words, we obtain a reduction in production times, with a reduction in costs and producing the desired quality at the first time. All this is supported by the improvements made by the Lean system in the productivity and capacity of the assembly line.

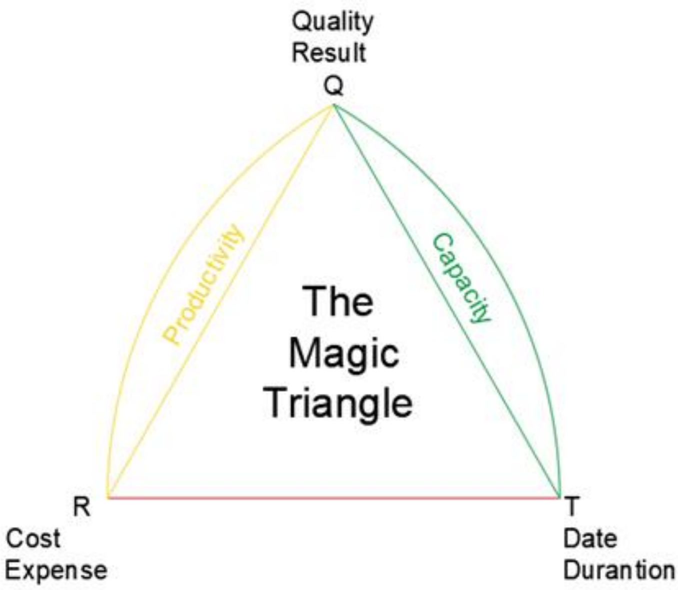


Figure 4: Magic triangle [3]

As defended in [4] there are different types of learning factories, one of them is the industrial application scenario. The companies found really profitable to simulate the new production methods or lines in order to provide to their workers, new competences and skills. This competences and skills will allow maintaining a sustainable productivity. Without this training environment some companies found impossible to properly introduce a new production method to their factories. This is because the incorporation of learning laboratories softened the introduction of incremental and even radical changes in the assembly line. Another type of learning factory is the academic application scenario. Where learning factories act as a physical educational platform to help the students to understand the theoretical concepts explained in class that may not have been fully internalized. This training module allows the students to have a hands-on experience into real life applications. These laboratories are also focused on motivating the students through an action-oriented learning. A third type of learning factory is the remote learning scenario, where the factory environment is integrated with the factory. The academic lab and the factory are connected through a bi-directional knowledge communication channel that brings the classroom to the real factory. This remote interaction between the engineers and the students allow working together on real-life problems. The forth learning factory type is the changeability research scenario, which consists of modules that can be easily reconfigured to modify the layout of the system and its functionality. The knowledge that is acquired in these factories is based on the product design, customization and personalization. The fifth type of learning factory is the Consultancy application scenario, also called consulting business learning factories. Which are applied in the same way as the ones used in the previous industrial application scenarios. The sixth and last learning factory type is the Demonstration scenario, which is responsible for the demonstration of the ideas of future production scenarios. Simulating the functionality of the new systems getting the basic understandings of the performance of the new system and the possible interaction with the environment.

In order to create a learning factory that achieves the desired results for the participants, it is necessary to be clear about the purposes of these training modules. When creating a learning factory, it is important to create an environment that recreates the factory, allow the workers to interact and experiment with the environment and with the changes wanted to be introduced in the assembly line. And finally, the effects of the environment on employee training will be studied.

Moreover, as it is stated in [5] it is crucial to understand to whom is the training module addressed. Knowing the main target of the laboratory allows adapting it to increase the efficiency. It is not the same to design a learning factory for experienced workers than to do it for students. On the one hand the workers possess a higher tacit knowledge and need a deeper help of debriefing, guidance and group-reflection. Whereas on the other hand, the students have a higher explicit knowledge, so the knowledge they possess is more portable what allows them to transfer knowledge from one domain to another.

Once the purposes and the main target of the laboratory are visualized and clarified, it is important to implement a laboratory operation that engages workers to continue learning and advancing in training. As it is stated by Kolb [5] with the Serious gaming theory and lean production games, there is a flow channel which must be followed to get the participants involved in the training. This flow can be observed in figure 5, which represents 3 main zones, the Frustration zone, the Boredom zone and a zone in between. The latter, in which the operation of the laboratory must be found, is divided into the learning cycle zone and the gaming zone. To provide a proper balance between learning and entertainment for participants, laboratory development should wave between these two zones as the difficulty of the game and the level of the player increases.

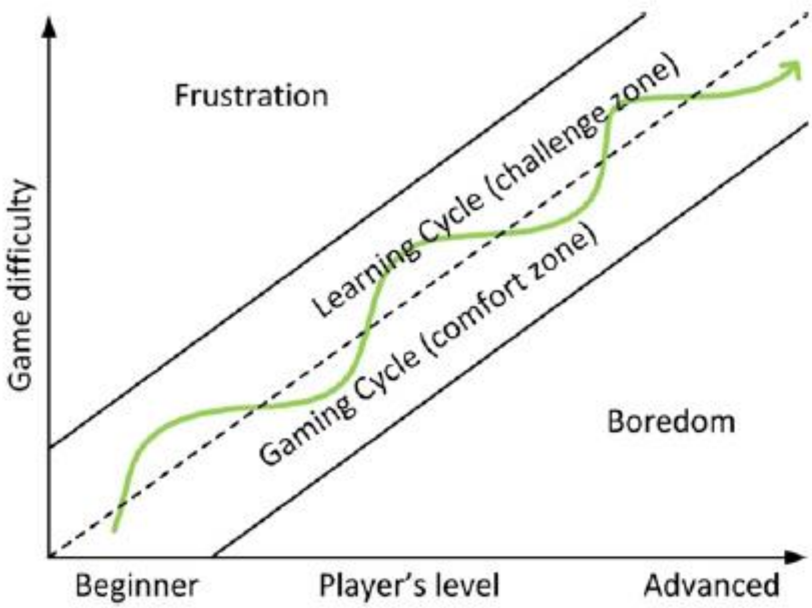


Figure 5: Flow channel according to Kolb [5]

This wave between the challenging zone and the comfort zone is described graphically in Figure 6. It can be observed how the two zones are cycled connected and mutually feeding to achieve higher levels of learning. In the challenging zone the participants observe the performance of the laboratory, they reflect and then they plan the next step it should be applied. On the other side of the picture, in the comfort zone, once the participants have reflected on and decided on the plan of action, they implemented in the system. Once the implementation of the improvement has been applied it is time to again observe on the results obtained.

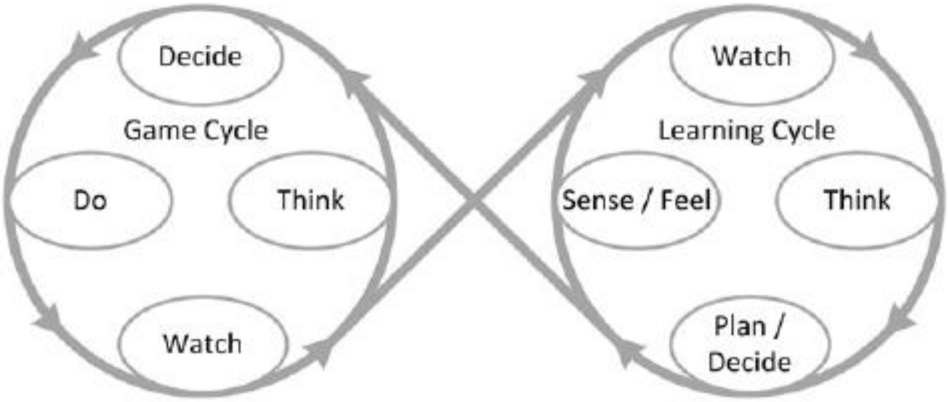


Figure 6: Flow channel according to Kolb [5]

In order to allow participants to advance towards new challenges and thus expand and strengthen knowledge, the laboratory must evolve. To this end, as it can be observed in Figure 7, a series of interaction rounds with the laboratory and breaks for discussion and reflection are prepared. During these interaction rounds the workers have an objective and rules presented at the beginning and for a limited time the workers interact with the laboratory. Once the time allotted to each round is over, the participants meet and discuss the most important aspects observed. These discussions also encourage reflection on proposals for improvement for the next round. And so on, different rounds would be advanced to reach the most optimal assembly line possible thanks to the introduction of the lean philosophy.

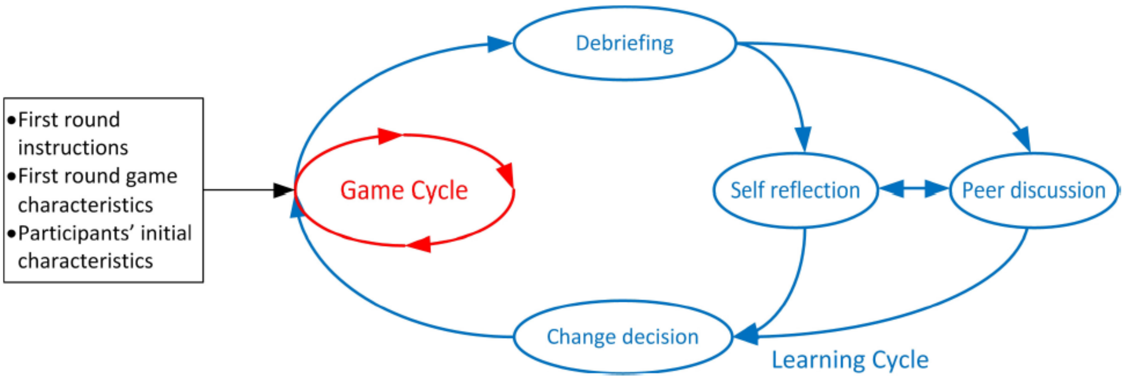


Figure 7: Flow channel according to Kolb [4]

Lean manufacturing is a methodology that brings to the company great improvements on the quality of the products or services, an optimization of the processes and a reduction on the production time. All of these are achieved thanks to the different tools that compound the lean systems, which are responsible for monitoring the value flow and minimizing the waste. But to convert an assembly line to a lean assembly line it is not a simple thing. There are several concepts of lean philosophy that must been understood by the managers and the workers before designing or getting to work on the new line. As it has been explained before each lean system is unique and not suitable for any other assembly line, the wastes need to be identified and the value flow tracked for each specific assembly line. Moreover, the workers that are going to interact with the workplace need to be informed, and more important they need to understand and feel the lean philosophy in order to allow the new system to deliver its maximum potential. Many companies misunderstood these first ideas and the results obtained from the new system were not the ones expected. The design and operation of a line inappropriately, in addition to being a great waste of resources, prevents the company from providing adequate services. For this reason the lean learning factories acquire a special value on the industry. It could be said that it is a necessary step for any company that wants to embrace the Lean philosophy in an appropriate way. Moreover, from the point of view of the education centers, the concepts of the lean philosophy are not completely internalized by the students through the theoretical classes. The students know how the functionality of the principles and the tools, but they are unaware of how to use them. Because of this, the principles of lean manufacturing need to be studied before, in the theoretical lectures, but the students will understand the powerful of this tool by “hands-on experience” in real life applications which are provided by the learning factories. These training modules are the door through which the students get into the Lean culture.

As mentioned above, the reason why the concept “factory” is used in this type of training modules is because it seeks to simulate the real environment found in assembly lines. But it is also important to highlight the relevance that the concept “learning” has in the name chosen to describe this methodology. Already from the name of the method, with the word “learning”, is presented the motivation and the path through which it is wanted to make known the desired concepts. One could think that learning and teaching could be synonymous in a certain way, but it has been chosen “to learn” for a very important reason. In these training centers the participants learn for themselves the importance, the mechanisms and the application of lean philosophy. It is the experience they acquire by interacting with the environment what gives them the knowledge. It is true that there are people in charge of guiding these trainings with an explanation of how the workshop works or through mediation in the discussions, but are the participants who discover the background. It is for this reason that we must be aware of maintaining the purpose of these laboratories, which is more to let the participants to learn than to teach them. This is achieved by developing a learning factory that provides all the necessary tools for participants to discover by themselves and through the experience of interacting with

2.3. Manufacturing automation and lean manufacturing: definition and relation

Automation has been taking part of manufacturing for many years. It is a well settled technology that liberates the workers of hazard or repetitive duties, allowing them to devote themselves to other tasks. Moreover, as Automation bases its operation on the repetitiveness and on the reduction of the variance in the output, standardization and build in quality are more attainable. But it is important to remark that not all the processes could be automatized, it depends to a large extent on the development of the right technology. So there may be the situation where a particular process has to wait a while until the necessary technology for automation emerges. However, the development of technology is having great upgrades in recent times, mainly due to the emergence of various technological advances such as Big Data, robotics, machine learning, artificial intelligence and Internet of Things among others. As it is stated by Harminc Drive in the article [6] robotics trends are driving a revolution on the manufacturing automation. Especially the so-called cobots, which are responsible for working side by side with human workers improving efficiency while reducing hazards. One of the main improvements related to cobots is that being more compact and versatile they can be used for a greater number of applications saving valuable space in the factory or in the warehouse. In addition old systems can be remodeled, so that they can be adjusted to new production requirements without having to make a large outlay. But, as Mckinsey presents in [7] automation is not being applied in all processes where it could be used with the technology currently available. It means that there are other factors, beyond the availability of appropriate improvements in technology, that influences the likelihood of introduce automation to a manufacturing process. Moreover, there are five conditions that directly affect the implementation of automation in production. The first condition to be meet is the technical feasibility for automating a given work activity. The second condition is the cost of developing and deploying both the hardware and the software for automation. Although once automation is implemented the economic benefits are, in most cases, significant, the company must be able to make the first investment. The third condition is related with the cost of labor and connected supply and demand dynamics. An example could be when there is a large supply of workers at a price below the cost of working with automation. The fourth factor is the benefits the company can obtain beyond the labor automation, here it is included the higher levels of output, the improvement of the quality and the reduction of the errors. And finally, the fifth factor to consider is to take into account the regulatory and social-acceptance issues. This last factor is referred to the degree in which the machines are acceptable in any particular setting, especially when they interact with humans. Also, another aspect that the manufacturer needs to consider is the automation maturity, which helps to capture as much long-term value as possible from automation. The automation maturity has a spectrum of four stages. The first stage is the Low maturity in which the infrastructure for employing the automation is limited. Maybe some basic sensors of pressure, flow or temperature as well as simple task execution. On the second stage is the Mid maturity in which it can be found an important automation infrastructure placed but with only a small part of this potential used. This is the case when there is a great quantity of sensors distributed on the assembly line but the majority of the data is not used, the value streams is not optimized and the data-capture is low. In the third stage there is the High maturity, where the traditional technology available is used to its full potential. Here the technology is used to display advance programming optimization routines or to create automation centers of excellence. And finally, in the fourth stage the Best-in-class, where the latest technology is applied at its full potential for the best possible outcomes. Here we found the utilization of latest optimization automation programing as Artificial intelligence or advanced robotics.

