ENHANCING THE CNC MACHINING PROCESS WITH LEAN MANUFACTURING TOOLS

Case Tambest

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ABSTRACT

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TIIVISTELMÄ

Tämän opinnäytetyön tavoite oli tutkia, millä Lean-johtamisen työkaluilla CNC koneistuksen prosessia voisi tehostaa. Tarve tutkimukselle syntyi yhdessä työn tilaajan Tambest Glass Solutionsin kanssa, CNC työvaiheen ollessa tuotannon pullonkaula. Tässä opinnäytetyössä on keskitytty Lean-ajatteluun, sen keskeisiin työkaluihin sekä laadun parantamiseen, laadun ja työvaiheen suorituskyvyn ollessa kytköksissä toisiinsa.

Pääongelmat CNC työvaiheessa olivat itse koneen puutteellinen suorituskyky, vanhentunut ohjainyksikkö sekä tavaroiden ja tuotteiden varastointi. Puutteellisen suorituskyvyn on aiheuttanut koneen huollon osittainen laiminlyöminen sekä ymmärtämättömyys automaattisten toimintojen tarpeellisuudesta. Tutkimuksessa myös selvisi, että CNC koneistuksen ohjelmisto on päivityksen tarpeessa. Ohjelmiston valintaan ei tässä työssä ole kuitenkaan keskitytty, vaan sitä pitää punnita erikseen.

Pienillä muutoksilla työskentelyrutiiniin on suuri vaikutus CNC koneistuksen tehoon: työpisteen ja sen työkalujen uudelleenjärjestely, päivittäisen sekä viikoittaisen huollon auditointi sekä koneen käyttöä helpottavien toimintojen korjaaminen käyttökuntoon.

Avainsanat Lean-ajattelu, laatu, toiminnanohjaus, cnc, koneistus

Sivut 40 sivua, joista liitteitä 8 sivua

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ABSTRACT

The goal of this thesis project was to study, which Lean management tools would suit best for enhancing the process of a CNC machine with the commissioner. The demand for this study came from the CNC machining phase being the production's bottle neck. This project was focused on Lean thinking and its essential tools as well as on improving quality, quality and work phase performance, connected to each other.

The main issues in the CNC work phase were the machine's poor performance, the outdated control unit and the placement of the equipment. Poor performance was caused by partial ignorance of maintenance and a lack of understanding the importance of automatized functions. The study also revealed a need for updating the CNC machining software with the commissioner. However, choosing better software was not included in to this thesis project, but needs a further study.

Small changes in the working routine have a major impact on CNC machine's performance: reorganization of the workstation and its tools, auditing for daily and weekly maintenance and repair of automatized functions.

Keywords Lean management, quality, supply chain, cnc, machining

Pages 40 pages including appendices 8 pages

CONTENTS

LIST OF ABBREVIATIONS

CNC	=	Computer Numerical Control
JIT	=	Just in time
JIC	=	Just in case
WIP	=	Work in progress
ERP(S)	=	Enterprise Resource Planning (System)
QR code	=	Quick Response code
CAD	=	Computer-aided Design
CAM	=	Computer-aided Manufacturing

1 INTRODUCTION

This thesis was commissioned by Tambest Glass Solutions Oy because of their CNC machine's poor performance, the CNC process being bottleneck in the production chain. The goal of this study was to discover different solutions and tools to enhance the process and to reduce stress for the employees operating the CNC machine.

1.1 Commissioning company

The company which commissioned this thesis was Tambest Glass Solutions Oy. Tambest Glass Solutions is one of the biggest glass manufacturers in Finland, being precise, it is the sixth biggest operator in the glazing industry, when concentrating on turnover (Asiakastieto, 2016). It has a 10000sqm production line in Forssa, and the production line has a wide variation of different processing steps of glass, from cutting it to bending it. Tambest Glass Solutions employs about 65 people at the moment. It's production, sales and administration locate in Forssa. Tambest Glass Solutions has over 30 years' experience in glazing business: in 1984 established Tambest Oy and in 1985 established Suomen Turvalasi Oy. (Tambest, 2016)

At the beginning of the company's history, it was called Lounais-Hämeen Lasipalvelu. First few years the business was about glasses' repair work, changing windshields etc. In 2001 it started to produce tempered safety glass and changed the name to Suomen Turvalasi, as it was better describing the new direction of the company. In 2005 they started to produce also laminated safety glass, following their new strategy plan. From 2008 they have had curved glass in their selection, as a result of purchasing business of Tambest Oy. (Tambest, 2016)

Tambest Oy was founded in 1984 and its business has always focused on challenging curved glass plates, meeting the customer requirements, in Finland and in international markets. (Tambest, 2016)

After the factory expansion in Forssa finished in 2010, the whole production centralized in Forssa. At the same time Tambest and Turvalasi were united and the name changed to Tambest Glass Solutions, as it described the comprehensive business better. (Tambest, 2016)

Great part of Tambest's orders are glazing for public buildings from shopping malls to airports. Main glazing objects are glass walls and glass railings. Among glass walls and glass railings Tambest's products are balcony glazing and architectural glazing. Tambest also has their own installation department, but this research is focused only on production. (Tambest, 2016)

1.2 Research objectives and methods

The objective of this research project was to clarify by which actions it would be possible to enhance the glass production phase at the CNC machine's workstation. What could be done to make it more efficient for the employee to produce more, focusing on the condition of workstation, layout, hardware and software of the workstation.

The project was concluded through a background study of literature and internet articles about Lean Management. A major part of field study was done following qualitative research methods by interviewing responsible employee, observing the environment, taking field notes, conducting semi-structured interviews and through on the analysis of gathered data. Semi-structured interview means that basis of the interview has structured, but new ongoing ideas can lead the interview to various directions. By interviewing and discussing with the employee one could learn a great amount of tacit knowledge from the process. The employee's day-to-day working was observed and spaghetti diagrams were drawn.

Spaghetti diagrams were chosen as a major tool in the field study because they represented comprehensively the process, how different objects were moving during process and the waste was revealed instantly. Time studies were combined with the spaghetti diagrams to measure the production time as well as the changeover time.

2 LEAN MANUFACTURING

“Any discussion of lean would be incomplete without reference to kaizen” (Trent 2007, 140). Kaizen is Japanese and it means continuous improvement. It is what everything in lean manufacturing aims to. That is why lean manufacturing have no end point, it is endless journey for company. It can be thought as revealing the improvement chances in processes with giving the employees right tools and methods. (Trent 2007, 140)

In every production line there is all kind of waste. Not only physically broken orders, but everything which doesn’t add value for the company. When the cost of waste is reduced a company will improve their profit. There are many different tools to detect different kinds of waste when manufacturing goods. Toyota’s Chief Engineer Taiichi Ohno developed very efficient tool to minimize waste (originally called Toyota Production System (TPS)) but it is nowadays more commonly called Lean manufacturing. (McBride 2003)

Lean manufacturing is focused on continuous improvement and reducing waste in all levels, not only Muda but Mura and Muri as well. Muda is caused by Mura and Muri and therefore it will automatically reduce some of the eight wastes when concentrating first to Mura and Muri, in that specific order. (Lean Manufacturing Tools 2017; Trent 2007)

2.1 Three different kind of waste

As mentioned, waste is not just defect orders, in fact defects are just a tiny single section that a company can waste. 3M’s of lean manufacturing, Muda, Mura and Muri are all waste, even though usually people are talking only about Muda when talking about waste. While Mura and Muri are not that well known they are not less important. Actually, Mura and Muri creates Muda, so it is vital to concentrate them as well. (Lean Manufacturing Tools 2017)

2.1.1 Muda (The eight wastes)

Originally there were seven wastes that one should take in account. Later there has been added eighth waste and these eight wastes are listed below and explained afterwards:

- Overproduction
- Waiting
- Transporting
- Inappropriate processing
- Unnecessary inventory
- Unnecessary motion
- Defects
- Underutilization of employees

There are some variations presenting wastes for example TIM WOODS. TIM WOODS' letters stand for Transport, Inventory, Movement, Waiting and delays, Overproduction, Over processing, Defects and Skills. These terms differ a bit but the meaning is same and it is a pretty clever mnemonic.

Overproduction means that production line manufactures the order before it is required for the next process or just manufacture too much of a product for certain order, which customer usually isn't willing to pay. Overproduction is one of the worst wastes there are because it will generate more waste. In manufacturing it is much cheaper to produce orders just-in-time (JIT) than just in case (JIC) which can relate to overproduction. Overproducing creates storage costs, because after overproducing duplicates the company must either bin them or send them to customer. Either way it will cost the company way more than the order requires. Other scenario is to produce the order before it is actually needed, this affects in many things. It would extend the lead time because the order just lays there without any purpose and before it is required. It would also raise the storage costs for the orders laying there and reserving the space from more urgent orders. (McBride 2003; Lean Manufacturing Tools 2017; Carreira & Trudell 2006, 20.)

When overproduced the company ties its cash to production, to be more exact, in excess stock, excess raw materials, work in progress (WIP) and finished goods. If a company would go by JIT it would release more money for paying the bills or gaining the profit. The company would do better when it didn't have much money tied to their production. Another great expense is storing all the products overproduced. It will need space, it will need employees and equipment to move around and it will reserve trolley et cetera to store it on. (Lean Manufacturing Tools 2017)

Causes of overproduction might be many. One could be unbalanced processes. If the first process takes half of the time the next process takes, it leads to long queues for latter process. The first process should be balanced to flow smoothly with other processes without creating queues. Second cause might be long changeover times. If time between orders to change the setup is high, companies usually prefer big batches and it sounds reasonable to overproduce. Therefore, a company should decrease the changeover times. (Carreira & Trudell 2006, 21.)

Waiting is everything else happening to order than producing normal speed during the production process. Most of the product's time in production line is waiting and it is either because material flow is poor, there are bottlenecks in production line or distances are too long between production processes. Ideal case would be matching the processes to feed each other without forcing orders to wait but straight away continue processing in the next processing line. Bottlenecks are big thing in waste of waiting and a company should take in account how they could improve production processes to not having any bottlenecks. Balancing the processes is a key to prevent bottlenecks. (McBride 2003; Lean Manufacturing Tools 2017)

Almost all the time in order's lifespan during the lead time product is waiting. Therefore, any time saved from the queueing will decrease the production costs and turn to profit. Company must pay salary for the employees also for the time they are waiting. Company can't add employees waiting time's salary to customers' invoice, so a company must take the money straight from its profit. Often when there is waiting at some point in production line, it is compensated with overtime work, which isn't good for a company's profit either. (McBride 2003; Lean Manufacturing Tools 2017)

Unreliable processes cause waiting because of various reasons. These reasons might be for example breakdowns, quality problems, poor information flow or too long distances between processes. Many other waste creates waiting like overproduction, unnecessary inventory and transporting between processes. Efficient information flow is also great and relatively easy asset to reduce waste. If information flow is not efficient enough, employees waste time figuring out details of an order or what order to process next. (McBride 2003; Lean Manufacturing Tools 2017)

Transporting orders during manufacturing is non-value adding process within production. Every purposeless transfer or handling of the order is a risk for product to get damaged and chance for quality to suffer. This is one of the hardest wastes to reduce because it usually takes unreasonable amount of money to rearrange production lines or redesign layout so that distances are short. In addition, it might be tricky to prioritize which processes should be next to each other. (McBride 2003; Lean Manufacturing Tools 2017; Carreira & Trudell 2006, 23.)