Lean manufacturing is a management model focused in minimizing the losses in the manufacturing systems at the same time it maximizes the value creation for the ending customer. By the implementation of a lean manufacturing system the company is improving the quality of its services or products and at the same time increasing the efficiency. In the theory [8] it is explained that Lean Manufacturing considers a waste anything that is not related with the creation of value for the end customer. It is true that there are other production strategies that have the objective of increase the value for the end customer. But it is in the Lean Manufacturing where the focus is on the improvements that can be made on the entire value streams whereas most of the other methods tend to focus on individual processes [9]. To achieve this, it uses the minimum amount of resources needed for the growing. Lean manufacturing is a method that aims to maximize the utilization of the industry capacity by minimizing the waste in all its forms. Applying properly lean manufacturing the efficiency and the production of the line increases, this is a consequence of the importance given by the Lean Manufacturing to the reduction or elimination of the non-value-adding activities, which is the main objective. Some of the key principles on which the Lean philosophy is based are perfect first time quality, continuous improvements, minimization of the waste by eliminating the non-adding-activities, the flexibility and the long term relationships.

The economies are growing and production systems need to adapt. Lean systems have been shown to help to optimize production, reduce waste and focus on the value chain, but they need to cope with new situations. An example might be the fact that the Lean production system has been focused so far on the human-centered production systems. Which, despite having great flexibility, have some drawbacks. Some of these setbacks are the length of training processes for a worker, the difficulties of finding specialized operators and the fact that the workers are not errors-free. Finally, as it is stated in [10] there is the threat of the "job-hoppers”, which is counterproductive when it comes to having well-trained and specialized workers in the processes carried out on a given assembly line. In order to cope with this situation and as the technology is advancing by leaps and bounds; it is almost an obligation to introduce these technological advances into production systems as efficient as the Lean manufacturing. For this reason, to prevent that human errors or other inconvenience causes lean systems to become outdated and affects production and also maintaining the necessary flexibility that characterizes it, a lean automation is created. This combination of lean manufacturing with the technology provided by the manufacturing automation allows extracting values close to 100% of the use of the machine while maintaining flexibility. It is possible to improve what they consider essential, the rhythm of work of the teams by integrating signals and connections between workstations, but maintaining as a priority the focus on the value stream and the minimization of the waste. One of the main drawbacks that this combination is the expenses of this improvements, which may further impede companies located in developing parts of the world from competing with more powerful companies.

Doing more with less by employing ‘lean thinking'. Lean manufacturing involves never ending efforts to eliminate or reduce the waste in design, manufacturing, distribution, and customer service processes. Some countries, especially those in the process of development could find difficulties and barriers on its intention to implement the lean principles to their assembly lines. This is because they do not have the same economical possibilities to change the distribution of the assembly line in order to minimize the wastes. This is not just due to the cost of the materials employed in this new distribution, it is also due to the pre-study the company needs to conduct in order to locate value stream and identify waste. This pre-study is crucial since each factory is unique and the implements required are not the same from one assembly line to the other.

On the other hand automation is settling as a mature technology, the prices of these systems are being reduced. It is therefore possible that in the near future these improvements will be cheap enough to be accessible to all companies, creating lean automation as a mature production system established around the world.

3. Methodology

For the development of this thesis the sources of information have been diversified to reach a more global and solid result. The initial foundations are based on a learning laboratory from Atlas Copco where it was used as a training tool for employees in order to get them familiar with lean principles. Last year the laboratory was handed over by this company to KTH University to be used as a teaching tool. For this reason, the laboratory is now installed at KTH University to train students in lean philosophy from an experience that simulates the environment of a real workplace. As the objective of the present work is the study of lean laboratories and then to introduce improvements towards automation, it has been decided to begin by breaking down everything that constitutes this type of laboratory. It has been carried out an extensive search and study of the different concepts that forms lean laboratories. The first phase of literature review focuses on analyzing deeper the lean philosophy, going into detail only in those most important tools for the development of the thesis as it is the case of the VSM, 7+1 types of waste, pull system or the 5s. Although some of these tools already existed in the previous laboratory, this research and analysis intends to highlight their important benefits as well as to give them a twist to improve their impact on the assembly line. The learning factories concept on which the lean laboratory is based was then presented. This study has been of great importance as it has shed light on the most important aspects of the learning impact the laboratory has. It has been known the points to be taken into account when designing learning factories, the aspects to be learnt by the students and the different types of configuration that can be used depending on the situation. Finally, in this section of literature review, it was wanted to know the advances in automation manufacturing and the relationship and application that can be given to this automation manufacturing in the Lean manufacturing. This section has been key in allowing knowing the latest developments and possibilities to improve the current lean laboratory. In this search, a multitude of articles from ScienceWeb, Science Direct, KTH Primo have been consulted allowing to unit a wide range of information from which to source. All this information has been summarized and organized in the Literature Review paragraph. When introducing improvements of the current set-up of the laboratory, it was necessary to observe the operations of the laboratory in several occasions. During these experiences, notes have been taken on possible improvements that will take the laboratory to a higher level, especially in relation to automation. These personal notes and observations have been complemented by the brainstorm between the different members of the department, which has been a great help in the development of the thesis. In addition to watching and studying how the laboratory worked with the interaction of students, it was necessary to go on several occasions to interact alone with it. This experience of performing the different tasks by oneself, searching for the best practices, repeating processes and searching for the source of value has been of great benefit and from which a large amount of information has been obtained. For example, during these sessions, improvements have been proposed and studied related to the standardization of operations and the better arrangement of elements such as the Andon, Poka-Yoke instructions or the possibility of incorporating a second row of rollers connected by chains.

4. Presentation of the current set-up

As it is explained in the introduction the lean manufacturing laboratory is divided in 3 stages. In every stage, the students will run the assembly line trying to reach the customer expectations. The different scenarios are settled with the intention that the students will not be able to reach the customer demands until the last stage, where all the process and control measures are applied. In this last stage all the operators will start with the exact number of pieces needed to produce the product since the beginning.

The lay-out of the assembly line will be changed after every running cycle, applying the improvements discussed during the break between them. In the sections below it will be described the lay-out, the results of the students and the improvements of every stage. The results presented after each one of the stages are the average of five lab sessions attended to gather information about the laboratory.

4.1. First stage

During the first stage the operators will be placed in 1 workplace and their command will be produce as fast as they can, following a push strategy without any production control applied. All the pieces finished will be storage in the next workstation as WIP inventory. To analyze the results in all the workstations during the stages, the time used in the analysis will be the average of the 5 laboratory sessions attended.

4.1.1. First Lay-out

The “First stage lay-out” in the Annex 1 shows the disposition for the first stage, all the operators have 2 tables with the pieces and tools required and a workbench where they will assemble the parts. When one operator finishes the pieces he will have to call the logistic so he transports the parts finished to the next station, the logistic will be also called when the operators run out of pieces.

4.1.2. VSM

In the VSM shown in the Annex 2 “First stage VSM”, we can observe the values flow from the beginning until the delivery to the customers during the first stage.

$$Takt\ time = 10min \times \frac{60\ sec}{1min} \times \frac{1}{5\ products} = 120\ sec$$

$$Cycle\ time = \frac{751\ sec}{5\ products} = 150{,}2\ sec$$

$$Lead\ time = 336\ sec$$

$$Cycle\ time = 150{,}2 > Takt\ time = 120sec$$

As the Cycle time is higher than the Takt time is impossible that the objective of deliver 5 products in 10 minutes could be achieved.

4.1.3. Results

After the running the laboratory for 10 minutes the operators, logistics and people timing gather together to share the information, own experiences and thoughts about the problems they had during the running time. The figure 8 shows the results of the assembly line during the first stage. The data of the following graphic is the average time of 5 laboratory sessions.

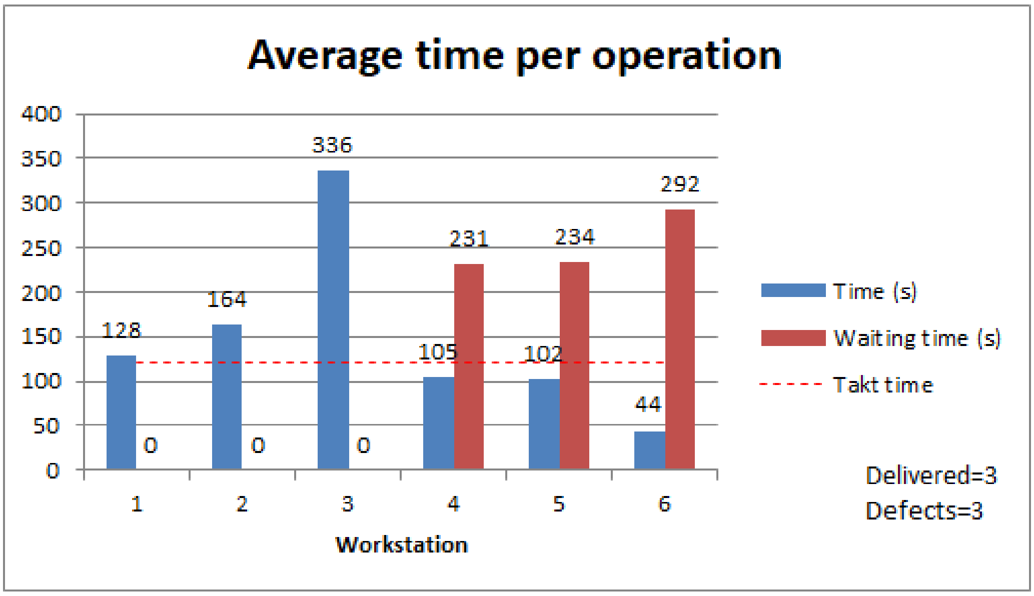


Figure 8: Average time per operation in the first scenario

During the 10 minutes the line is not able to produce what it was expected from the customer demands, the average in the laboratory are 3 final products delivered and 2 defects. It is easily recognizable that the workstation 3 is the bottleneck of the assembly line, with an average of 336 seconds. Workstations 4, 5 and 6 are below the Takt time, this shows that the work in the line is unbalanced. Meanwhile 3 is carrying out most of the work, stations 4, 5 and 6 have to wait until 3 releases the part. Stations 1 and 2 are above the Takt time, even with the station 3 being the bottle neck, the stations will need improvements to meet customer expectations.

4.1.4. Discussion

The table 3 shows the discussion made after the result analysis and tries to find a reason for the 7 types of waste.

7 Waste analysis		
Type of waste	**Level of waste**	**Observations**
Transportation	Very high	- Too much movement for the logistic - As the stations 1 and 2 produce faster, they need way more pieces and logistics travel a lot.
Inventory	Very high	- As the stations 1 and 2 produce faster, the station 3 accumulates a lot of WIP inventory.
Motion	Very high	- All the workplaces have 2 tables with the tolls and pieces plus the workplace, the operators require excessive movements.
Waiting	High	- Station 3 is clearly the bottle neck and all the stations downstream have to wait.
Overproduction	High	- Only stations 1 and 2 overproduce because station 3 did not need more pieces.
Overprocessing	Very high	- Taking out the pieces from the bag is a non-required action.

Defects	Very high	- Final pieces with defects - Lack of capacity to find defects until the product is finished.

Table 3: Waste analysis of the first scenario

After this analysis, some ideas are introduced to improve the line and try to be able to serve the customer making the Cycle time lower than the Takt time. For this reason, it is important to focus the first improvements in reduce this Cycle time of the workstations. To reduce this Cycle time improvements need to be introduced in the motion, the standard activities, the overprocessing and the overproduction.

4.2. Second stage

In this scenario a new production control method is implemented, a push strategy, through the utilization of a kanban system. With this kanban system the operators will not start producing until the next kanban is empty, this will reduce the inventory levels, specially before the bottleneck (Workstations 1 and 2). Also in these scenarios there is a change in the lay out that will be explained in the next section. To reduce the overprocessing the bags that cover the pieces will be removed. To analyze the results in all the workstations during the stages, the time used in the analysis will be the average of the 5 laboratory sessions attended.

4.2.1. Second Lay-out

Before the students start producing in the line for the second time, they are asked to improve their workstation as they want, taking into account the discussion made after finishing the first stage. The result is a workstation with only one table and one workplace that reduces the motion of the workers to only one side. The kanban system implemented will be a visual kanban in the downstream workplace; the pieces required for one station will be placed in a colored plastic. The stations will only start producing whenever the plastic located in the downstream workplace is without pieces. The annex 3 “Second stage lay-out” shows the final disposition of the lean laboratory in the second stage.

4.2.2. VSM

In the VSM shown in the annex 4 we can observe the values flow from the beginning until the delivery to the customers during the second stage.

$$Takt\ time = 10min \times \frac{60\ sec}{1min} \times \frac{1}{5\ products} = 120\ sec$$

$$Cycle\ time = \frac{567\ sec}{5\ products} = 113{,}4\ sec$$

$$Lead\ time = 268\ sec$$

$$Cycle\ time = 113{,}4 < Takt\ time = 120sec$$

In this second round it has been possible to reduce the cycle time below the Takt time. This mainly due to the introduction of upgrades in the motion of the operators thanks to the 5s principles; moreover, the elimination of overprocessing also favors the reduction of the Cycle time.

4.2.3. Results

The figure 9 shows the results for the 10 minutes run in the line at the second stage.

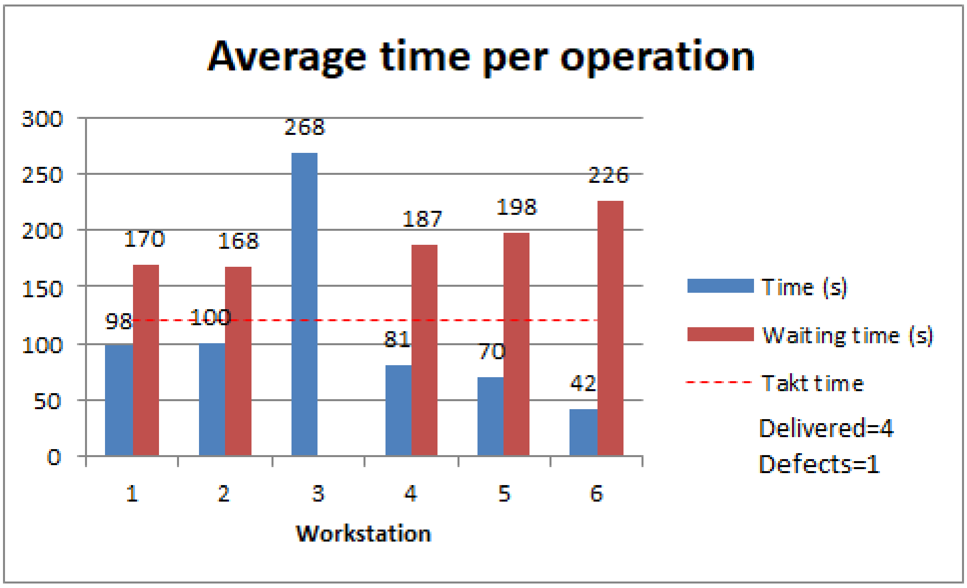


Figure 9: Average time per operation in the second scenario

During the 10 minutes run the average was 4 pieces delivered and an average of 1 piece with defects detected. Reducing motion and over processing produces a reduction of the cycle time in all the work stations. Now stations 1 and 2 start producing under the Takt time but the station 3 is still the bottle neck producing over Takt time. The Kanban system avoids WIP stock in workstation 3 but increases the waiting time in the stations 1 and 2.

In order to be able to achieve the customer demands for the third round improvements in balancing the line and in reduction the transport in the line will be introduced.

4.2.4. Discussions

After the 10 minutes the production are over there is another discussion about the results and the experiences and comments of the operators, logistics and people that is timing the operations.

7 Waste analysis		
Type of waste	**Level of waste**	**Observations**
Transportation	Very high	-Too much movement for the logistic - Reduced because stations 1 and 2 produce less.
Inventory	High	-The waste in the inventory level is improved because of the kanban system that stops the production in stations 1 and 2 when the station 3 does not need more pieces.
Motion	High	-The motion is improved because in this stage there are less tables in the workplace
Waiting	Very high	- Station 3 is still bottle neck, as the kanban stops stations 1 and 2, these also wait in this stage.
Overproduction	Low	-The kanban system stops the overproduction of workstations 1 and 2.
Overprocessing	Very low	-There are not movements/actions that are not needed.

Defects	Very high	- Final pieces with defects - Lack of capacity to find defects until the product is finished.

Table 4: Waste analysis of the first scenario

At the end of the discussion it is clear that the line will not be able to satisfy demand simply by improving movement and reducing inventory and overprocessing. There is necessary to reduce the transport and balance the line because most of the workload is carried out by the 3 work station.

4.3. Third stage

In the third stage the lay-out of the laboratory is completely changed, instead of 6 workstations there will be only 4, so 2 operators will not be required in this stage. There are not workplaces next to the operators; all the operations are done in the workbench that has all the pieces and tools needed. The tools are screwed in the rolling table and hanging from the ceiling. During the 10 minutes of production the operators will work in the workbench, once they finish they will unclamp the workbench and wait until all the operators finish their work. When all the processes are done the rolling table will move the entire workbench till the next operator workplace, who will clamp the workbench before start working. To analyze the results in all the workstations during the stages, the time used in the analysis will be the average of the 5 laboratory sessions attended.

4.3.1. Third Lay-out

In the third stage the lay-out completely changes, the tables are removed and the operators are placed next to the rolling tables. In this stage the workload of the operators changes, trying to balance the work during the line, with this new distribution 2 operators are not required. The workbenches are not fixed and have the entire amount of piece needed. When all the operators have finished the work, the rolling table will start moving and send the workbenches to the next workstation; this favors the continuous flow during the line. The “Third stage lay out” in the annex 5 shows the lay-out in the third stage.

4.3.2. VSM

In the VSM shown in the annex 3 we can observe the values flow from the beginning until the delivery to the customers during the third stage.

$$Takt\ time = 10min \times \frac{60\ sec}{1min} \times \frac{1}{5\ products} = 120\ sec$$

$$Cycle\ time = \frac{464\ sec}{5\ products} = 92{,}8\ sec$$

$$Lead\ time = 0\ sec$$

$$Cycle\ time = 92{,}8\ sec < Takt\ time = 120sec$$

In the third round considerable reductions are achieved on the Cycle time, placing it well below the Takt time. This is due to the introduction of a new way of distribution workload between the stations; to the point that now there are 4 workstations instead of the 6 workstations present on the other 2 rounds. Moreover, a new display of the material in the workstations leads to a reduction of the motion.

4.3.3. Results

The figure 10 shows the results for the 10 minutes run in the line at the third stage.

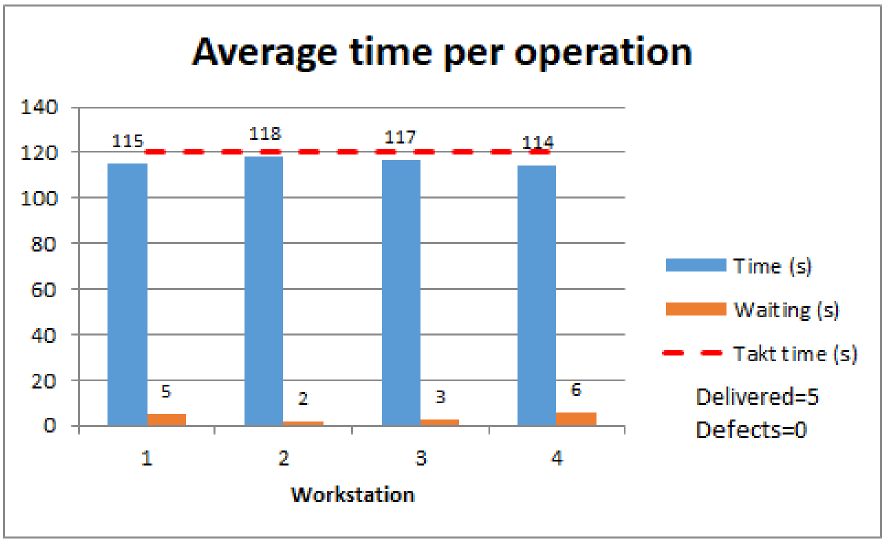


Figure 10: Average time per operation in the third scenario

4.3.4. Discussion

After the 10 minutes of production there is another discussion about the results and the experiences based on the comments of the operators, logistics and people that is timing the operations.

7 Waste analysis		
Type of waste	**Level of waste**	**Observations**
Transportation	Low	- Movement between the stations is reduced but there are still improvements needed.
Inventory	Very Low	- As it is a continuous flow there is no inventory in between the operations.
Motion	Very Low	- All the tools and pieces needed are in the same place, it is clearly reduced.
Waiting	Very Low	- The workload is equal in all the stations so it is much reduced.
Overproduction	Very Low	- The operators cannot start production until all stations have finished.
Overprocessing	Very low	- There are not movements/actions that are not needed.
Defects	Very Low	- Even though there are no pieces with defects, there is not chance to check inner screws.

Table 5: Waste analysis of the first scenario

The assembly line improves widely with this disposition, the continuous flow allows 0 WIP inventory and reduces the transportation. There is not overproduction as the operators cannot work until all of them have finished their job. In addition, the waiting is also reduced because the workload is balanced between operators. Finally, all the operators act as an inspectors checking that the work has been correctly performed, improving the quality of the products and reducing the amount of defects. Nevertheless, on the other hand, the assembly line is still not able to check the inner screws and cannot confirm 100% if the final product is without defects.

4.4. Conclusion

During these 3 stages the line is improved until it is reached a Cycle time below the Takt time in all the workstations, ensuring that the production requirements imposed by the client are met. Applying lean principles a reduction of the 7 types of waste is achieved but there is still a margin of improvements. There are still some problems in the line unsolved like having all the possible defects checked, transportations problems in the corners of the rolling tables or possible improvements in the motion of the operators.

Therefore, it is possible to separate the possible improvements in 3 types:

Automatize the line: Improve automatizing the line, making some processes not depending on the operators. Some examples of these could be including sensors to start and stop the line when the operators finish the job or change the corner of the rolling tables as the logistics has to move the workbench when it changes the direction.

Continuous improvement: Although during the previous 3 stages the waste has been considerably reduced by applying lean techniques, one of the bases of the lean principles is to continuously repeat an analysis trying to find the sources of waste and reduce them.

New techniques: In addition to improving the line to produce better and with less waste, there are other possibilities to upgrade it. One of them could be to prepare the line to produce different products and try to produce "just in time" for the customer. This will add flexibility to the production and will also teach new concepts to the students, which is the ultimate purpose of the lean manufacturing lab.

5. Improvements

At present, the lean lab has at its disposal rotary rollers that allow work plates to move from one workstation to another. The rollers are started by means of a switch, which is activated by a supervisor when all the operators raise their hands. The operators raise their hand indicating that they have finished their task and the working plates has been unclamped. Once the rollers are running, the supervisor has to be alert to stop the rollers when he considers that the working plates have reached the next workstation. However, operators have to stop the platform with their hands when it has reached its ideal position, so that the clamping can be done correctly. This does not represent a great danger to the safety of operators, due to the low speed of the rollers, but we believe it is better to put on the side of safety. In addition to safety issues, we consider an important advance to introduce automation in this part of the line and therefore approach lean automation. It is important to mention that the improvements proposed hereafter are a follow-up of the third stage of the current lab installed in KTH.

5.1 Automatize the line

5.1.1. Sensors

Before starting with the description of the different types of sensors it is important to make some reflections. It will be important to display the different workstations equidistant since the conveyor belt will stop when the first sensor detects the working plates. Otherwise, another solution may be the introduction of different motors for each of the sections. It is important to take these details into consideration, as it may be the case that one of the working plates reaches its working position while the rest remains by the wayside.

5.1.1 Stop the conveyor belt when the workbench arrives to the workplace.

The first improvement will be to introduce sensors at each workstation in order to stop the rotary rollers when the working platforms reach the next working position. There are different types of sensors [11], from Barrier Photocells, Auto-reflective Photocells and Reflective Photocells with Reflector.

The Barrier photocells detect the presence of objects when the light beam is cut off, as can be seen in figure 11. These sensors have the most reliable performance, as they have a larger range of action and are less sensitive in unclean environment. However, their main drawbacks are their difficulties on detecting transparent or translucent objects and the fact that the receiver and transmitter have to be encapsulated separately on both sides of the line. This could represent a problem in situations where the space is limited as both the receiver and the transmitter must be supplied with power.

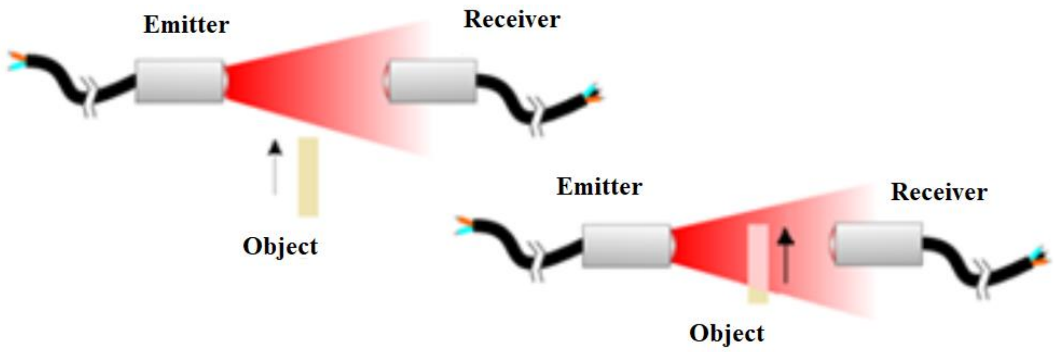


Figure 11: Barrier photocells operating principle

The Auto-reflective Photocells are the most economic nevertheless they are the less suitable for unclean environments or moisture. This is due to the fact that, as shown in figure 12 and figure 13, only one device is needed, which in turn acts as a light beam emitter and receiver. These photocells are indicated for situations where space and accessibility are very limited. The detection distance will vary depending on the color of the object to be detected, with white being the color that offers the greatest detection distance and black the lowest because it absorbs most of the light spectrum. This type of photocells is often used on conveyor belts.

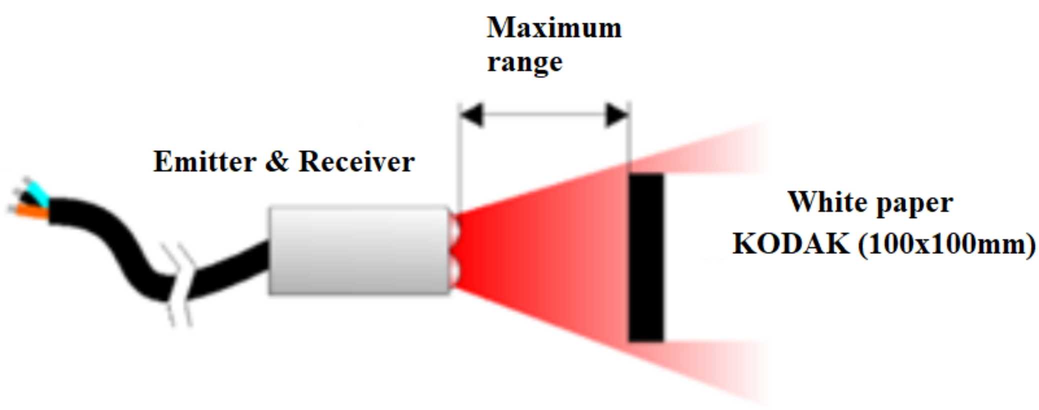


Figure 12: Auto-reflective Photocells operating principle

There are three types of Auto-reflective Photocells, the basic ones, the ones with “fund Deletion” and the “Suppression of First Plane”.

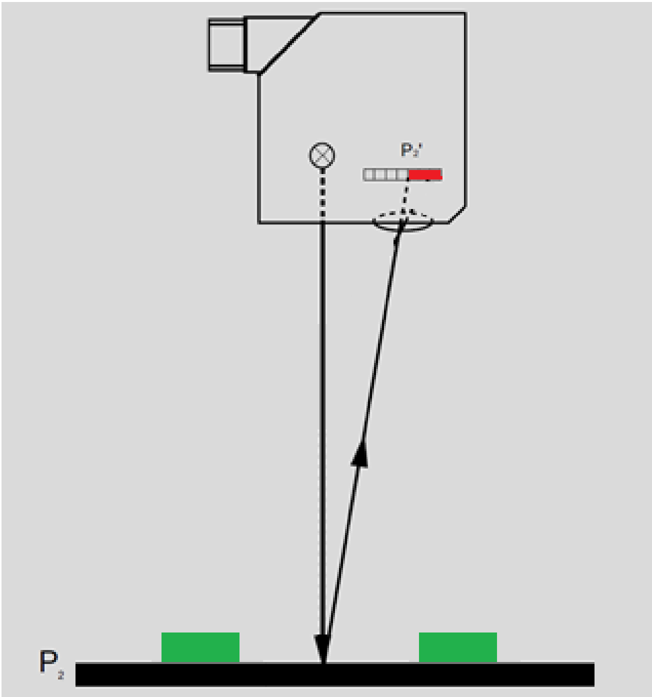


Figure 13: Auto-reflective Photocells operating principle

The Reflective photocells with reflector are based on the same principle as the previous photocells with the difference that the emitted light is reflected in a reflector, so as it can be observed in Figure 14 when light detection is interrupted alerts the sensor of the presence of an object. Mounting and installation are simple, as only one side of the sensor needs to be installed and powered. The main advantages of these photocells are that the range of detection is larger than on the Auto-reflective Photocells and that the detection of an object is not conditioned to its color.

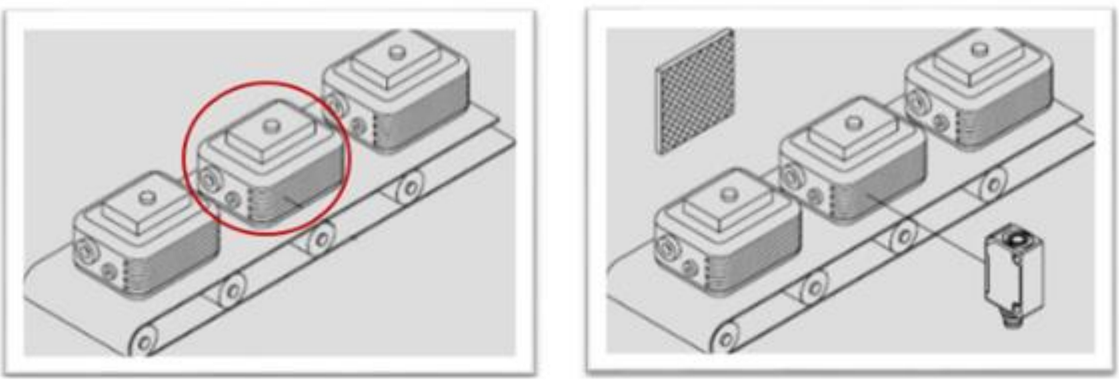


Figure 14: Reflective photocells with reflector operating principle

Based on the performance each one of the sensors presented has and the characteristics of the Lean Laboratory, it would be recommended to implement the Auto-reflective Photocells. This is because although we have enough space to place a Barrier photocell, we do not really need the precision and detection length that this sensor offers. Moreover, the Lean Laboratory does not present an unclean environment so the extra price for the installation of a Barrier photocell is not justified.