Transporting is often caused by overproduction. When overproducing there comes unnecessary inventory, another waste. Since there is extra inventory there is also extra transporting and handling of goods, because there might not be enough space in the facility to store all the orders overproduced. (McBride 2003; Lean Manufacturing Tools 2017)

Inappropriate or over processing means adding value to product when it is not required or desired. This waste is usually quite hard to see. For example, focusing to broken edge of a glass plate if it will be hidden after assembled. Over processing will cost the company not directly but by adding value that customer is not going to pay. It will also cost by unnecessary working time and wear in equipment. These costs are not ones' a company will prioritize to, but they will accumulate. Same amounts of time employees are using over processing, they could do something that would add value to a company. (McBride 2003; Lean Manufacturing Tools 2017)

Reasons for over processing can be divided in three main issues. One is unclear quality standards. Often employees try to do the best they can, but it can be unclear to them at what point it is enough processing, when the value stops adding. Second problem occurs if processing line isn't standardized enough. Then quality, processing times, efforts and methods are varied a lot between different working shifts and people. Third reason is differences in understanding the big picture between designers and practice. Design might demand higher precision in tolerance than it would need. (McBride 2003; Lean Manufacturing Tools 2017)

Unnecessary inventory is especially caused by overproduction, but waiting is also causing it. Product can be waiting for getting to next processing stage, because of unbalanced workflow also known as bottlenecks. Unnecessary inventory is a great tool to find out if there is bottlenecks in production line and where to find them. Unnecessary inventory will extend lead times, it wastes the floor space which could be used productively and hinders the communication. (McBride 2003; Lean Manufacturing Tools 2017)

Inventory which the company holds has always a cost. Inventory can be work in progress (WIP) or raw materials or finished goods waiting in stock. Either way it is money bind, which is money out of the company's cash, which could be used to something else. Furthermore, there is other costs that are off a company's profit, like transporting and handling the inventory, the space to store it, controlling and keeping track of it, insurances. There are many different costs to keep unnecessary inventory and it will cause raise to costs and lead times, this might lead to customer being not satisfied with the company's performance and in worst scenario losing its clients. (Lean Manufacturing Tools 2017)

Keeping inventory as a buffer if something goes wrong costs a company more than it should. If a company could lower the level of safety stock and fix the problems it reveals, it would save big amount of money. (Lean Manufacturing Tools 2017)

Unnecessary motion is waste of employees' energy, strongly associated with ergonomics. It includes every excess motion that employee needs to make to get the job done, like walking, lifting and reaching. Again, this does not add value to product. Company should focus on ergonomics and analyze the processes with personnel to minimize excess motion in different stages of production processes. This waste is also health and safety issue, which company should always use its effort to. It is much cheaper to keep employees in good shape than pay their medical leaves and substitutive workforce and other expenses. (McBride 2003)

Excess motion will lower company's working efficiency. If employees are using more time for searching the orders, lifting or moving objects from place to place rather than processing it, the company's efficiency is lower than it could be. If excess motion is constant and long lasting it will probably affect to employees' working condition. In worst case it will cause back strain or other handicap that will affect one's working condition. (Lean Manufacturing Tools 2017)

What is then causing the excess motion. It is caused by lack of organizing or standardizing cell layout, tools, component parts, working methods or even design of a product. Poorly arranged space or lack of it is causing unnecessary motion as well. Excess motion comes when one must use time and effort to find tools or component parts. It occurs when one must move a lot to use machines or continuously move the product. (Lean Manufacturing Tools 2017)

Defects resulting rework are enormous cost to the company. It also the most common waste people recognize when speaking about waste. This leads to wasted worktime, rescheduling and capacity loss. Company should be aware of how big part total costs of defects are from total manufacturing costs. Due to human resource and continuous process development (CPI) it is relatively easy process to reduce defects. (McBride 2003) (Lean Manufacturing Tools 2017)

“The general rule of thumb is to multiply the cost of the scrap by a factor of ten to arrive at the true cost to your business” (Lean Manufacturing Tools 2017). There are many different costs hiding during defect to redone, like problem solving, materials, rework, rescheduling orders, setups, transport, paperwork and increased lead times. In worst scenario delivery failures or company even have lost customer because of unreliability. (Lean Manufacturing Tools 2017)

Big portion of the defects could be avoidable with designing products, processes and equipment. Defects could be reduced by reducing previously mentioned wastes. For example, with standardization of work methods in different processes, to minimize the differentiation between shifts and employees. Maintaining the machines properly will reduce number of defects: when machine is working properly, it will make fine job. Employees don’t always have courage to highlight breakages and stop working during the maintenance is solving them rather than trying to do the best work with bad equipment. Also putting new employees straight to full speed production process and to do the same work as the employee who has been doing it many years. In production culture it is often rewarded to make quantity rather than quality. It would move money from cost to profit if orders could be done properly at once. (Lean Manufacturing Tools 2017)

Underutilization of employees is the eighth addition to seven wastes. It means to waste employees’ talent. Employees are the most valuable asset a company has and it should appreciate it. Employees make sure that machines work properly, they will ensure that orders leave on time and that processes are running. If they are motivated and loyal to a company, it will give competence that others might not have. Only if employees are committed to perform well and improve the processes, other wastes are possible to reduce. (McBride 2003) (Lean Management Tools 2017)

Main issue a company wastes with underutilizing employees is time. Company could do far faster the improvements and solve the problems if it relied more to employees, not only to experts. Even though the fact that supervisors, engineers and managers are probably more skilled they are outnumbered and employees have more practical experience about processes. If a company does not use its most important asset well enough, it means that competitors will start to gain more marketshares. (Lean Management Tools 2017)

Talent and creativity is wasted for many reason, main one being company failing to value the strengths and contribution of employees. This might come from thought that employees might become over trained and start demanding better wages and even changing the workplace. Company should give value to employee’s ideas and provide the support, time and resources to make the improvements if they are reasonable. (Lean Management Tools 2017

2.1.2 Mura (Unevenness)

Mura is the waste of unevenness and it creates many wastes of Muda. If a company's demand is not smooth it will waste its capacity. For example, manager having monthly output goals and the last week of month employees are working fast just to meet the monthly goals as in *Figure 1*. Next month's first weeks are slow because of various reasons. Either there is no work to be done or company is short of raw materials or components. (Lean Manufacturing Tools 2017)

When production's demand isn't predictable and smooth, it will push the problems forward to processes and employees and create excess inventory and other wastes. When the company's demand is not even it will waste the company's production capacity. This is shown in *Figure 1* as the company is wasting its capacity during the first three weeks, the fourth week is run with full capacity. (Lean Manufacturing Tools 2017)

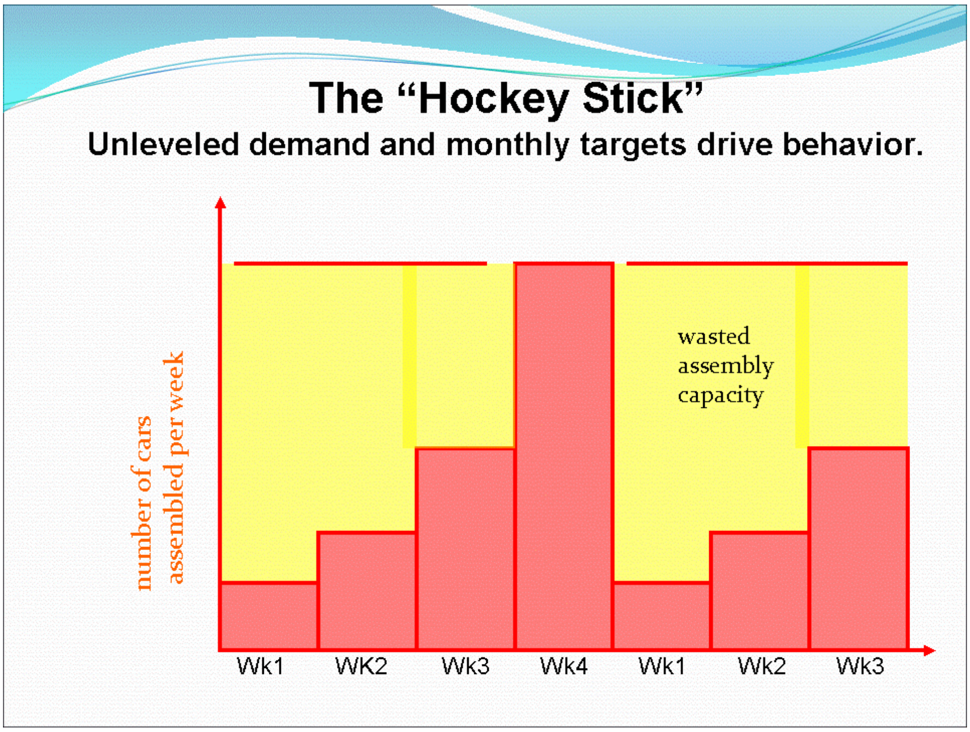

Figure 1 Uneven production demand. The term"hockey stick" derives from the shape of the diagram (Lean Manufacturing Tools 2017)

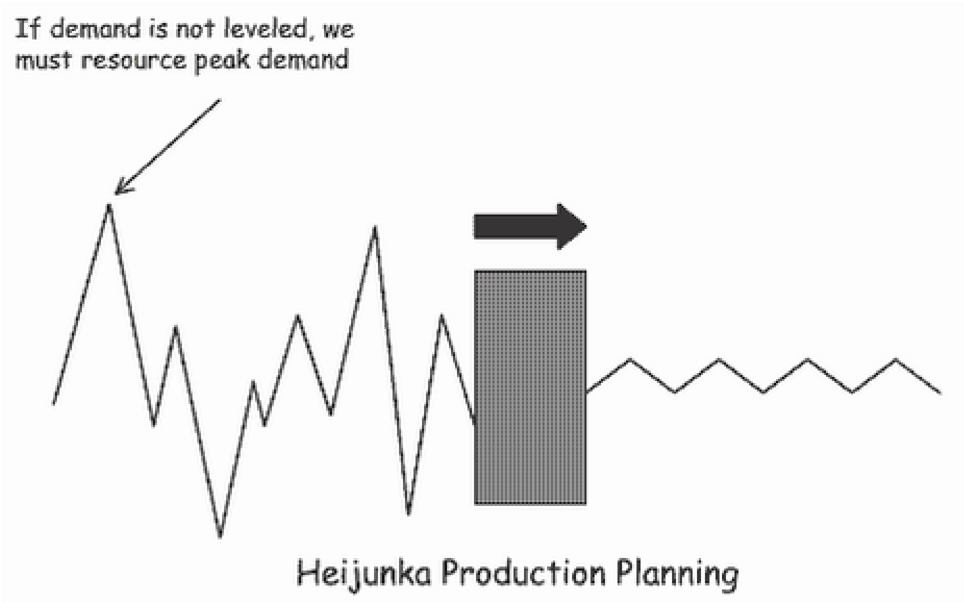

Figure 2 Heijunka production planning, levelling the production demand. (Dennis 2010, 195)

If the company only produces JIT then the customer demand is uneven and Mura happens. Instead the company should plan leveled production schedule and leveled information flows. If the customer demand varies much the company must have resources to meet the peaks in the production demand as in *Figure 2*. *Figure 2* shows that after reducing Mura, resources needed to produce same number of products is decreased drastically. Heijunka is Japanese and means leveling. (Dennis 2010, 194-195.)

Company should focus on doing better in management of demand rather than reacting it. It is great improvement if one can level demand as much as it is possible for the business. Companies often have hard times trying to level the demand especially when the demand is highly erratic and products varies a lot. (Trent 2007, 95-96.)

When levelling the demand one important thing to give attention to is takt time. Takt is one of the few non-Japanese words within lean management. It is German and stands for the stick the bandmaster uses when leading an orchestra. In Lean management takt time means the rate customer demands a product. For example, if tempered glass plate processing line is working 5 days a week, in 2 shifts, 7 hours and 60minutes per hour they have 4200 minutes available per week. Let us assume that Tambest has 60 customer orders per week for tempering line, this means employees have 4200 minutes / 60 = 70 minutes to use for every order. If takt time is less than expected processing time the company will most likely have backlogs. (Trent 2007, 96.)