On the other hand, the installation of a reflective photocell with reflector would force us to place a reflector on the wall, reducing the space we would have to install the instructions of the Poka-yoke system. For this reason, the Auto-reflective Photocell is the sensor selected to be implemented in this section of the Lean Laboratory.
The following picture, figure 15, shows an example of how the presence sensor could be installed in the line to provide proper operation.

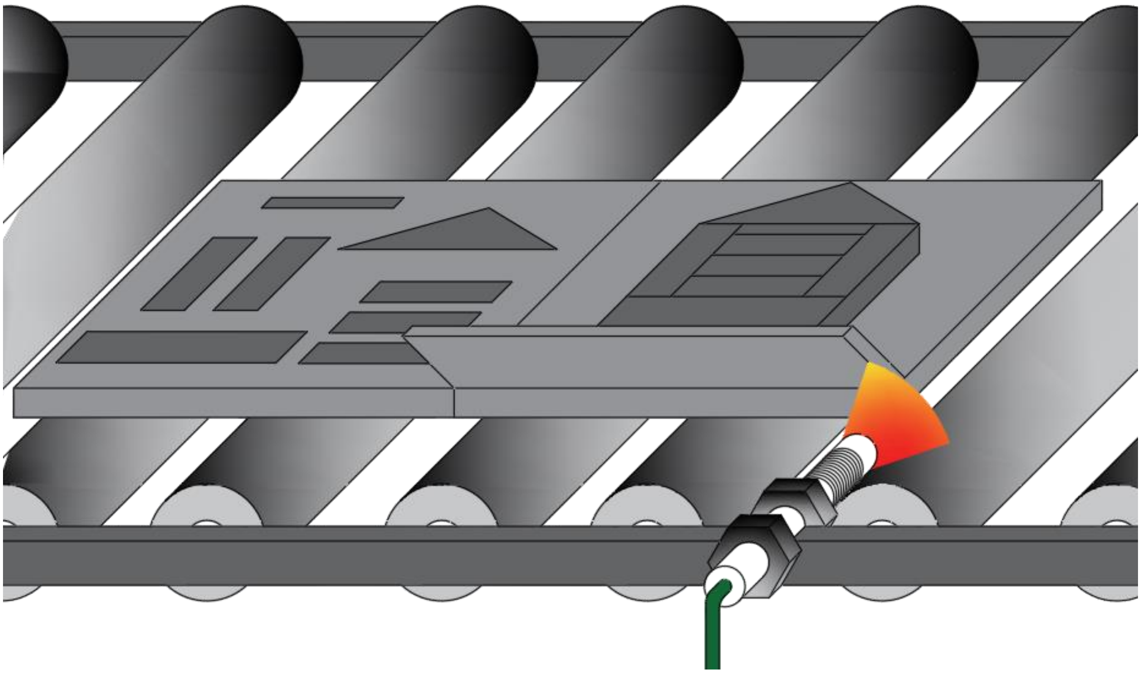


Figure 15. Example of the presence sensor installed in the laboratory.

5.1.1.2 Limit switch sensor

In order to provide a more ergonomic work for the operators it will be appropriate to have a piston that lifts the working plates. The position to which the platform is lifted could be adapted to the conditions of the operator. In order to allow the cylinder for lifting the platforms to stop at the height set by the operator, it is necessary to introduce limit switch sensors. Once the sensor has stopped lifting the cylinder, the operator can start assembling. Once the operator considers that its duties have been done he presses the button “unclamp”, indicating to the system that the works on the working plates are finished. So the platform is descended to the rotating rollers, when the platform reaches the initial level a signal is emitted to the system indicating that the platform is ready to move to the next station. For this operation it is necessary to introduce another limit switch sensor that will stop the descent of the cylinder and will also emit the signal that this platform is ready to advance to the next station. When all stations are in the same state, ready to move to the next station, the rollers start rotating.

It needs to be remembering that when the operators have finished their assigned tasks they need to unclamp the working plates. This unclamping could be pneumatic so the operator just needs to press a button and the platform will start the descent.

Since two sensors have to be installed per station and at this stage there are four workstations, eight sensors should be installed. This would allow the lifting of the working platforms to be properly automated.

These sensors should also be inserted into the cylinders that move the chains. These sensors should also be inserted into the cylinders that lift the chains. Two sensors per cylinder should be inserted, one to control the lifting and the other for lowering. Since there is one cylinder at each end of the assembly line, four sensors would have to be inserted in order to automate this section of the line.

For this reason, in total 12 sensors of this type will need to be installed in the line.

5.1.1.3 Safety measures when the rollers are rotating

The rotating rollers can be a source of accidents, as it can cause trapping of both the instruments and the operators themselves. It has therefore been decided to propose a series of systems to ensure that these accidents do not occur. It must be remembered that the safety of all workers is the first requirement to be fulfilled, but it must also be taken into account that accidents affect the production levels of the line. For this reason, the safety measures proposed are:

Acoustic signal: In order to provide a higher level of safety on the Lean lab, it could be possible to introduce an acoustic signal to warn operators that plates are moving.

Sensor of presence: In order to avoid accidents while the plates are moving, the possibility of introducing presence sensors similar to those described above can be considered. These sensors will stop immediately the rotation of the rollers when an operator enters the delimited area for the movement of platforms. It could also be considered the option of introducing an acoustic signal, different from the previous one, indicating the sudden stop of the rollers.

With regard to the security measures that can be introduced into the system, it is best not to skimp on resources. Although it would be possible to install only one of the security measures, it has been considered that the combination of the two can provide better results. In the event that one of the measures had to be chosen, because it provides a higher level of security on its own, the presence sensor would be chosen.

5.1.2 Andon

The communication between the operators, the logistics and the foreman is crucial for the proper development of the activity. Now the communication is carried out by means of a call, raising the hand, from the operator to the foreman or to the logistics. Once the logistics or the foreman arrives to the workplace, the operator explains why logistic was called. The most common situations range from a problem in the operation to the need for replacement parts for some of the components. For example, the operators might face quality problem, such as broken components what makes it impossible for them to be screwed, as it is the case of damaged threads, another type of quality problem could be deep scratches. Moreover, it could be the situation in which the operator might have a problem with tools or with the machine he is working on, such as battery runs out, damaged bits or wrong tool for that task, and he/she should be able to call of help. The main problem with this system is that a lot of motion is created, one of the 7+1 wastes which the lean philosophy cope with. In order to provide a more efficient communication system, which reduces the motion, exists the Andon. There are different types of Andon Systems, one of the most basic but effective in solving the problems currently encountered in the line, is the column of lights of various colors. This column of colors would be placed at the top of each of the workstations allowing it to be observed from any point on the line. Each color has a specific meaning but some example could be:

- Red for Quality problem
- Orange for Lack of material
- Green for normal production
- Black for Problem with tooling or machine

Figure 16: Andon system

The operator has on the workplace a connection panel with the Andon, in this case with four buttons. Pressing each one of them the operator is able to communicate quickly and effectively with the supervisor or the logistics, introducing a considerable reduction in the motion.

5.1.3. Pistons for adjusting the workplace to the operator

Providing a workplace with measures that seek to maximize the ergonomics of workers allows for better results in both product quality and production time. This is due to the fact that workers can carry out operations in a more agile and efficient way. In the search for better working conditions, it has been proposed to adapt the height of the working platform. Since each operator has a specific height, it has been decided to incorporate the possibility for each operator to adjust the height of the platform according to their needs at the beginning of the shift. As can be seen in Figure 17, in each of the stations will be placed four of cylinders that will raise both the working platform and the board to the working position. This working position will be determined by the operator, having 3 possible positions, which can be selected by means of a button threaded in the lower part of the cylinder or by a button panel. By means of this system the maximum ergonomics is looked for so that the operator feels comfortable and can develop the tasks in the best possible way. In order to provide good stability, it was decided to install three cylinders on the working platform and one in the platform with the kit of spare pieces. These three cylinders will form a triangle as can be seen in the Figure 18, this arrangement will provide good stability in the longitudinal axis, in the horizontal and in the torsion.

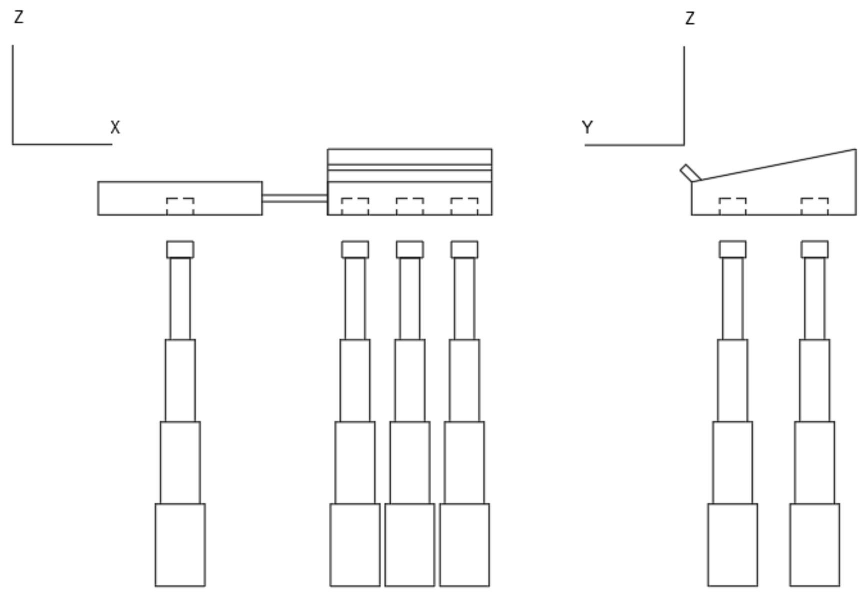


Figure 17: The front view of the telescopic cylinder (left) and the cross-section view of the telescopic cylinder (right)

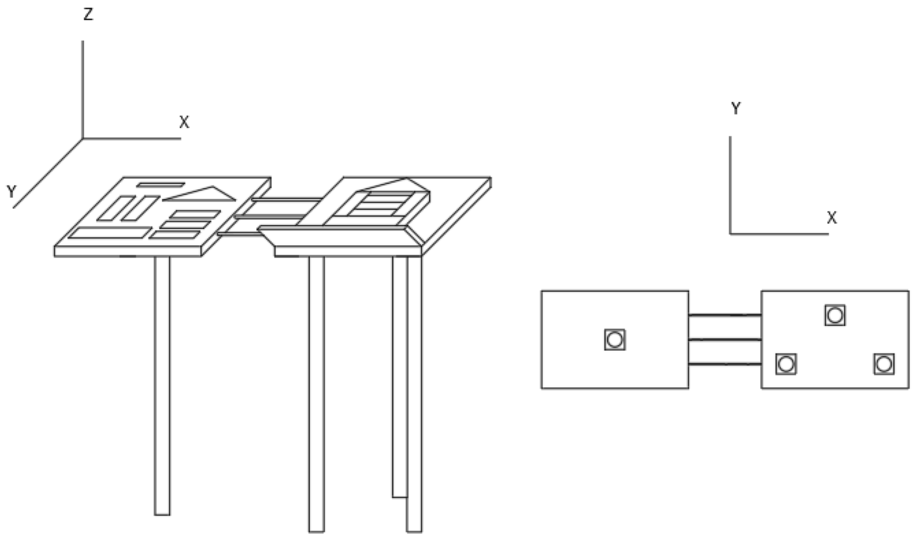


Figure 18: Pistons fully extended (left) and bottom view of the piston distribution(right)

In the Figure 19 can be observed the two positions of the pistons. The first one represents the initial situation in which the pistons are retracted and allow the working platform to move on the rollers towards the next station. On the second one the pistons are extended representing the working position selected by the operator.

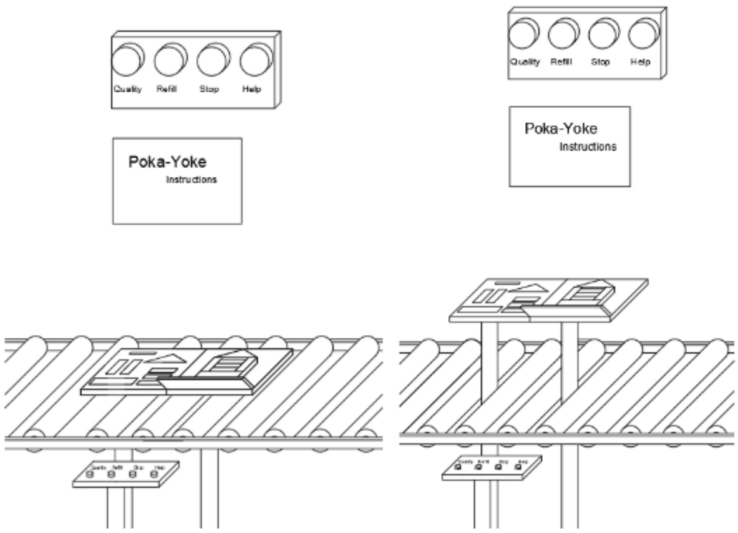


Figure 19: Two positions of the pistons retracted (Right) and extended (Left)

5.1.4. Chains to create a closed circuit

Another improvement in the lean laboratory is the creation of a closed production circuit. This makes it possible to automate processes and reduce the transport movements of empty platforms by operators from the end of the line to the beginning of it. For this to be possible, it is necessary that the platforms automatically return to the beginning of the line. In addition, it is desired that the extraction point of finished products is the same one where the platforms are replaced with the necessary kit to create another product. For this purpose, it has been decided to create an assembly line that presents two rows of rollers on which both the working platform and the board with the pieces move. The first row of rollers moves from left to right transporting the platforms on which the operators will be working. Once the finished pieces reach the end of the first line, on the extreme right, they will be extracted by logistics and stored. The same operator will then replace the empty parts kit with a new one with the parts necessary for the creation of a new product according to the requirements of the specific order desired by the customer. This kit has to be ready so that the operation is fast and does not produce cuts in the movement of the line. In order to avoid cuts on the line it is necessary that this process is shorter than the cycle time of the working stations. The Cycle time of the working stations is around 90 seconds. It is believing that it is long enough to allow the operator to extract the finish products and replace the piece's kit meanwhile the chains transport the platform from one row to the other. What is clear is that the necessary parts kits must be prepared beforehand.

The new working platform will continue moving on the second row of rollers thanks to retractable chains, which allows changing direction and connecting the two rows of rollers. The second row of rollers moves from right to left automatically. Once these working platforms reach the end of the second row of rollers again a unit of chains will displace them, with a 90 degrees movement, to the beginning of the first row of rollers. And the cycle starts all over again.

In Figure 20 it can be seen that these two roller rows are connected via chains. The chains are retractable, so they are initially hidden under the rollers. This allows both the platform and the board to reach the end of the line and be placed above the chains. When the platform reach the end of the line will be detected by the presence sensor, these sensors are identical as those installed at work stations to stop the rollers. Once the sensor detects the platform the rollers will stop, the chains are extended lifting the platform starting the transverse movement that connects the two rows of rollers. Once the board and the platform reach their destination and are detected by a second presence sensor, the chains retract again placing the load on the rollers.

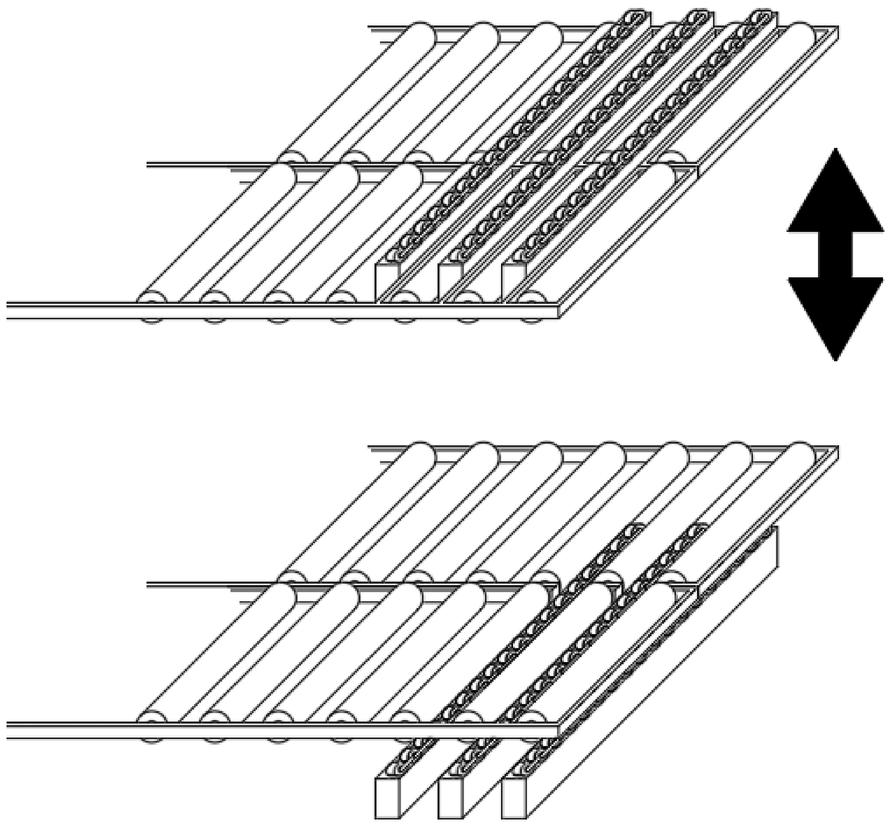


Figure 20: Detail image of the retractable chains

In order to make the process of lifting and lowering the chains automatic, a pair of sensors will be installed at each end of the lines. The sensors will be of the same nature as those previously installed in each of the stations and which allow the cylinders to raise the platforms. In this case, when the first sensor detects the presence of the platforms, for example at the end of the first row of rollers, it will extend the chains. When they have been fully extended, they will start to work. A second sensor installed at the beginning of the second row of rollers when it detects the presence of the platforms, will stop the operation of the chains and retract them, depositing the platforms on the rollers. Once the chains have been completely retracted, the rollers can start to work. The way the system knows when chains are fully extended or fully retracted is by installing limit switches. As previously explained, each cylinder will have two sensors, one to control the elevation and the other to control the descent.

5.2. Continuous improvement

5.2.1. Standardized work

Standardized work is critical to lean success. By documenting the current best practice, standardized work forms the baseline for kaizen or continuous improvement. As the standard is improved, the new standard becomes the baseline for further improvements, and so on. Improving standardized work is a never-ending process.

When running the third round of the Lean lab, the operators are not able to produce at Takt time during the first pieces even when they are supposed to do it. This is because not all the operators work in the same way and there is not standardization in the workstations. This is obvious when we check the times the operators achieve at the beginning and at the end of the ten minutes of the production. All the operators improve as they have more experience and they advance in the learning curve, but during the last pieces, the time stabilizes and they do not improve any more. Even though, once assisted to the different laboratories developed this year, some students achieved better times than the others because the way they were doing the job was more efficient in terms of motion.
The idea of including instructions in every workstation is to find the most efficient way to do the tasks in one workstation and standardize them. Making all the operators do the same movements and reducing the variability in every station.

The instructions can be placed in the wall, where all the operators can easily see them and it will have pictures and the explanation of what they have to do.

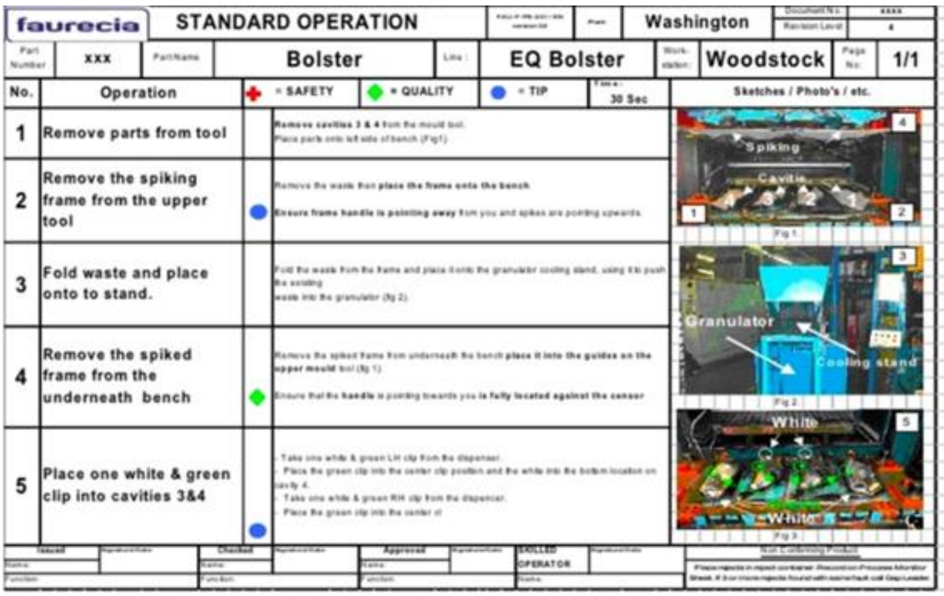


Figure 21: Work Instructions from Faurecia Interior Systems [12]

The work instructions will standardize the work and motion, reducing the time it takes to carry out an action between the beginning and the end of the shift and between the students.

In the annexes at the end of the document in the annexes 6-10 there are the work instructions for the lean manufacturing improvement. The instructions include the description of the task the operations need to do, as shown in Figure 21, it also includes an observation or an explanation of the task if needed. Finally, it has a picture to help the operators.

5.2.2. Use tools to help the operators to hold the pieces

During the observation of the third stage it could be seen that the operators had difficulties placing the blocks to screw in the first stage. Even though the workbench includes a hole to hold the blocks P1, P2 and P3; the blocks P4 and P5 are free move. Following with the principle 6 of the Toyota way: principle 6: "Standardized Tasks Are the Foundation for Continuous Improvement and Employee Empowerment" [2] the workstations can include tools to hold the pieces in the correct position while the operators work screwing them, this will help the operators to do their work as they will only have to place the pieces in the tools and start screwing.

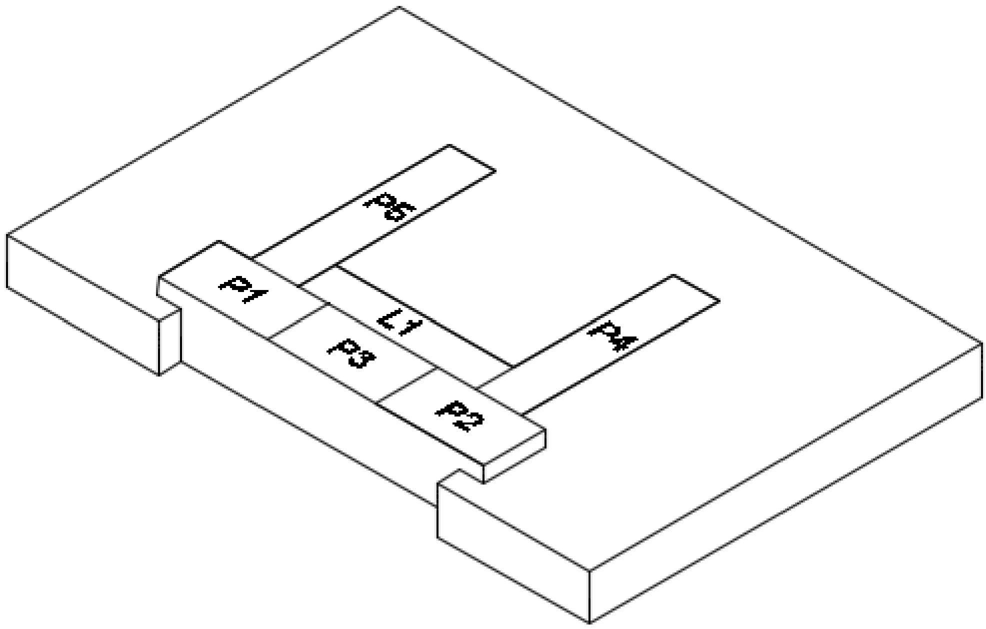


Figure 22: Mold model to align the holes P5-P1 and P4-P2

The tools should be simple and easy to use by the operators; it can be as simple a plastic base with the form of the pieces that the operators have to use. It can be easily made with a 3D printer, the figure 22 shows a draft of the mold.

Before the students start with the third round of the Lean lab, they do a quick practice in another class where they learn SMED concepts and how to reduce time between tool and pieces changes. By using these tools in the lean lab, the students will be able to see the concepts learnt, applied to a case that they already know.

5.2.3. Magnetic heads for screwdrivers

As observed in the operation of the laboratory, operators are having trouble tightening the screws. This is because the screws are small and fall to the ground easily. For this reason, it is proposed to replace the current screwdriver heads with magnetic ones, greatly facilitating the screwdriving operation. In the same way that screwdriving tasks are speeded up, it also avoids the loss of material or the operators having to bend down to look for it, creating situations of poor safety.

5.3 New techniques

5.3.1. Include variation in the production (Customization and JIT)

During the lean laboratory the students only have to prepare one type of product, the "house" with the lean principles, and they do not have to pay attention to the pieces they use.

The variation in the output in an assembly line is important as it allows the customization of the product and attracts more clients. A flexible manufacturing system (FMS) is the response to the need of produce what the client really needs and it faces one of the biggest problems in production planning.

Including FMS will show the students the difficulty to organize and plan the production when there is more than one possibility to produce. In some cases, as for example in the automotive industry, the customization ends in thousands of possible variations just for one product and the control and planning tools in the production of it have to be effective and efficient. Besides the variation of the products, another concept that can be taught is the Just in Time (JIT), this means that the students will not only have to produce different varieties of the same product but they will have to produce them in the correct sequence. JIT is a manufacturing technique that consists in producing just what the client needs and sends it to them just when they need it. This method allows reducing to the minimum the inventory costs but increases the transportations cost between the provider and the client. In addition, with this method it is obtained that the errors or the wastes rise to the surface allowing reducing them and obtaining products of the wished quality to the first one.

In the third shift with the current configuration, the kits for the production are already prepared by the assistants of the laboratory what leaves the logistics workless. The kits are the boards in which are placed in an orderly and intuitive way all the necessary elements to conform a product. These boards are an extraordinary measure to save movement and detect possible errors, since if at the end of all the stages there are pieces left over without assembling it is due to some error during the assembly. The problem is with the system of preparation of these kits, as currently is forming a large amount of necessary components stock to have all the kits prepared beforehand. With this system, the principles of the lean philosophy are not being respected and the production is not being adapted to the customers' demands. For this reason, the proposal to introduce a step in which the kits are prepared is so important. But it must be kept in mind that this process must be in line with the rest of the plant and based on the lean philosophy. Key to this is the design of this stage and that the operator who is working in this station preparing the kits is aware of the importance of their task. From an adequate distribution of the elements in the initial board, the rest of the operators will be able to carry out their task correctly. If on the other hand, one of the pieces is placed incorrectly or is absent; this can cause the line to stop, preventing the production objective from being met.

To go one step further, a storage room and pick-to-light system could be introduced to the Andon communication system available at every workstation. With this system the operators will concretize which spare part they require when they are indicating a lack of material. It could be possible for the operator to indicate which component he needs the spare part from, since at most 3 or 4 different components are used in each workstation. This information will be directly transmitted to the storage room. Moreover, as all the components arrive to the operators through the assembly board the Logistics needs to focus on provide properly the pieces to the first operator. This operator will distribute adequately on the assembly board. For this reason, it could be important to send the orders to the storage room so the Logistics will be able to collect the pieces needed for the assembly of each product. The storage room will be properly distributed on shelves with luminous signs.

When the information from the assembly line arrives or when the Logistics introduce the information form the order in the system, the sign of the required spare parts will be illuminated. The light signal indicates the location of the component as well as the exact quantity required, making component search and order preparation much quicker and more intuitive. The parts are placed in a small, easily accessible container, indicating which parts are contained and in what quantity. Although in the Lean Lab on which this project is working there is no need to prepare large orders, the introduction of the system pick-to-light will speed up the task of the logistic of identify and collect all the pieces.

5.4. Summary and final status of the line

The different modifications and improvements proposed in previous sections will be summarized and incorporated into the line in this section. Therefore, through drawings and relevant descriptions it will be presented how the new assembly line would be formed.

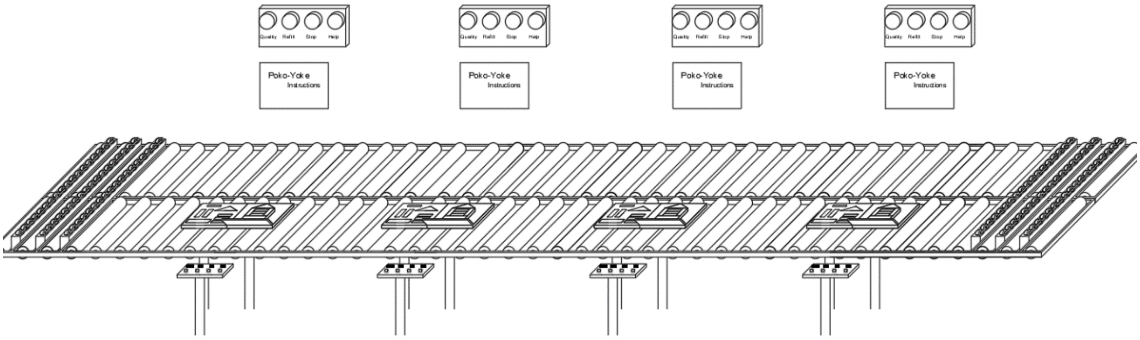


Figure 23: New assembly line in static mode

In this first draw Figure 23 it can be observed the new assembly line in a static mode. As in the third round of the previous laboratory, the working platform is being followed by a board where all the required pieces to form the final product are distributed. It needs to be highlighted that the working platform and the board are going to be joined, this will help to maintain everything close reducing the movement during the operations. The board, Figure 24, is formed by a soft material in which are the negatives of each of the pieces to be used during the whole process. This allows the operator to know where the piece he needs is at all times. Therefore, it is a Poka-Yoke system, as it helps when preparing the boards to identify if all the necessary pieces have been placed. If there were any missing, it would be easily identifiable, since the negative of the piece would be seen on the board.