2.1.3 Muri (Overburden)

Muri means causing overburden. This meaning to give unnecessary stress to a company's employees and processes. This is caused by Mura, undefined instructions in working or using machines or tools, wrong tools, untrained employees and poorly thought measurements of performance. (Lean Manufacturing Tools 2017)

Important aspect in reducing the overburden is to standardize the processes as far as it is reasonable for adding value. It is important to have processes with same exact output regardless whether it is morning or evening shift, who is doing the work or how long working experience the employee has. (Lean Manufacturing Tools 2017)

Employees should have right to stop producing if they see that something is wrong with the machine. This way company will build up the culture of fixing things to prevent defects and other waste rather than not daring to report the problems and keep running with them and keeping production running. (Lean Manufacturing Tools 2017)

In addition to common sense there are some tools to reduce Muri as well. One of these tools is 5S's and these S' stands for Japanese words Seiri, Seiton, Seiso, Seiketsu and Shitsuke. In English 5S means Sort, Set in Order, Shine, Standardize and Sustain. (Lean Management Tools 2017; Santos, Wysk & Torres 2014, 147.)

Sort (seiri), it should be clear to management and production employees which elements are necessary and which are not. For example, obsolete or worn out equipment might be stored somewhere just to be out of sight, just lying there and not being used for daily production operations. It will probably never be going to get disposed. This also works for products that are not produced or some parts of machine. Also, unclear instructions where to store WIP is common problem. (Santos et al. 2014, 151.)

Sorting is relatively hard as people usually can easily make up usefulness for nearly everything. This means it will become unclear which objects or elements are necessary and which are not. "It is necessary to get rid of all the unnecessary objects!" (Santos et al. 2014, 151.). This can be done by dividing stuff to three categories:

- Frequently used.
- Probably going to be used.
- Never going to be used.

Last two categories should be moved away from working area, but objects one might use can be temporarily stored somewhere. (Santos et al. 2014, 151.)

Great tool when starting to implement is placing a red tag on equipment. Red is because it is bright, noticeable and it is concerned to symbolize warning or stop. Goal is not to change the whole factory to red, only small part at time. Company can divide equipment to three groups like above, and put same red tag all but frequently used ones. When used two colors, decision making becomes more difficult and might confuse people. So, when in hesitation, the object should tag red. (Santos et al. 2014, 157-158.)

Set in order (seiton) is only applicable if sorting has done properly. There is no point of set in order something that is unnecessary to be there. Ultimate goal of set in order phase is to eliminate the time used in searching objects. One of the most common wastes is inability in finding tools or drawers in work places, tools or equipment in there are rarely in any specific order. As these improvements might take time and resources to carry out, it is preferred to focus on the most urgent ones first. (Santos et al. 2014, 152.)

Setting signs to factory has many advantages. One group will especially benefit from visual signs or codes, newcomers who don't know the factory and practices within. Visual signs would be good to point out machines as well as place for particular WIP, also different parts of factory could be coded. (Santos et al. 2014, 158.)

Maintaining things that have set in order might be difficult. Especially tools that have been organized. There are three techniques when trying to deal with that chaos:

- *Suspension.* Tools can be suspended with sheave to keep tool in assigned places with convenient range.
- *Incorporation.* Indicators or measures can be attached to machines.
- *Use elimination.* Tools usage should be combined as far as possible. For example, using only one type and size screw-heads or change machines nuts to same size.

This way it is quite easy to handle the order of tools. When one tool fits in many usages and tools' location are fixed, the number of tools one must keep in order is low. (Santos et al. 2014, 161-162.)

Shine (seiso) as keep your work place clean. It will reduce the potential medical leaves and waste as clean windows let more light in and there is no oil, dust or any else dirt in the floor. For example, the glass dust is extremely slick and is a risk for accident when left in the floor. Dirt will also cause machine break downs. In worst case it will reduce the life span of machines, if not maintained properly. Company can outsource its cleaning but still, specific machine maintaining remains usually in company's responsibility. Company should try to create cleaning to daily routine and culture to do it. This should be implemented as an independent project, as this work does not concentrate on maintenance. Ultimate goal of shine is to solve the source of dirt and fix it. So to say the aim is to work for having no need to clean. (Santos et al. 2014, 152-153., 162.)

Standardized or visual control (seiketsu) doesn't have a clear goal to aim to. It is accomplished when three earlier stages are put into practice. Goal is to prevent the repetition of effort company used implementing three earlier stages. Preventive actions are to search the source of the problem. For example, machines usually drop some oil and as a result, employees usually clean the oil from the floor. Preventive action in this case is search the leakage and repair it. This can be linked to maintenance project, as it aims to change the culture of troubleshooting. (Santos et al. 2014, 153-155.)

Sustain (shitsuke) means discipline for monitoring the improvements. If company or employees will lack in discipline the earlier stages will be undone very quickly. Returning to improvements by doing everything is always harder, so it should be done right from the beginning. As the number of managers who can assign and monitor tasks are quite few, responsibility could be given to shift leaders to ease the maintaining. (Santos et al. 2014, 155-156.)

Managers have the responsibility to promote the actions for improvements to the employees. It is important to get the employees to believe in company's cause, to make them want the improvements. Because that's the asset which is going to make it happen. There are some mentionable tools to promote, for example:

- *Slogans.* For example, "Factories like to be clean, too."
- *5S news bulletins.* Short information with good description and perhaps couple of good pictures.
- *Pictures panels.* Before – after improvement pictures.

Pocket manuals. Small manual to present for employees the main idea of 5S and benefits it gives. These would be given to all to help reduce possible resistance to make changes. (Santos et al. 2014, 162-163.)

2.2 Myths about the Lean

There are many myths about Lean management. Main single issue one must always remember when talking about Lean, it is all about continuous improvement. Here are listed some of the most common ones:

Lean is about cutting costs. Although when reducing cost is done properly it can reduce waste from production. Still lean manufacturing isn't about cutting the costs, it's about reducing waste and a cut in costs is the desired result. (Trent 2007, 17.)

Lean is about internal production. Lean is not just in internal production, but it can be applied in every section of supply chain. For example, lean material management, lean systems development and many more. (Trent 2007, 19.)

Lean is for manufacturing companies. Even though people often speak about lean by lean manufacturing, it is far from truth as said in previous myth. Lean can be applied in many other fields of supply chain as well. (Trent 2007, 19.)

Lean is your most important strategic objective. Lean isn't the most important thing one's company can have. Far more important thing for the organization is to have good strategy to make well in business than only focus on quality. One can make fine quality job but still be no good in business. (Trent 2007, 20.)

Lean is a series of techniques. Company that tries to only complete separate techniques will fail to apply Lean to whole supply chain. Lean is more way of thinking than a series of certain actions. (Trent 2007, 20.)

Lean means Just-in-time. Even though JIT and Lean are linked, they are not synonyms. Quality will not improve with only changing company's delivery system to JIT, it must change also its business philosophy. (Trent 2007, 18., 21.)

You can't be too lean. If Lean is followed too strictly, safety stock is relatively small, then there might be serious troubles if something goes terribly wrong. (Trent 2007, 21.)

Lean is forever. Company's situation might change dramatically for example when conquering new markets in new country. There aren't any final goals in lean, just the journey. (Trent 2007, 18., 22.)

Lean stifles innovation. It is quite the opposite. When lean is done correctly it will encourage to innovative thinking rather than stifles. (Trent 2007, 18.)

3 ANALYSIS OF CURRENT STATE

The results of the field study are shown, explained and analyzed here. Semi-structured interviews with the responsible employee and spaghetti diagrams revealed several issues in the production process:

The CNC machine was operated poorly. It had many functions that the company did not use or were broken. The broken functions that should ease the process, were executed manually by the employee. It was an unnecessary effort from the employee and was slowing down the process. The CNC machine used during this research was highly automated, these functions just were not in use. Why? The employee could not answer.

Confirming the order completed was done through ERP with a computer, which was located at least 100 meters away. There was a computer attached to the CNC machine, but it was not online.

Collecting the orders to the workstation, completed by other production phases, could be next to the earlier phase. Most of the next orders were near the CNC machine, but it took extra time daily to search for the next order and to bring it to its place.

Self-control was concluded by hand and contained information on the project, amount of glass plates manufactured, defects and it was collected once a week.

Counterbore, which is drilling into an angle the edges of the hole in the glass plate, takes extra time when processing the glass plate. It was unclear to the employee if this was or was not ordered by a customer. It was not mentioned in the drawings whether one should process this. The employee just made it because he thought it was ”nice to have”. Therefore, it was not adding value to the process.

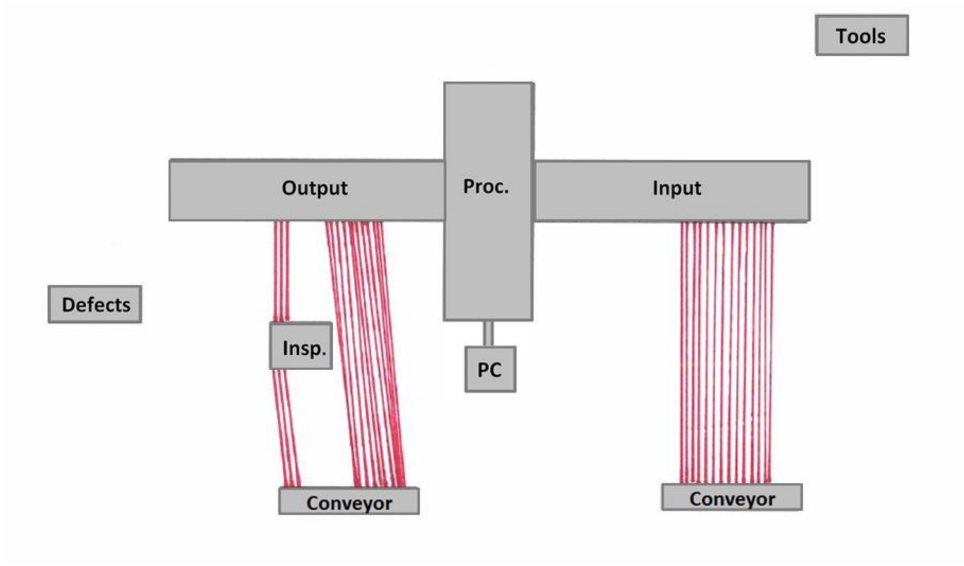

Figure 3 Efficient material flow on CNC machine. (Personal field study drawings, 2016)

Glass plate arrangement on the conveyors was concluded often very well as one can see from the spaghetti diagram in *Figure 3*. The process was efficient and the glass plates were put straight to the CNC machine and after processing, moved to a conveyor reserved for processed glass plates. But on a daily basis glass plates were sorted very badly and the employee would need to rearrange the glass plates, as shown in *Figure 4*. The employee needed to move several glass plates to gain access to the one he needed to put on next.