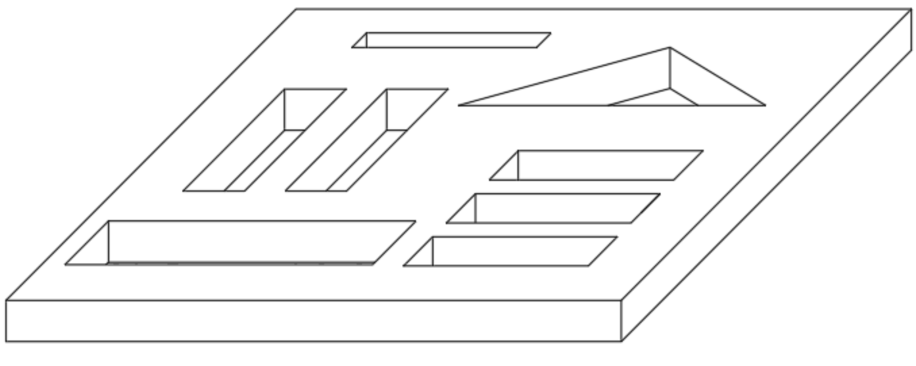


Figure 24: Board with the negatives of the pieces

Moreover, the working platform will have the necessary grooves which, together with the standardized procedures explained in the previous section, allow operations to be carried out in the most efficient way. These standardized operations will be explained to the operators before start the production but in order to help them to follow these Poka-Yoke instructions, a series of posters will be placed. The poster corresponding to the operations of that station will be placed in front of each one of the workstations as it can be observed in Figure 23. Therefore, each poster is independent and belongs to a single workstation. Above these posters and in an elevated position visible from the entire room are the light signals belonging to the Andon system. These signs, as well as the Poka-Yoke signs, are located in front of each station. With these signs as explained above, operators can indicate a quality problem, the requirement for a spare part, the urge to stop the line or the need for help. These Andon system light signals are controlled by button panels installed in front of the workstations. Each of the light signals is connected to a button to speed up the sending of the warning. It has been decided to place the button panel in front of the work stations but at a lower level to maintain its easy accessibility but without representing an obstacle for the operator.

In the Figure 25 it could be observed the new assembly line with the cylinders extended. So it will be a static position of the line while the operators are working. The height at which the working platforms are raised can be changed by the operator. An adjuster with 3 available heights is available to offer a more ergonomic position for the workers.

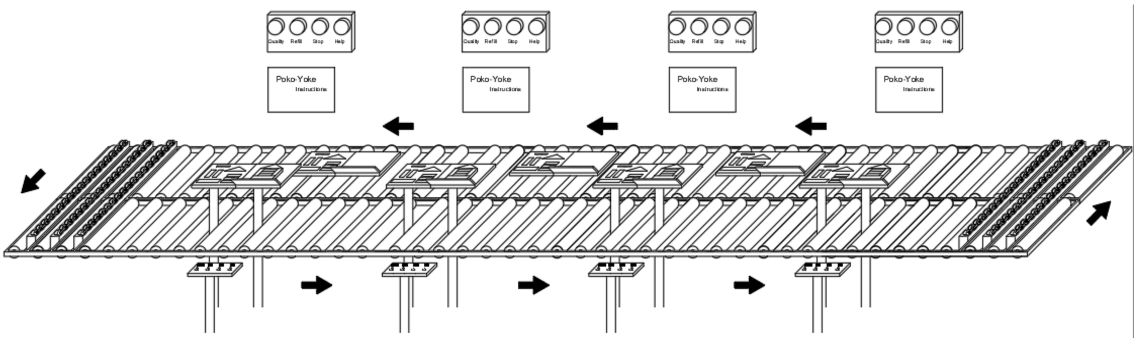


Figure 25: New assembly line with the cylinders in static position

The operation of the cylinders will be automatic, thanks to the installation of the presence sensors mentioned in the previous section. These sensors stop the rollers once they detect the presence of the platform. Then, with the rollers stopped, the cylinders extend to the height predetermined by the operators. Once the final height of the cylinders has been reached, the operators can begin to perform the tasks assigned to that workstation. When the operator finishes these tasks, he presses a button to lower the cylinder. When all the cylinders are hidden, the rollers are automatically put back into operation. In order for this system to function properly, it should be ensured that the workstations are equidistant. If this were not the case, the first platform to be detected would stop the operation of the rollers, preventing the rest of the platforms from reaching their corresponding work stations. If equidistance between stations cannot be guaranteed, the line should be separated into different roller sections, each one with an independent motor. This allows the platforms to reach the corresponding stations even if they are located at different distances.

The installation of a second row of rollers is motivated by the desire to achieve a closed circuit in which the materials circulate. This allows the system to both extract the finished products and be fed with new kits of parts by a single point.

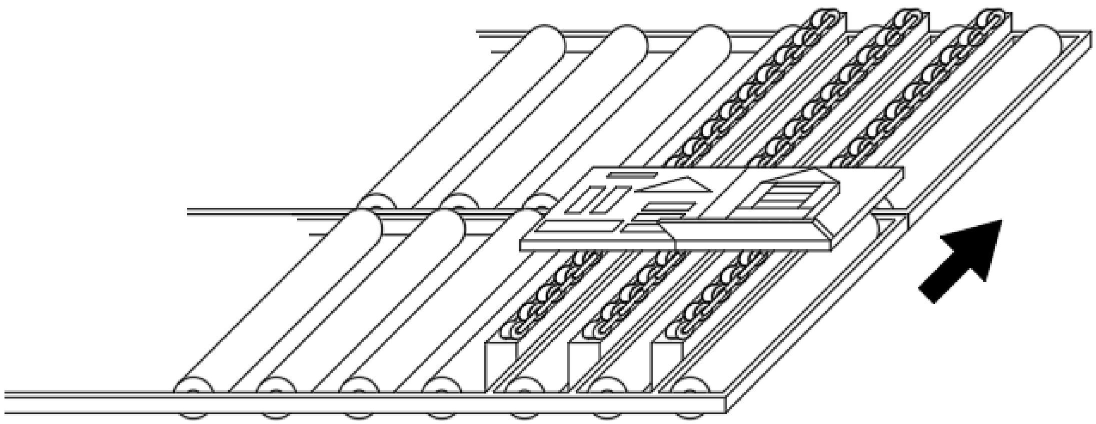


Figure 26: Chains linking the two rows of rollers

To do this, it is necessary to incorporate chains that allow the two rows of rollers to be connected, as it can be observed in the figure 26. In these points of union between rows of rollers also sensors are installed to automate the process. The presence sensors mentioned above make it possible to stop the roller line once the platform has reached the end of the first row. Then the chains are extended and only when they have been completely extended, they start to work, moving the platforms towards the second row of rollers. In the second row of rollers there is also a sensor, which stops the operation of the chains and retracts them, depositing the platform on the rollers. When the chains have been completely retracted, the second row of rollers can start working. It is very important that this process of moving the platforms from one row of rollers to another is fast enough so that the rest of the operations are not obstructed. But at the same time it has to allow the operator assigned to this point of the line to extract the finished products and replace them with the new parts kit. As it has been explained the takt time to deliver 5 products in 10 minutes was 120 secs, but the Cycle time obtained in the 3rd stage of the previous lab was lower that the takt time. This is what allows the lab to produce the amount of products on time. But this entails that in order to not introduce interruptions in the line in the chains connections it is fundamental to assure that the time takes to transfer the platforms to one row to the other is shorter than the cycle time of the workstations. As it is considered that the kits are prepared beforehand, with 90 seconds it should be enough to complete this task. This time has been approximated by laboratory experimentation. If the transition time is 90 seconds, there is enough room for the cycle time of the workstations to be reduced before this section becomes the bottleneck.

6. Conclusion

The aim of this work is to study and analyze lean laboratories, in particular the one installed at KTH. For this reason, it has been deepened in the lean philosophy, understand and internalize the functioning of the learning factories, comprehend the benefits of automated production and finally it has been analyzed the current laboratory in search of improvements.

It may seem that this work is focused solely on the improvement of the current lean laboratory installed at KTH University. But this is partially true, since has been commented on several occasions each production system is unique. Each assembly line has a flow of intrinsic value that differentiates it from the rest, and for this reason it requires specific lean measurements according to this flow. However, the steps for the application of these measures are general, regardless of the production system. First of all, the current status of the line must be known, the value flow must be familiar and for this task a VSM diagram can be of great help. Once this information is available, it is important to be aware of the tools that exist, in this case in both lean philosophy and automated production. Finally apply all reachable means to smooth the transformation from one production system to another. And for this purpose learning factories are used. These competency oriented trainings simulate the real production environment with the improvements to be introduced, offering workers the possibility to familiarize themselves with new practices and superiors to understand the responses in the new working environment. It should be noted that this step of providing tools that facilitate the transition from one way of working to another such as learning factories is paramount. Creating an environment in which essential capabilities are developed and trained to help achieving competitive advantages and technological changes in the production system. Some companies leave this aspect in a second section, limiting or even preventing the improvements introduced in the system from working as expected. The introduction of a philosophy such as Lean based on continuous improvement entails the need to evolve in the search for the flow of value and the reduction of waste. Therefore, the exercise developed in this thesis of introducing improvements in the assembly line is a necessary process that has to be carried out regularly. However, it must be remembered that in order for these improvements to be correctly integrated and achieve the desired objectives, their functioning must be known and shared by all the links that make up the production chain. To complete this function, we have the learning factories, which are presented in this work.

Once the proposed improvements have been made, it should be noted that the next step would be to introduce them in the current lean laboratory. After these improvements have been introduced, and the students have been able to interact with the new laboratory, these improvements must be evaluated. As it is defended in the article [1], in order to optimize the training modules and to make sure that competencies are learned in a satisfactory way, it is required to evaluate these competencies. If the results show it necessary, some of the proposed elements should be modified, added or removed in order to achieve the line improvement objectives.

If it is considered convenient, the improvements proposed could be tested before to be implemented in the line. Some simulation tools that can be used in this future work could be ExtendSim or Plantsim.

Finally, it should be noted that the purpose of this lean laboratory installed at the KTH is to bring the philosophy of lean closer to students. Giving them the opportunity to know and have a first-hand experience of how the different lean tools bring an assembly line closer to the value desired by the customer, making it possible to achieve objectives that were unattainable at first.

7. References

[1] J. P. Woman and D. T. Jones, “Lean Thinking - Banish waste and create wealth in you corporation,” pp. 1–396, 1996.

[2] J. K. Liker, “The Toyota Way: 14 Management Principles from the World’s Greatest Manufacturer,” 2004.

[3] “Lean Laboratory - Improve Efficiency and Simplify Processes | METTLER TOLEDO,” 2017. [Online]. Available: https://www.mt.com/se/sv/home/library/collections/laboratory-division/lean_lab.html.

[4] E. Abele *et al.*, “Learning Factories for research, education, and training,” *Procedia CIRP*, vol. 32, pp. 1–6, 2015.

[5] L. J. De Vin, L. Jacobsson, J. Odhe, and A. Wickberg, “Lean Production Training for the Manufacturing Industry: Experiences from Karlstad Lean Factory,” *Procedia Manuf.*, vol. 11, pp. 1019–1026, 2017.

[6] “How Manufacturing Automation Is Evolving - Robotics Business Review,” 2018. [Online]. Available: https://www.roboticsbusinessreview.com/manufacturing/how-manufacturing-automation-is-evolving/.

[7] M. Chui, K. George, J. Manyika, and M. Miremadi, “Human + machine: A new era of automation in manufacturing | McKinsey,” 2017. [Online]. Available: https://www.mckinsey.com/business-functions/operations/our-insights/human-plus-machine-a-new-era-of-automation-in-manufacturing.

[8] A. Nassereddine and A. Wehbe, “Competition and resilience: Lean manufacturing in the plastic industry in Lebanon,” p. 11, 2018.

[9] A. Anvari, Y. Ismail, and S. M. Hossein Hojjati, “A Study on Total Quality Management and Lean Manufacturing: Through Lean Thinking Approach,” *World Appl. Sci. J.*, vol. 12, no. 9, pp. 1585–1596, 2011.

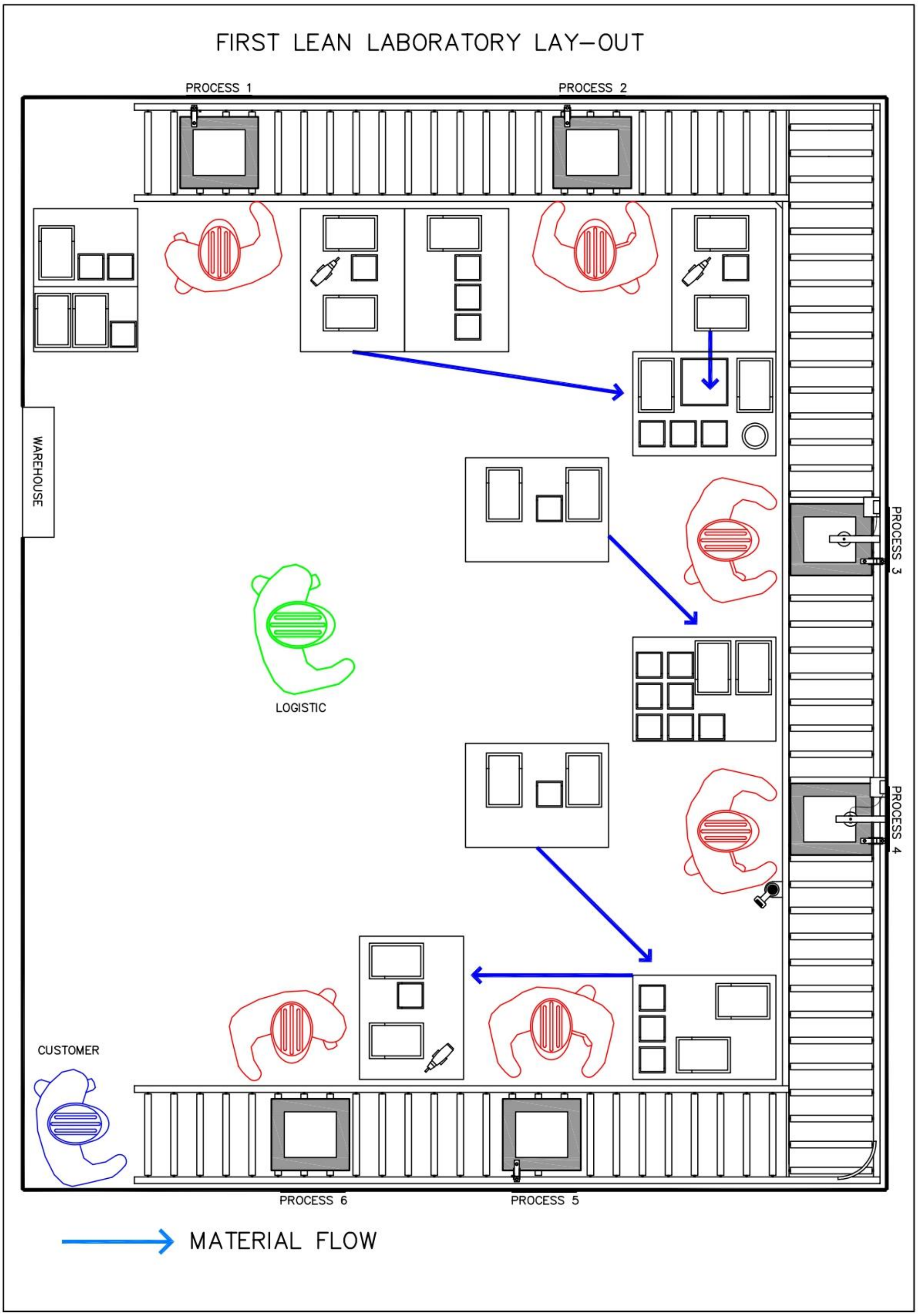
[10] Y. Yamazaki, S. Takata, H. Onari, F. Kojima, and S. Kato, “Lean Automation System Responding to the Changing Market,” in *Procedia CIRP*, 2016.