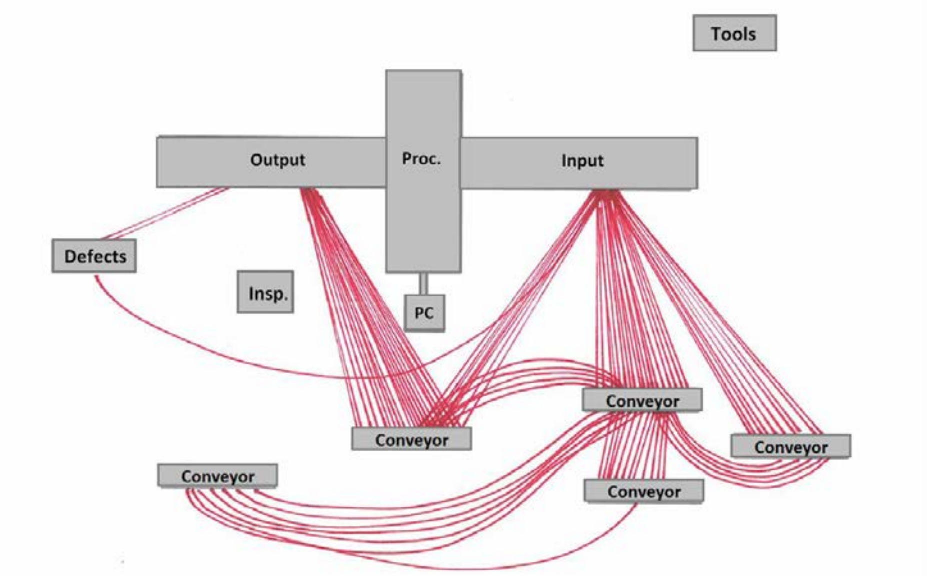

Figure 4 Inefficient material flow on CNC machine (Personal field study drawing, 2016)

In *Figure 4* one can see that it is highly inefficient to rearrange the glass plates at the work station. In some cases, one would have to rearrange the same glass plate many times, which not only slows down the process, but also burdens the employee.

The workstation was in poor order. Most of the drilling tools were in the cabinet pointed for tools, but a great part of them was on top of it and even a greater part was put on a window ledge. Most of the tools were unnecessary. They were not used anymore since they were too worn out. In addition, the tools were too far, as they are needed in the midpoint of CNC where the actual processing happens.

Ordering replacements was done by writing this down on a paper sheet, including order specification and glass plate’s measurements, making a photocopy from the drawing and then delivering it to a mail box reserved for them. Management then picked up the replacement orders and put them to a job queue. With a proper ERP system this could be done by computer without any extra steps and time.

3.1 **Spaghetti diagrams**

During the practical study period, I studied how different objects moved during the different phases of the process. The different monitored phases included how the employee moved while processing the order, how the employee moved during changeover and how the glass plate moved while processing the order. Starting and ending times were also recorded.

3.1.1 People flow

The first diagram *Figure 5* was concluded on 17 February and it represents the people flow during the changeover. Changeover time means how long will it take from the employee to prepare the CNC machine for next order, time is measured from last completed piece of previous order to first completed piece of next order. There one can see how the employee must move long distances to finish the changeover. Drilling tools are in the top right corner. Two lines in the bottom left corner were caused by retrieving new order from earlier processing phase and third line was the employee going to computer, which was located nearly 100 meters away, to confirm previous order completed.

In *Figure 5* the change over time was 20 minutes. In addition to earlier definition of changeover time, it includes every step the employee needs to complete, before he can start the next order. The employee needs to mark the work completed, deliver the finished order to next phase, clean up, change the drill tools if next order requires it and change settings of the CNC machine. During settings change the employee needs to adjust the drilling depth and holes’ locations and amount.

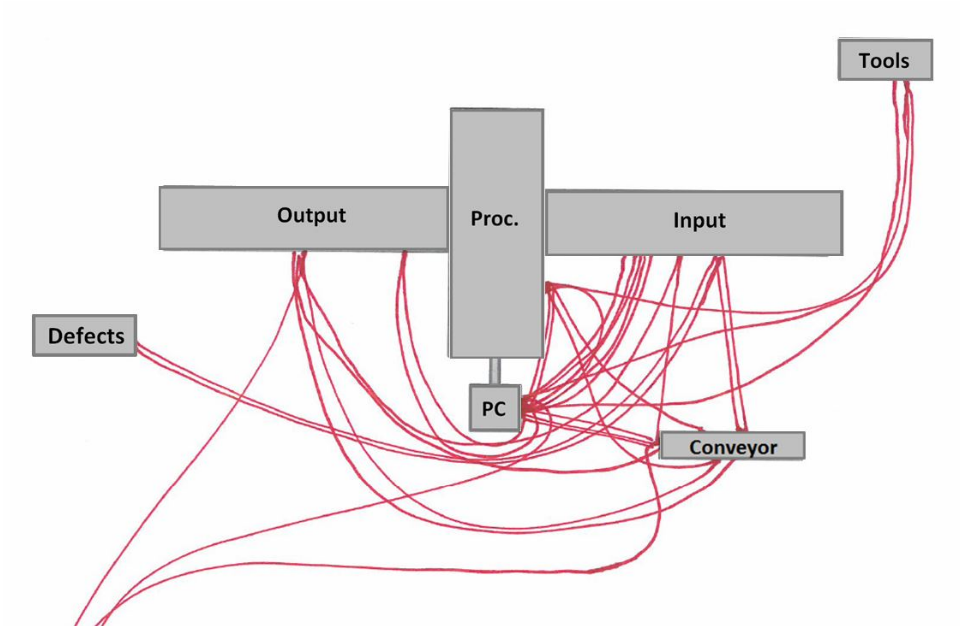

Figure 5 People flow during the changeover (Personal field study drawing, 2016)

The changeover time in the first measurement results recorded on 20 February are presented in *Figure 6*. The employee had to take excess steps here as well. The main reasons remained the same; the machine was not functioning well and the drilling tools were relatively far away. The changeover time during this setup was 22 minutes.

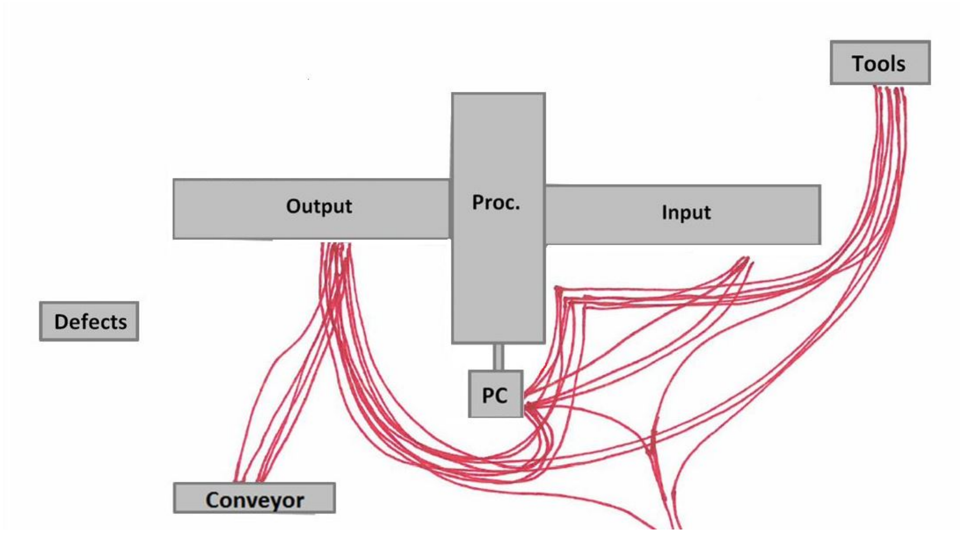

Figure 6 People flow during the changeover (Personal field study drawing, 2016)

In *Figure 7*, the second people flow diagram of the day, changeover time was quick, when compared earlier changeovers. It was seven minutes, which would be a major improvement to earlier times. But in this case the next order was much alike previously finished order so the amount of changes required in set up was small.

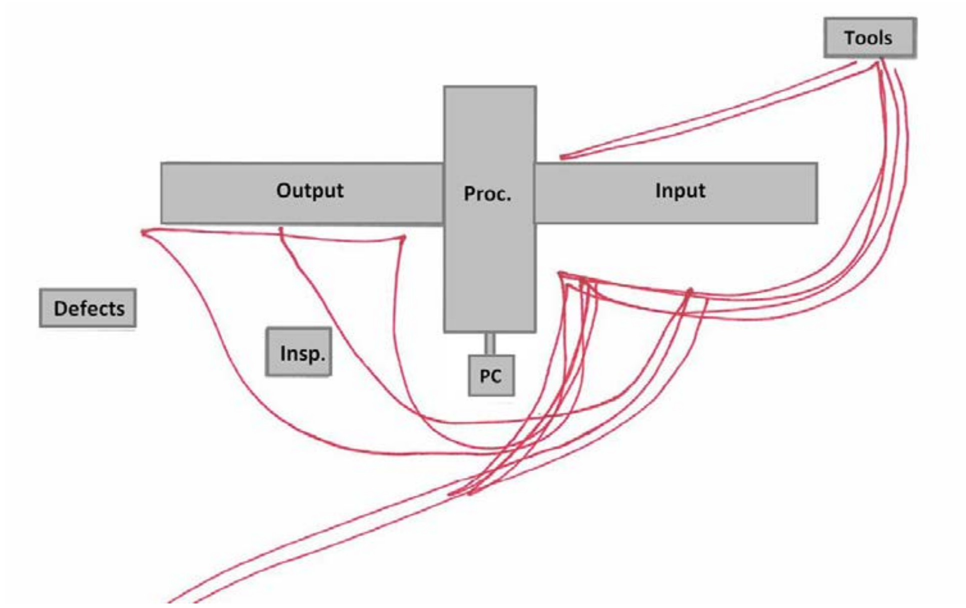

Figure 7 People flow during the changeover (Personal field study drawing, 2016)

As *Figure 7* represents, the employee must make excess steps in various orders through a day as the drilling tools are far away near the wall in the top right corner of the diagrams. Also, he was forced to change drilling tools from the back side of the machine. Two lines heading to bottom left corner were caused by the employee taking the paper for the next work phase.

The third changeover time of the day was again a bit slower, 18 minutes, as presented in *Figure 8*. Major issue that increases the changeover time is manually concluded settings. During this changeover there was not much excess movement, but it still took long time to conclude. In diagram one can again see the employee leaving the work station to confirm finished order completed, this computer was in other direction than in *Figure 5*, also nearly 100 meters away.

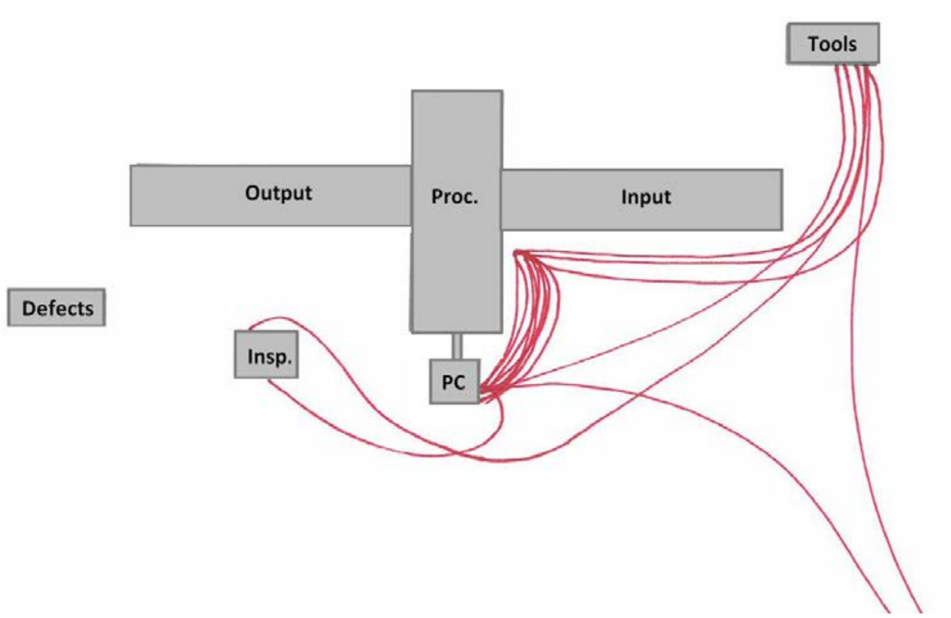

Figure 8 People flow during changeover (Personal field study drawing, 2016)

In *Figure 9* again the excess moving distance is represented. The tools being far away and paying check visits on the left-hand side proves that there is opportunity to enhance the process. Check visits reveal malfunctions of the CNC machine: if it would be functioning like it should, the two visits would be unnecessary. The changeover time was eight minutes, which is again better than average time in field study samples.

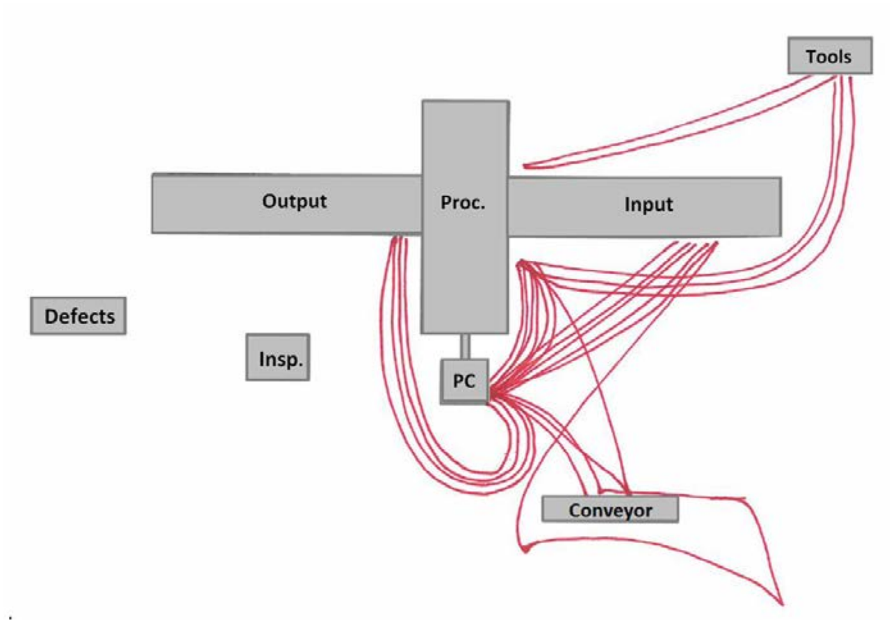

Figure 9 People flow during changeover (Personal field study drawing, 2016)

Sometimes the employee needs to sharpen the drilling tools during the order processing, to ensure the decent quality. *Figure 10* is representing sharpening process done, it took four minutes and is a minor operation.

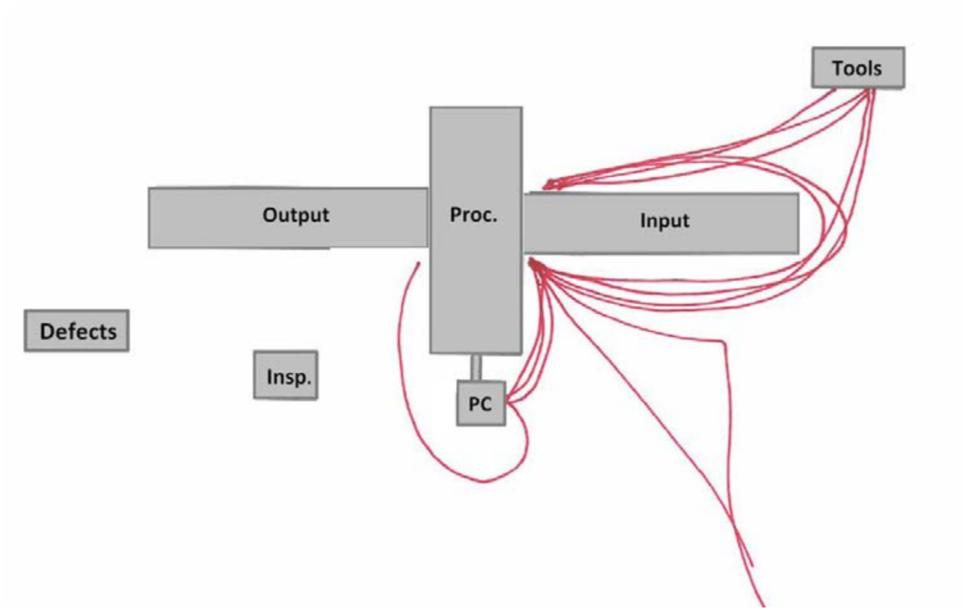

Figure 10 People flow during tool sharpening (Personal field study drawing, 2016)

Changeover time on 22nd of February's first order recorded, represented in *Figure 11*, was from 9:37 to 9:42, making it five minutes. Again, better than average, but in these quicker changeovers it was usually caused by not needing to change the drilling tools as there was similar holes.

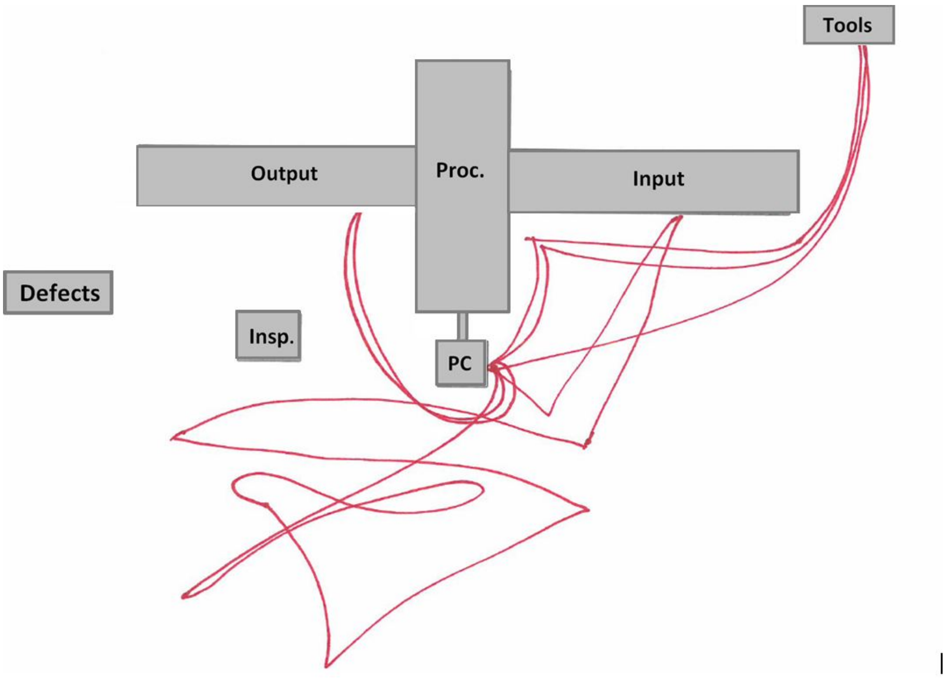

Figure 11 People flow during changeover (Personal field study drawing, 2016)

In *Figure 12* changeover time was 17 minutes, which is near the average changeover time recorded. Here again the confirmation for completed order is represented in bottom left corner. During this changeover there was more excess movement by the employee than in most of the changeovers. This was caused by changing drilling tools, sharpening them and making many test drives as the machine was making non-reliable quality. Excess test drives can be eliminated by repairing the CNC machine, which makes it function as it should and ease changeover and processing overall.

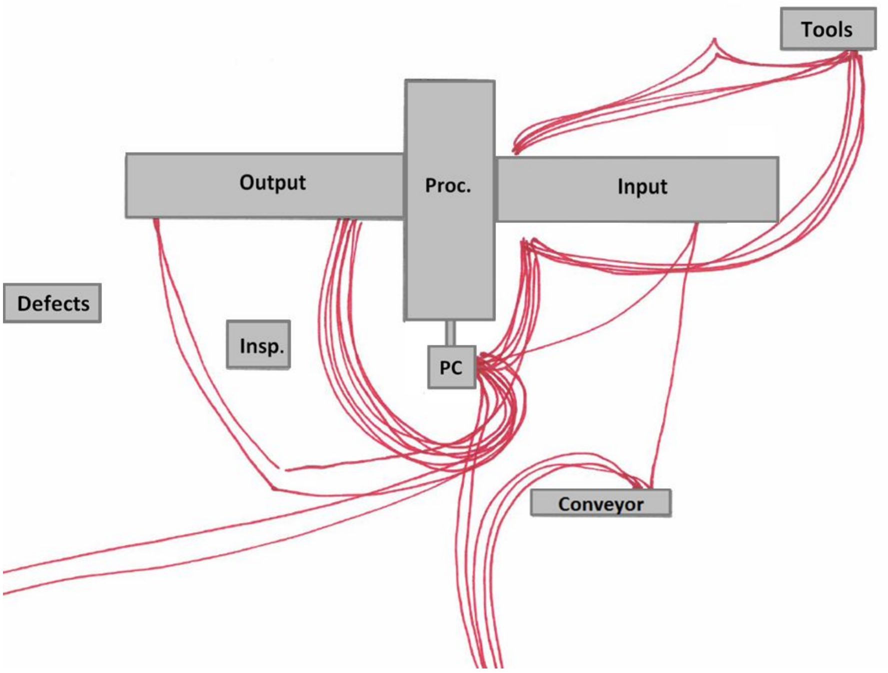

Figure 12 People flow during changeover (Personal field study drawing, 2016)

The changeover in *Figure 13* was near the fastest that it was possible to conduct via current layout. This changeover time was only three minutes, with no excess movement by the employee.

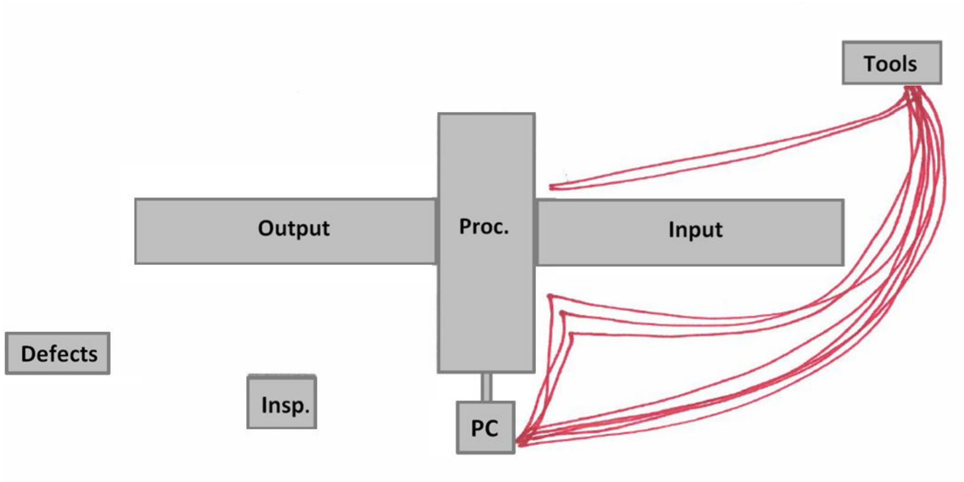

Figure 13 People flow during changeover (Personal field study drawing, 2016)

During the field study it was also examined how the employee moved during the order processing and based on that movement, spaghetti diagram was conducted. In the *Figure 14* it is shown that the employee had time during CNC machine processing the glass plate, this is part of the reason for the movement. One can also see that glass plates on the conveyor was not in order, so the employee needed to rearrange them. Other thing that affected to extra lines was because of starting hole did not go through the glass palte at first so excess movement was also caused by it. Starting hole was drilled, when the processed hole was big enough, that no drilling tool could make it, therefore the starting hole was milled to correct dimension.

Lines in bottom left corner was caused by the employee having wrong assembly drawings. He had to go and get the original drawing, come back to take a copy of it and then take the original drawing back again. Also, there are lines for the employee taking the assembly drawing to the next phase. Working with paper, transporting them back and forth adds time used for order, time has expenses and it is taken out from order's profit.