[11] “CONTAVAL,” 2014. [Online]. Available: https://www.contaval.es/.

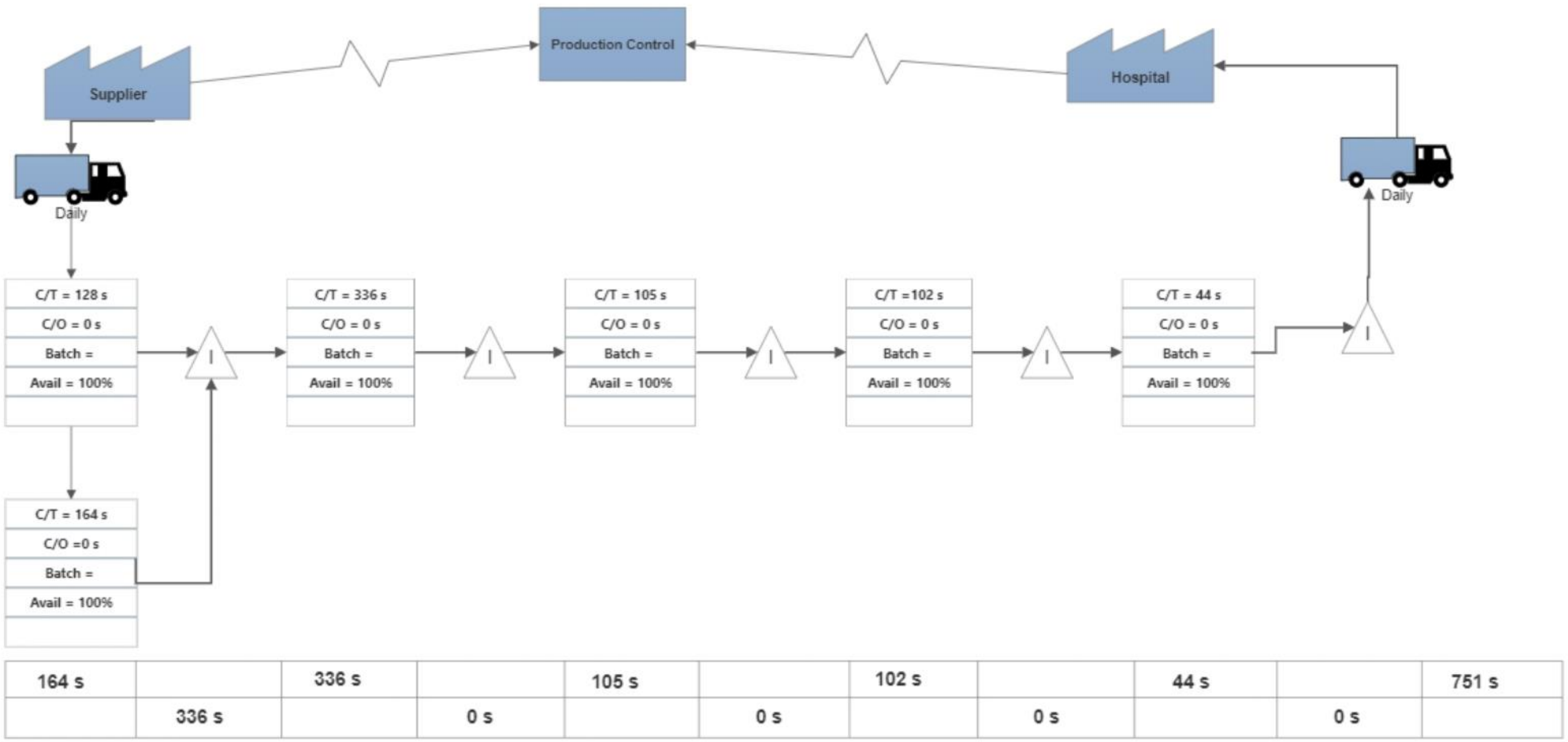
[12] “Work instruction - Ajan.ciceros.co.” [Online]. Available: http://ajan.ciceros.co/work-instruction/.