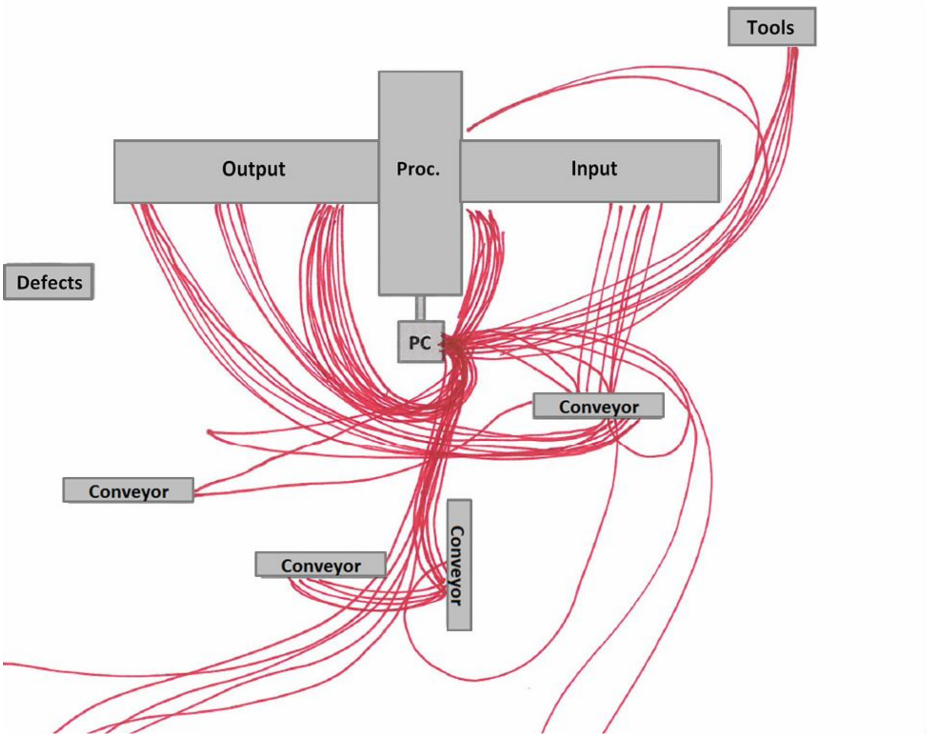

Figure 14 People flow during processing the order (Personal field study drawing, 2016)

In the *Figure 15*, it is represented that with current system, there was not much excess movement from the employee. The more lines there are near each other the more there were same kind of movement and therefore no dispersion. There was no excess movement near the conveyor, so the glass plates were in the right order from the start.

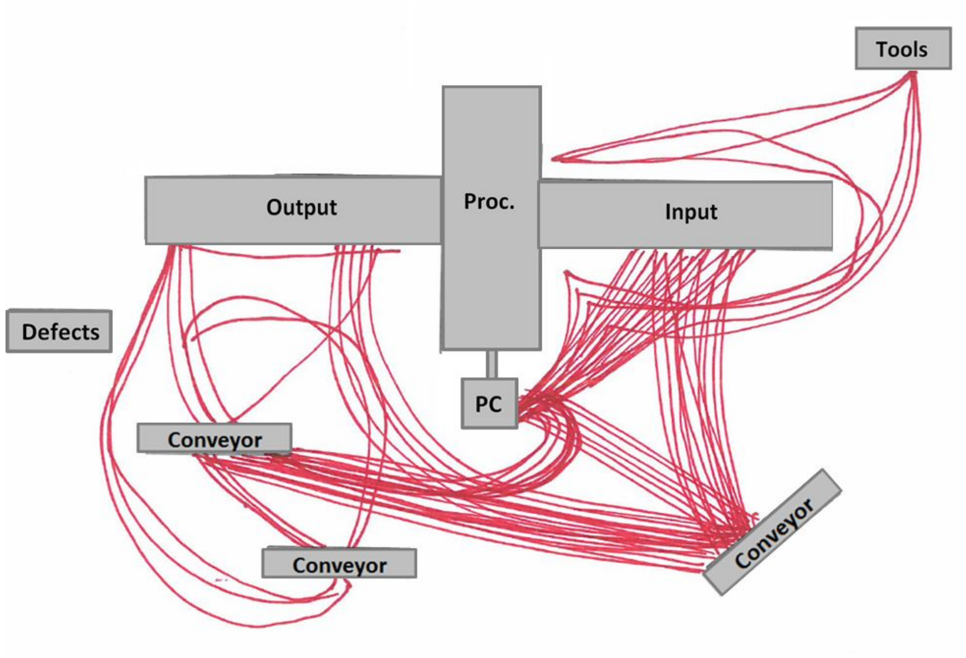

Figure 15 People flow during order processing (Personal field study drawing, 2016)

3.1.2 Material flow

It was also recorded how materials moved during the process. There were two scenarios on how the orders were proceeded, either the glass plates were in order on the conveyor or then they were not. In next figures it is represented the material flow during both examples.

In *Figure 4* on page 16 one can see the conveyor on right hand side where glass plates were put on CNC machine from. There was excess movement as the employee was forced to move glass plates between conveyors to put them in correct order. After machining it could only put on conveyor as they were already put in order. One glass plate was drilled poorly, as one can see on the left-hand side, one glass plate was lifted to conveyor reserved to defects and further back to CNC machine to process it again. Also, for one reason or another defect glass plate was carried further away to bigger trash bin reserved for defect glass plates.

Other example in *Figure 16* was concluded on same day 21th of February. In that order glass plates were not put in order for the employee. It is not as poor as in *Figure 4*, but extra work anyway.

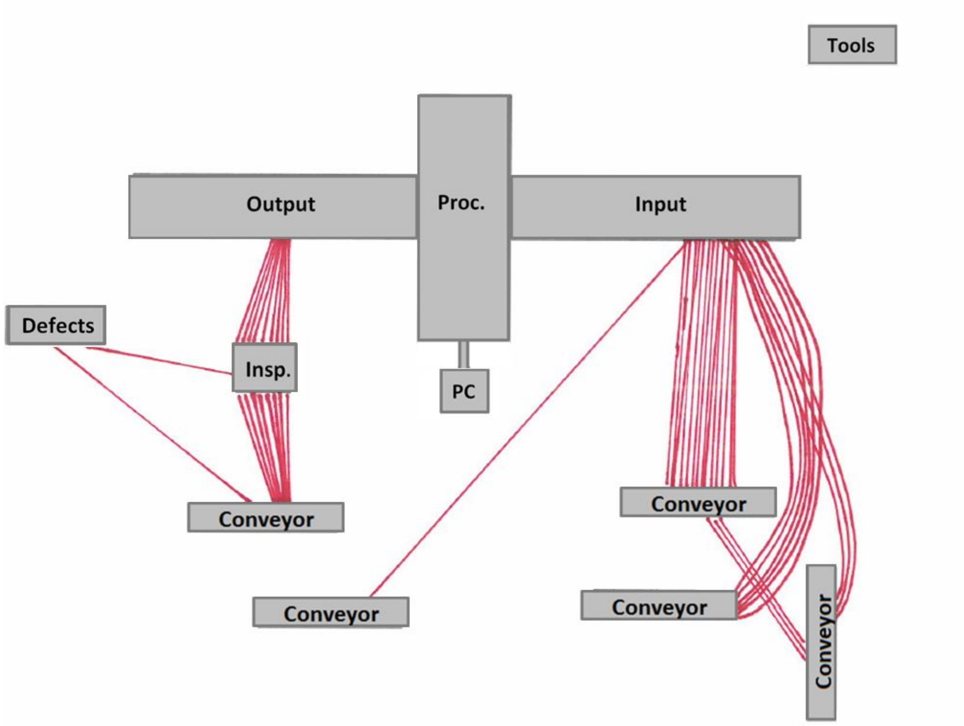

Figure 16 Material flow during order processing (Personal field study drawing, 2016)

Other scenario is when glass plates are put in order, so the employee only needs to put glass plates on CNC machine and after process put them on the conveyor he transports further for the next phase. Within this scenario there were two possibilities, either glass plates were in the right order or all glass plates were parallel so the order was irrelative. Both possibilities' spaghetti diagrams appear similar, so only diagram of this is *Figure 3* on the page 15.

3.2 **Summary**

As the changeover times varied a lot, from three to 22 minutes, this proved the instability of the process. In addition, the average changeover time in these samples was 12.5 minutes. The duration of the changeover time was due poor software, choosing and sharpening the tools in a distance and malfunctions on the CNC machine.

According to the employee, the CNC machine used was highly automated, but during the time, poor maintenance and ignorance, the automation level had been dramatically dropped and now there were several phases done manually instead of being run automatically.

At the time the field study was concluded, it was not clear for the employee whether a customer had ordered counterbore or not. It was just done just in case, which is considered overproduction, discussed in chapter 3.2. It also not add any value if it is not ordered and therefore it is waste.

The order of the glass plates on the conveyors was disorganized on a daily basis. This forced the employee to put in extra effort and increased the overall production time. In addition, it increased risk for defects as every excess lift of the glass plate is considered as a risk. This is also part of the reason why there is extra glass plates made in the process as it is thought it is better to make a few glass plates extra than order replacing glass plates. If extra glass plates are made rather than an exact amount, it proves two things: unstable processes raise the risk for defect and/or too laborious order process for replacing glass plates in case defects occures.

During the field study poor usage of IT was also considered. Even if the employee had a computer at the workstation, he had to borrow other computers to confirm the orders completed. The reason for this was that the employee’s computer was not online. Also, as mentioned before, neither the software for setting the CNC machine up nor the operating system were up to date.

4 RECOMMENDED ACTIONS

Tool that the company's management can start to enhance and measure the working environment at the CNC machine with is 5S. 5S is introduced to the employee by management, the employee will then start to plan the layout and actions for his workstation, with the help of the management. The employee's input is required because he knows the workstation best. Well executed 5S will reduce time used during processing orders and will result in reducing time and movement.

4.1 5S

The 5S is a great tool to start with. It commits the employee to his/her work, when he/she is given responsibility. The employee needs to think about the process and follow the five steps: Sort, Set in Order, Shine, Standardize and Sustain. Well executed 5S will save resources used in the process, as a result the employee uses less time to find tools, also the changeover time and walking distances are reduced. This will reduce labor input to orders and in the end the company will gain more profit per order.

The first step is to sort the equipment used in operations; only leave the equipment that is used on a frequent basis to the work station, not tools that may be used or are probably not going to be used. This phase will give the work station decent order. After the employee, in collaboration with the management, has stored the unnecessary equipment well, the remaining equipment should be put in to order. As this is a laborious task to finish, it should be divided in to stages, starting from the most critical ones.

The management should also consider putting visual signs to the work station, as they quicken the process when workers do not have to know things by heart. This helps when a regular employee is on a vacation and another employee will work as substitute. Visual signs can include for example colors, shapes or written text plaques. One example of a tool trolley is to mark which drawer includes what. Inside the drawers there could also be a visually or physically marked place for different tools. Also, better signs for placement of WIP and queuing work; it was not well organized when observed in the factory.

The management should also require and support a culture of cleaning on daily basis, as this will reduce sick leaves and risks of accidents, at every other work station as well. The employee should not be consent to cleaning up, but continuously find the source of the dirt, solve this and repair this with the needed resources; aiming to needlessness to clean. These first three stages are supposed to be monitored by the employee and management, to not going back to previous practices as "old habits die hard".

4.2 Hardware and software

The hardware of the work station was from the 90's. It should be brought to the 21st century. First, the internet connection. Everything is stored in cloud servers nowadays, so every computer should be online. From there data can be fetched, orders followed in real time and as presented in the field study, unnecessary walking around the factory can be avoided.

The software must be updated as well. Now the employee had to copy paste the instructions to the software, which was followed by the CNC machine. This could be done by adding a bar code or a QR code to the glass plate identifying sticky label. It is then read by a bar code reader and it includes information of the specific piece and the whole order, so that every code is not needed to read, only the first one. Software will gather the dimensions of various machining operations and the employee then picks the correct piece by glass plates' identifying number.

What comes to choosing the right CAD/CAM (Computer aided design/Computer aided manufacturing) software, additional research is required. There are plenty of different softwares in the market and as important as updating the software, is choosing the correct one. It should neither be too laborious nor it should be inefficient.

4.3 Lean manufacturing tools

Root cause analysis with asking five times why will lead to root of the problem. Asking multiple time same questions will in most cases reveal what is the initial cause for some error in the process. This is useful tool to reveal causes for CNC machine's malfunctions. (Chandra 2018)

Takt time is meant to measure how fast the employee should produce units. Takt time is defined by how much time passes between start point of two different units. It is calculated by following formula:

$$\text{Takt time} = \frac{T}{D}$$

T = Available production time of desired sample period
D = Customer demand for same sample period as T

For example, Takt time is calculated with one-week sample time for one shift, therefore T = 420 minutes. Let the customer demand be day by day 20, 50, 130, 141, 89, therefore D = 430 units Takt time being 0.98 minutes (59 sec)/unit. This means the employee needs to produce one unit per every 59 second to meet weekly customer demand. If this is not met, process should be improved with standardization and other tools mentioned before. (Chandra 2013)

5 CONCLUSION

The machining process at the CNC workstation is currently inefficient which was also proved during this study. Spaghetti diagrams presented the movements of the employee and the manufacturing products. The spaghetti diagrams were quite complex, it revealed the main problems within the process alongside with time management. The main issues at the CNC machine were placement of tools, order of glass plates on conveyors, general condition and software of CNC machine.

Implementation of 5S is obligatory to put the workstation in order. In addition, with 5S this will help the employee to get rid of unnecessary equipment around the workstation and help the employee to work faster when the layout and placement of tools are well considered. This will reduce the distance between frequently traveled spots. The second issue is to repair the machine to its full potential. There were several functions out of action, update and maintenance greatly enhance the performance alone. As it was shown in the diagrams, malfunctions alone were forcing the employee to excess work and a waste.

This study revealed, that the current CAD/CAM -software is inadequate. As the quantity and therefore the speed of processing has increased over time, the software has remained inefficient. It needs upgrading but a choice of compensatory software would require further study. This is to ensure updated software meets the requirements of the process. Without a profound study of the requirements, there is a high probability that the software will be too advanced to use or vice versa.

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Appendix 1 Original spaghetti diagrams