8. Annex

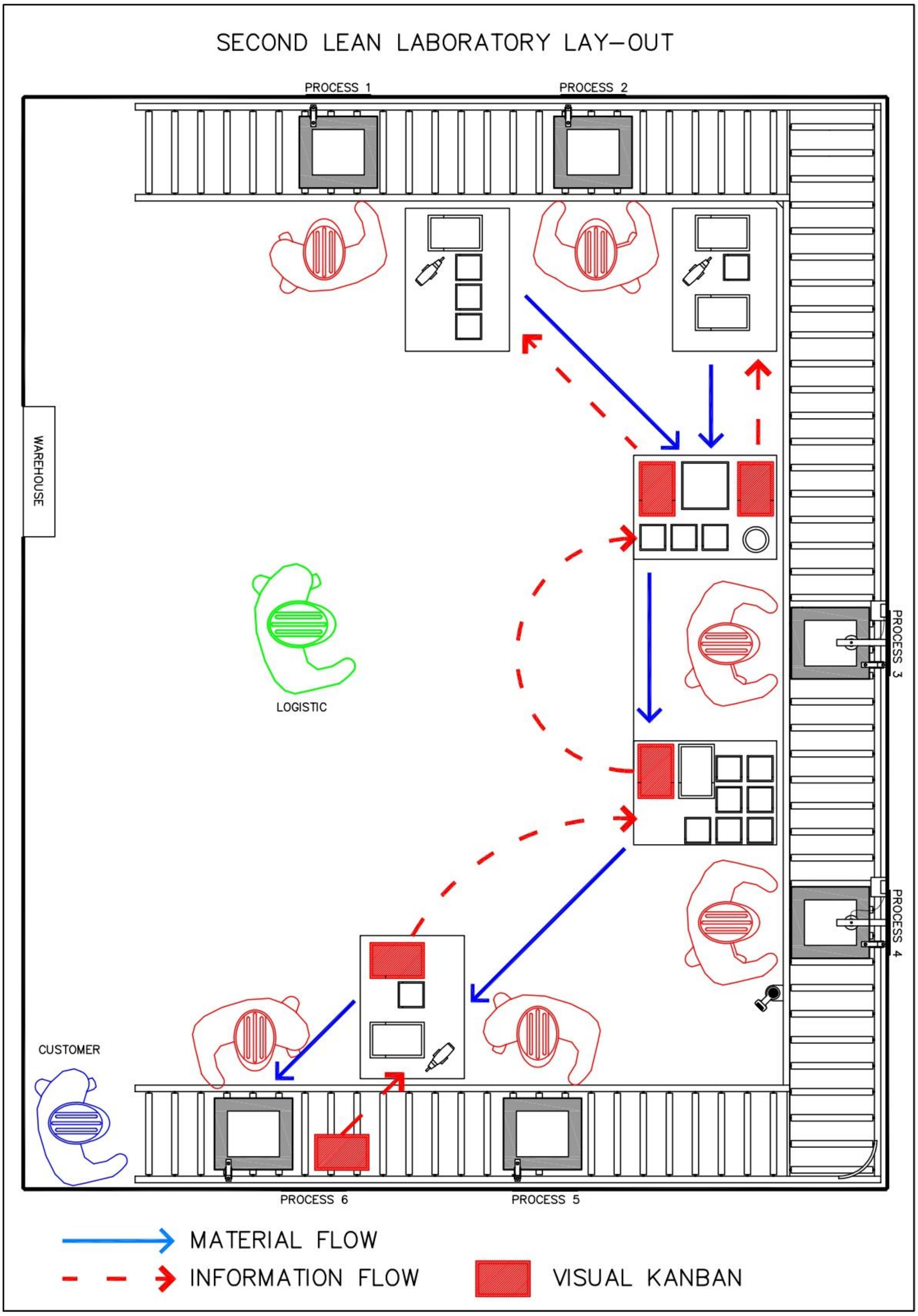
8.1. First stage lay-out



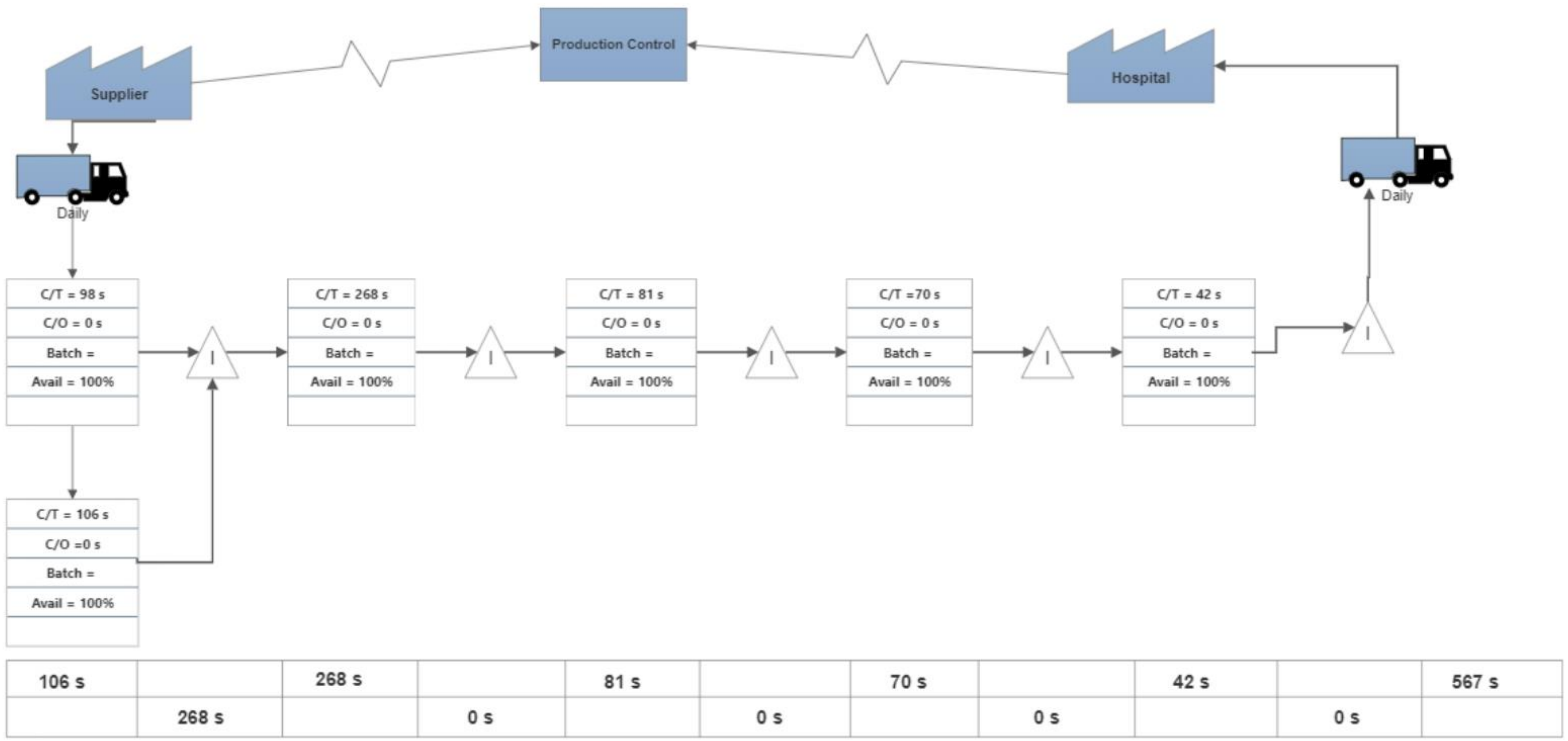
8.2. First stage VSM



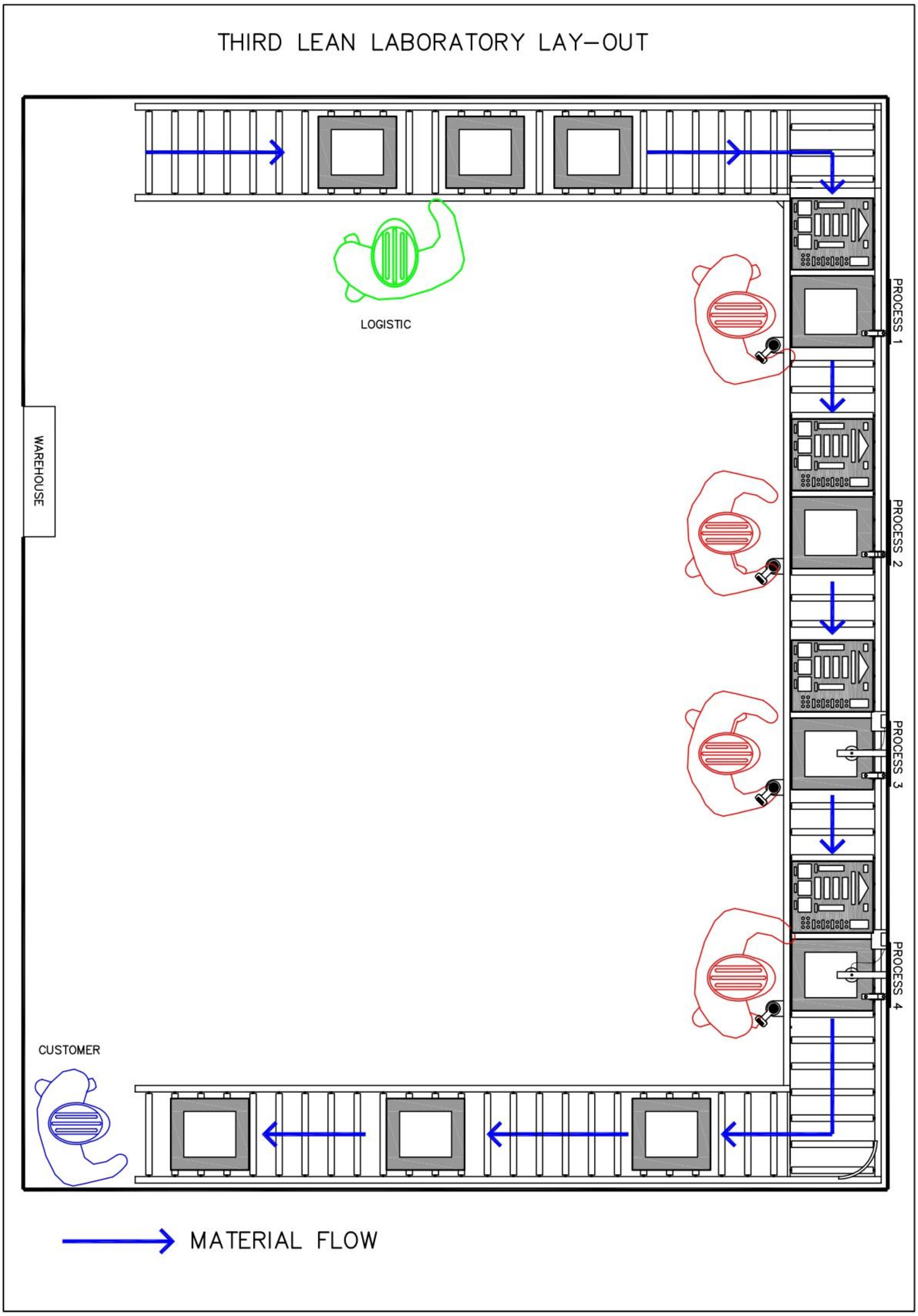
8.3. Second stage lay-out



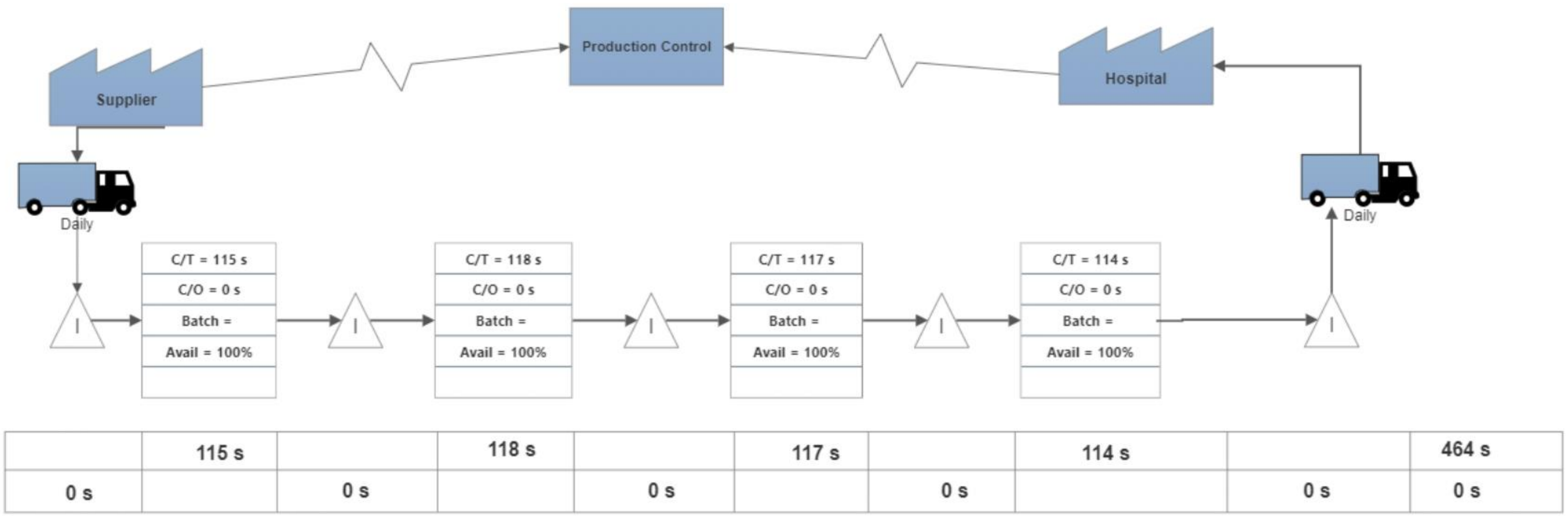
8.4. Second stage VSM



8.5. Third stage lay-out

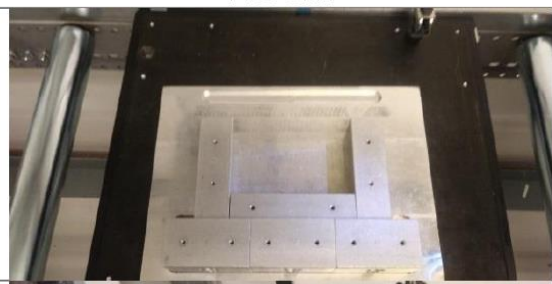
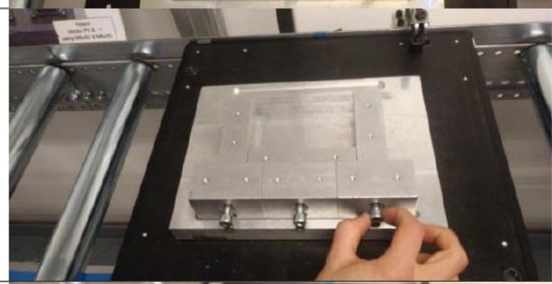
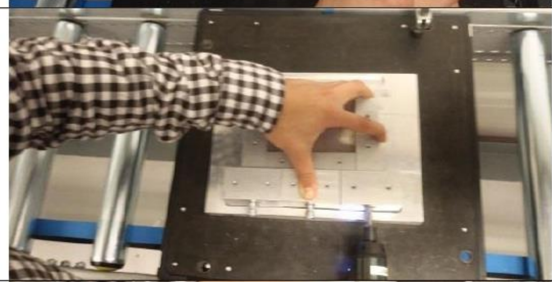
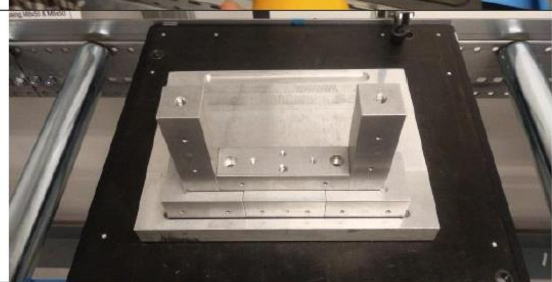
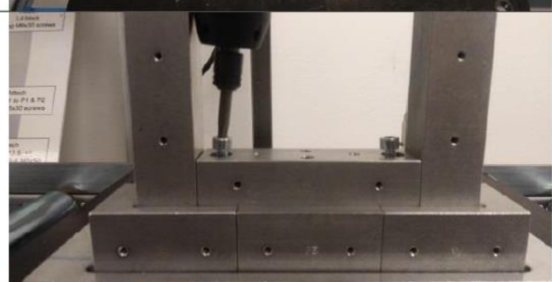
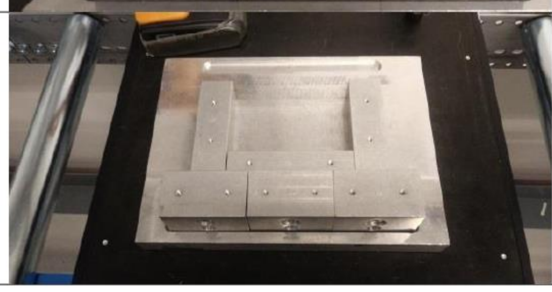


8.6. Third stage VSM



8.7. Work instruction for work station 1

KTH LEAN LABORATORY – WORK INSTRUCCIONS – WORKSTATION 1

№	INSTRUCTION	COMMENTS	PICTURE
1	**PLACE ALL THE PIECES IN THE WORKBENCH AS SHOWN IN THE PICTURE**		
2	**PLACE THE 6 SCREWS IN THE HOLES (3 M8x50 & 3 M6x50)**	• Screw manually 2 or 3 turns so the screw stays stable	
3	**USE THE SCREW DIVER TO SCREW THE 3 M8x50**	• Make sure the screwdriver is set in "screw" position. • You should screw until the screwdriver stops.	
4	**CHANGE THE BIT OF THE SCREWDRIVER TO M6x50**	• Pull the bit of the screwdriver and remove the head. • Place the new bit and push the head back again. • Make sure the head is fixed.	
5	**PLACE ALL THE PIECES VERTICALLY AS SHOWN IN THE PICTURE**	• Use the hole in the workbench to stabilize it.	
6	**PLACE THE 2 SCREWS M6x30 AND SCREW THEM WITH THE 2nd SCREWDRIVER**	• Screw manually 2 or 3 turns so the screw stays stable before using the screwdriver.	
7	**LAY DOWN THE BLOCK FOR THE NEXT STATION AND INFORM THAT YOU HAVE FINISHED YOUR WORK**		

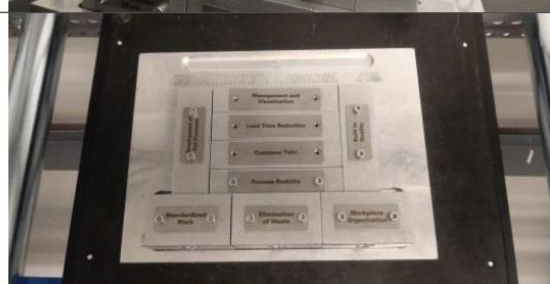
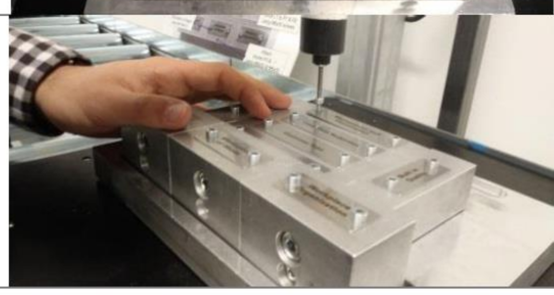
8.8. Work instruction for work station 2

KTH LEAN LABORATORY – WORK INSTRUCCIONS – WORKPLACE 2

№	INSTRUCTIONS	COMMENTS	PICTURES
2	**PLACE ALL THE LABELS IN THE CORRECT POSITION**	• Check the labels are correct as well as the orientation, as the picture in front of you shows.	
3	**SCREW MANUALLY**	• Screw manually the 12 screws M4x10, do 2 or 3 turns to make sure it stays stable.	
4	**USE THE SCREWDRIVER**	• The screwdriver will beep when the 12 screws are done.	
5	**INFORM THAT YOU HAVE FINISHED YOUR WORK**		

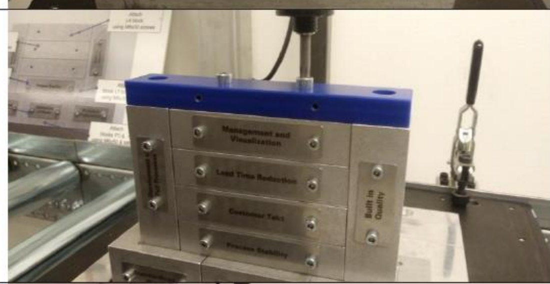
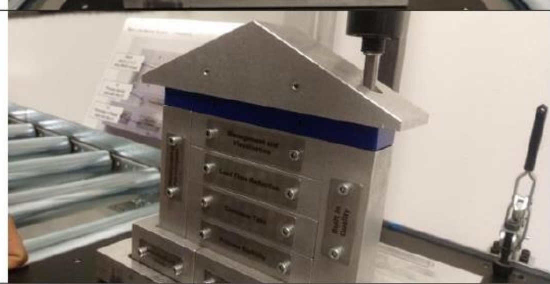
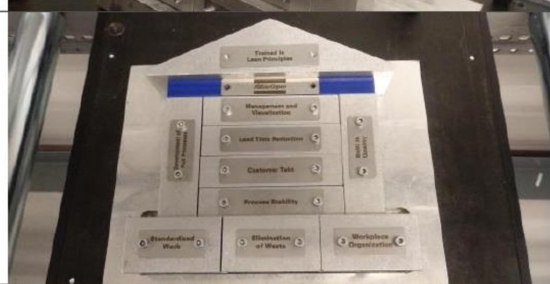
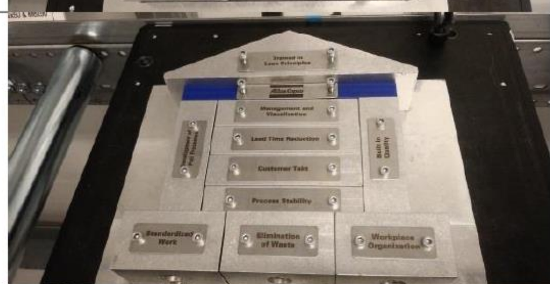
8.9. Work instruction for work station 3

KTH LEAN LABORATORY – WORK INSTRUCCIONS – WORKPLACE 3

№	INSTRUCTION	COMMENTS	PICTURE
1	PLACE ALL THE PIECES IN THE WORKBENCH AS SHOWN IN THE PICTURE	• Use the hole in the workbench to stabilize it.	
2	PLACE THE BLOCKS L2 & L3 AND THE 2 SCREWS M6X30	• Screw manually 2 or 3 turns so the screw stays stable before using the screwdriver.	
3	USE THE SCREWDIRVER		
4	PLACE THE BLOCK L4 and the screws M6x30	• Screw manually 2 or 3 turns so the screw stays stable before using the screwdriver.	
5	USE THE SCREWDIRVER		
6	LAY DOWN THE BLOCK AND PLACE THE LABELS AS SHOWN IN THE PICTURE	• Check the labels are correct as well as the orientation, as the picture in front of you shows	
7	SCREW MANUALLY	• Screw manually the 6 screws M4x10, do 2 or 3 turns to make sure it stays stable.	
6	USE THE SCREWDRIVER AND INFORM THAT YOU HAVE FINISHED YOUR WORK	• The screwdriver will beep when the 6 screws are done.	

8.10. Work instruction for work station 4

KTH LEAN LABORATORY – WORK INSTRUCCIONS – WORKPLACE 4

№	INSTRUCTION	COMMENTS	PICTURE
1	**PLACE ALL THE PIECES IN THE WORKBENCH AS SHOWN IN THE PICTURE AND PLACE THE BANNER BLOCK**	• Use the hole in the workbench to stabilize it.	
2	**FIX THE BANNER WITH 2 SCREWS M6x30**	• Screw manually 2 or 3 turns so the screw stays stable before using the screwdriver.	
3	**USE THE SCREWDRIVER**		
4	**PLACE THE ROOF BLOCK AND SCREW MANUALLY THE 2 SCREWS M8x30**	• Screw manually 2 or 3 turns so the screw stays stable before using the screwdriver.	
5	**USE THE SCREWDRIVER**	• Change the bit M6 to M8	
6	**LAY DOWN THE BLACK AND PLACE THE LABELS**	• Check the labels are correct as well as the orientation, as the picture in front of you shows.	
7	**SCREW MANUALLY**	• Screw manually the 4 screws M4x10, do 2 or 3 turns to make sure it stays stable.	
8	**USE THE SCREWDRIVER AND INFORM THAT YOU HAVE FINISHED YOUR WORK**	• Change the bit M8 to M4