Figure 3

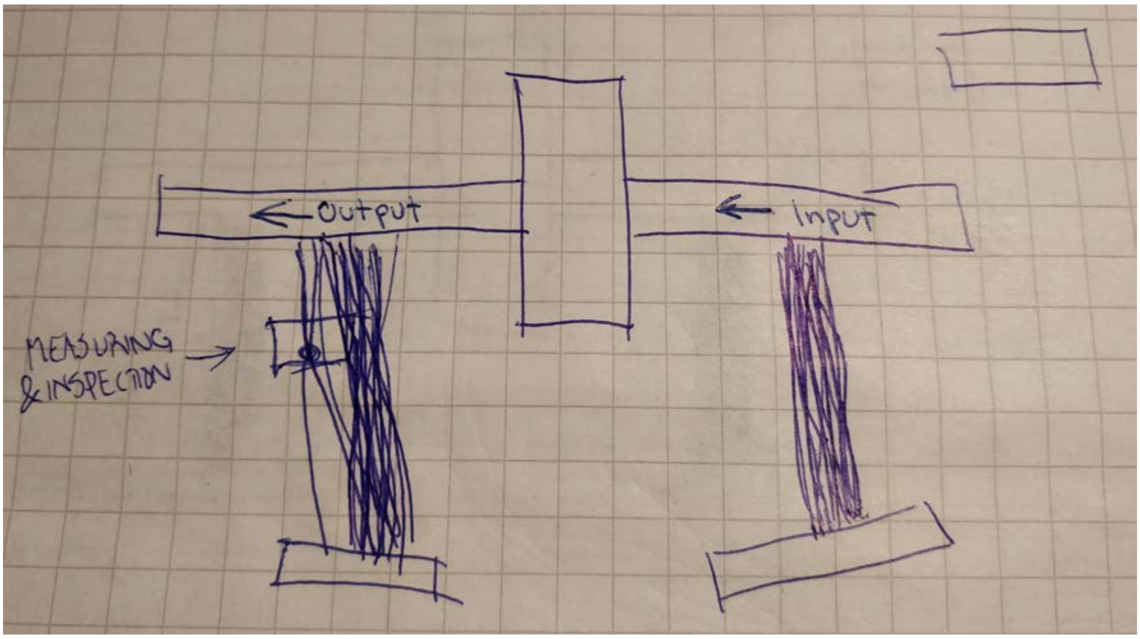

Figure 4

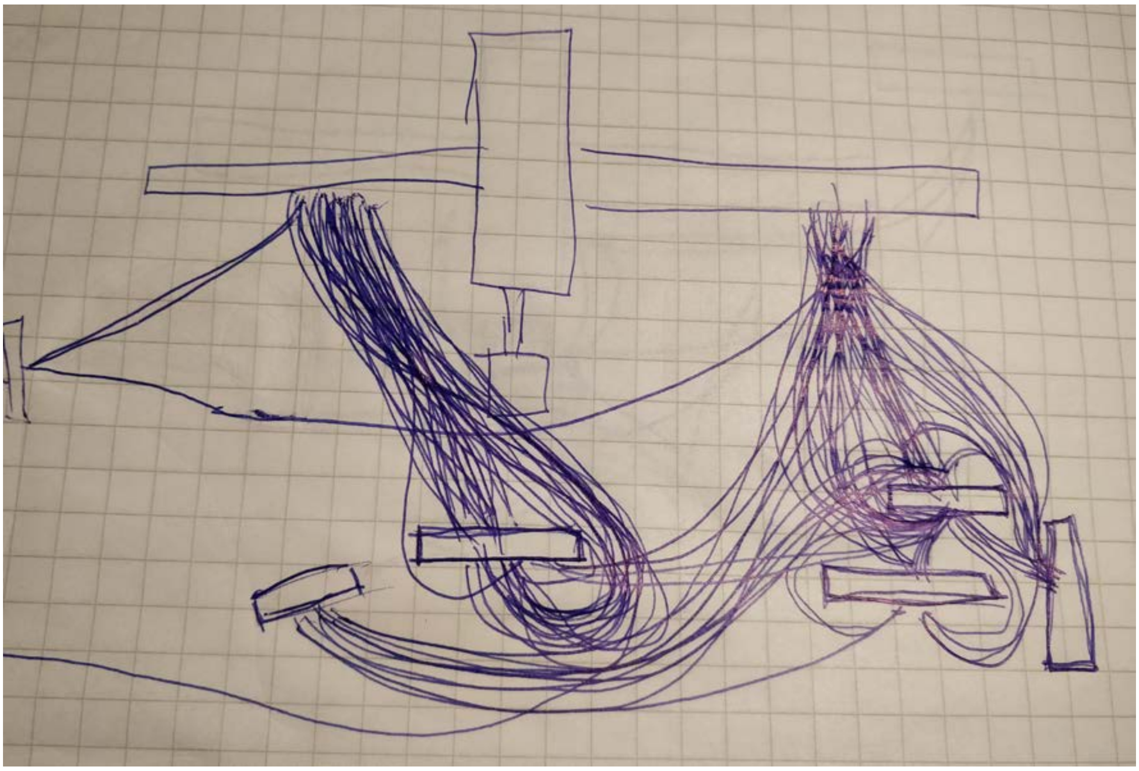

Figure 5

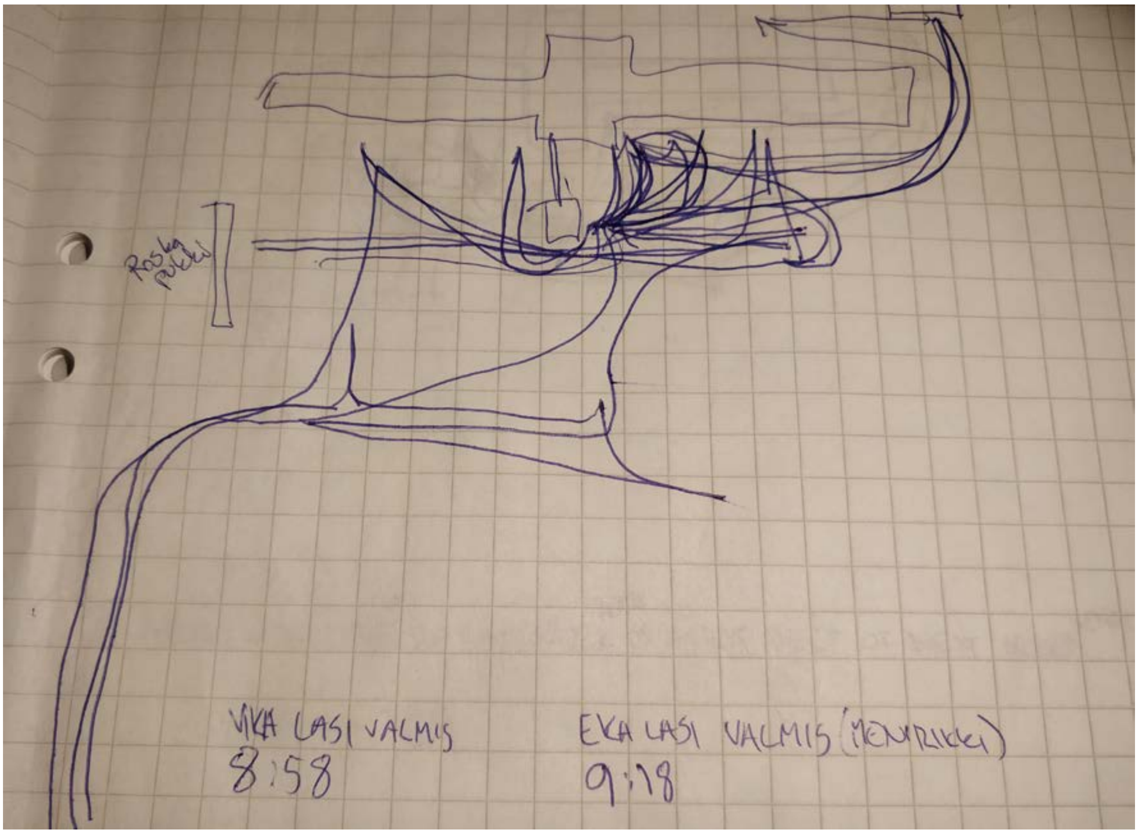

Figure 6

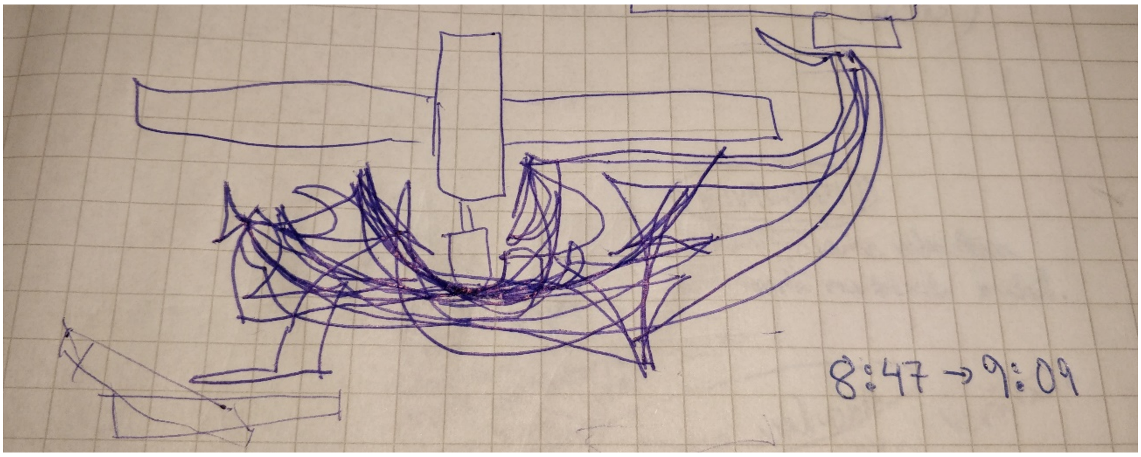

Figure 7

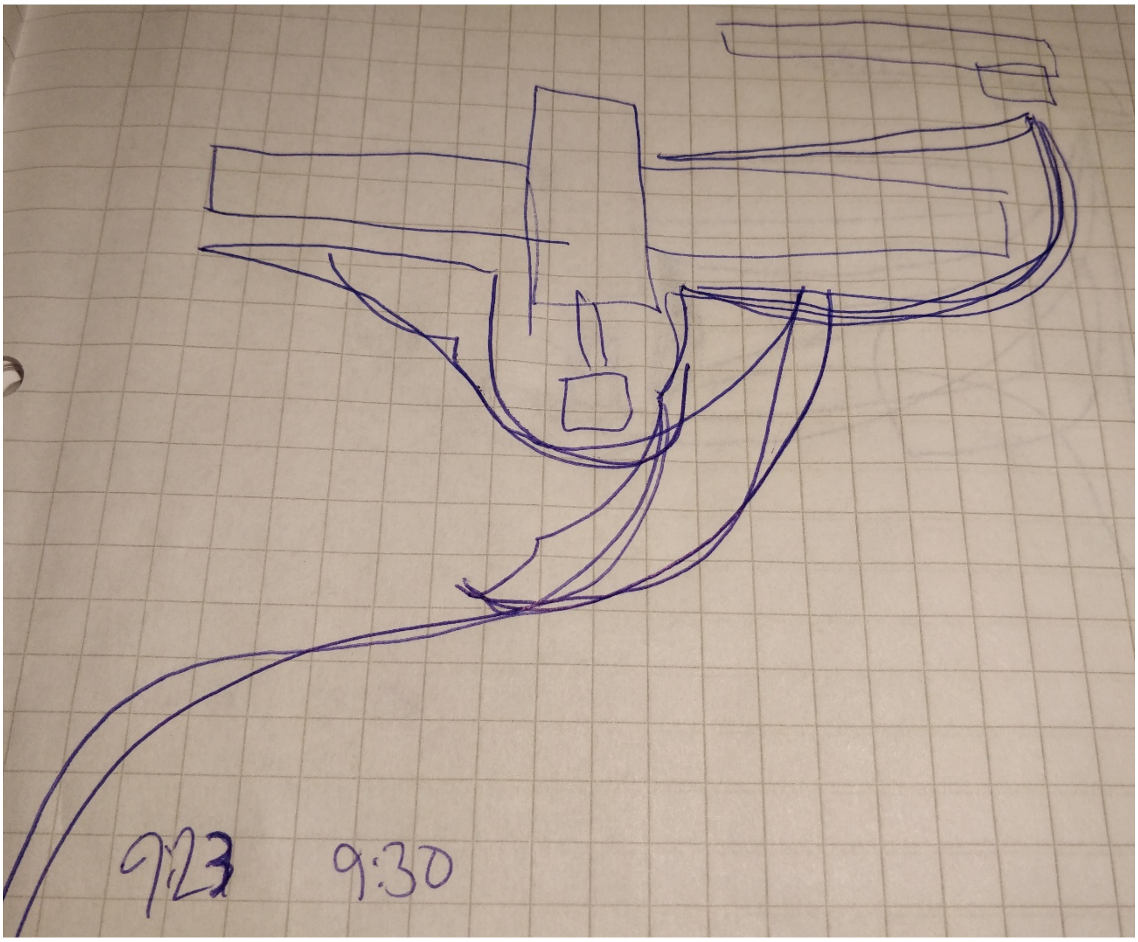

Figure 8

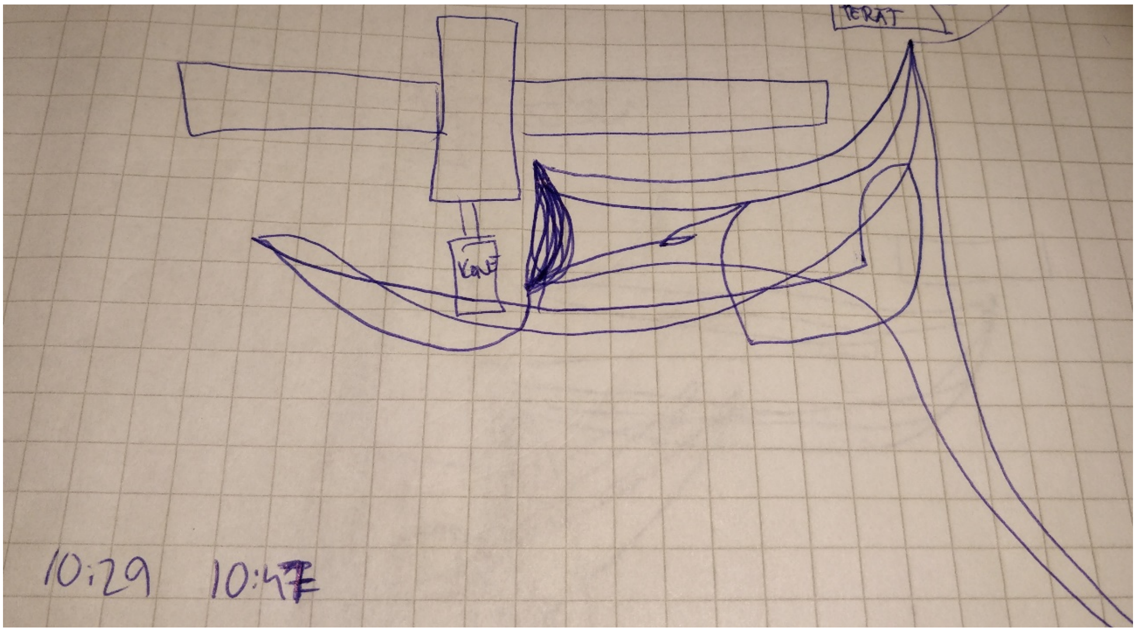

Figure 9

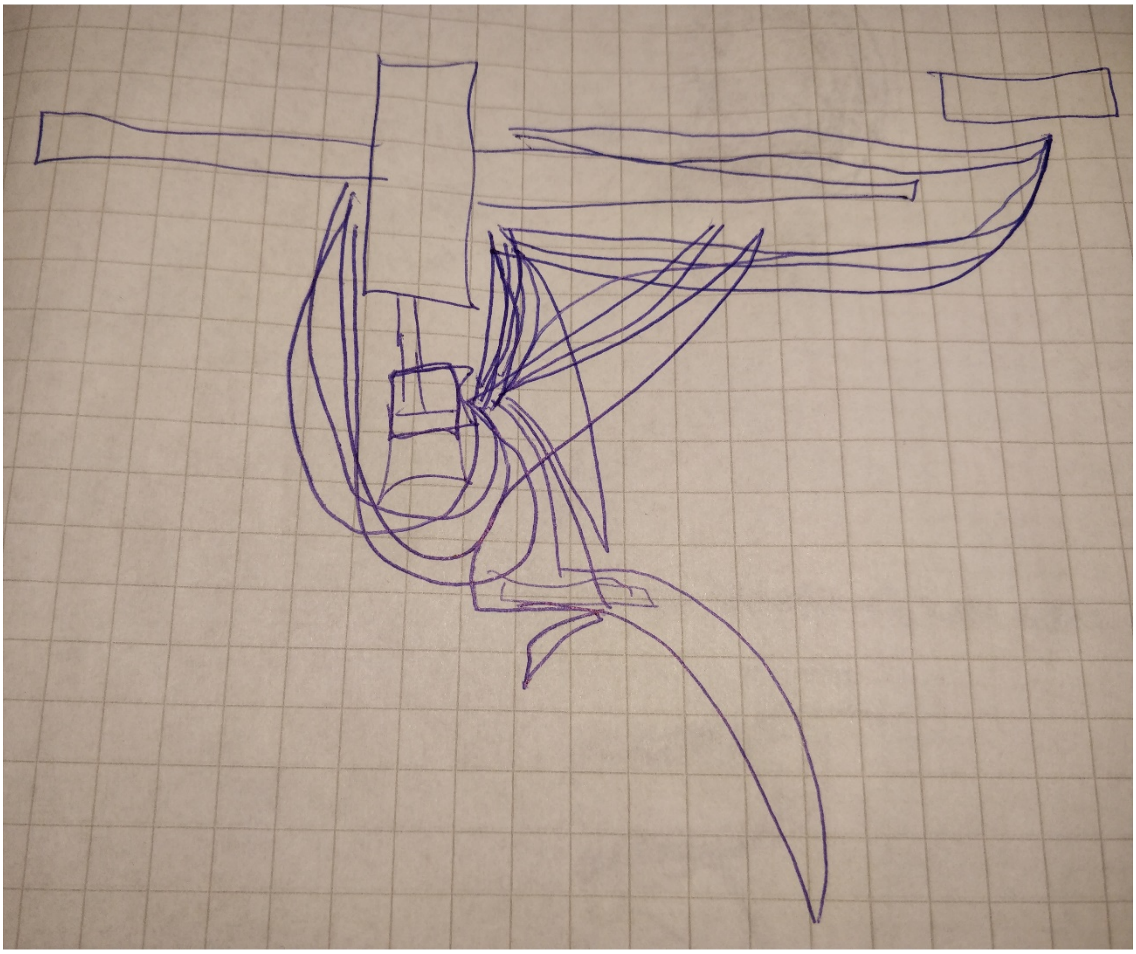

Figure 10

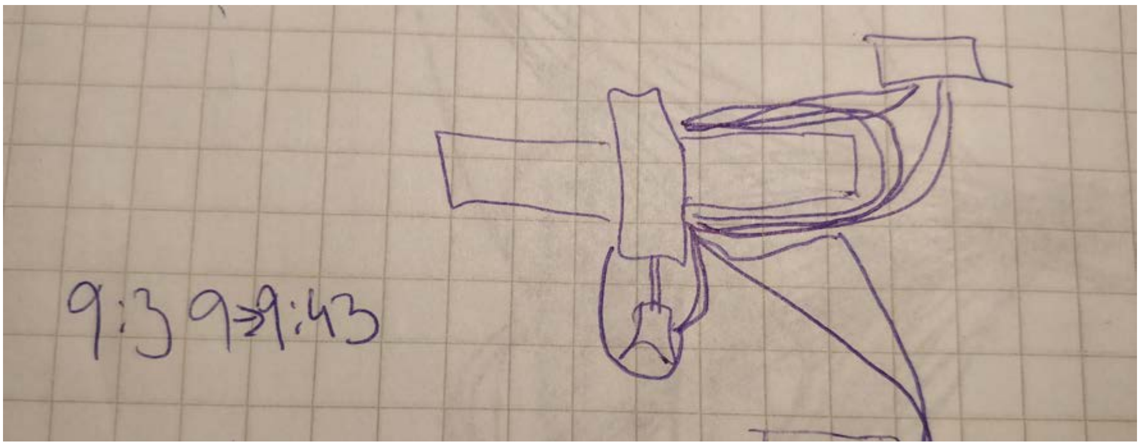

Figure 11

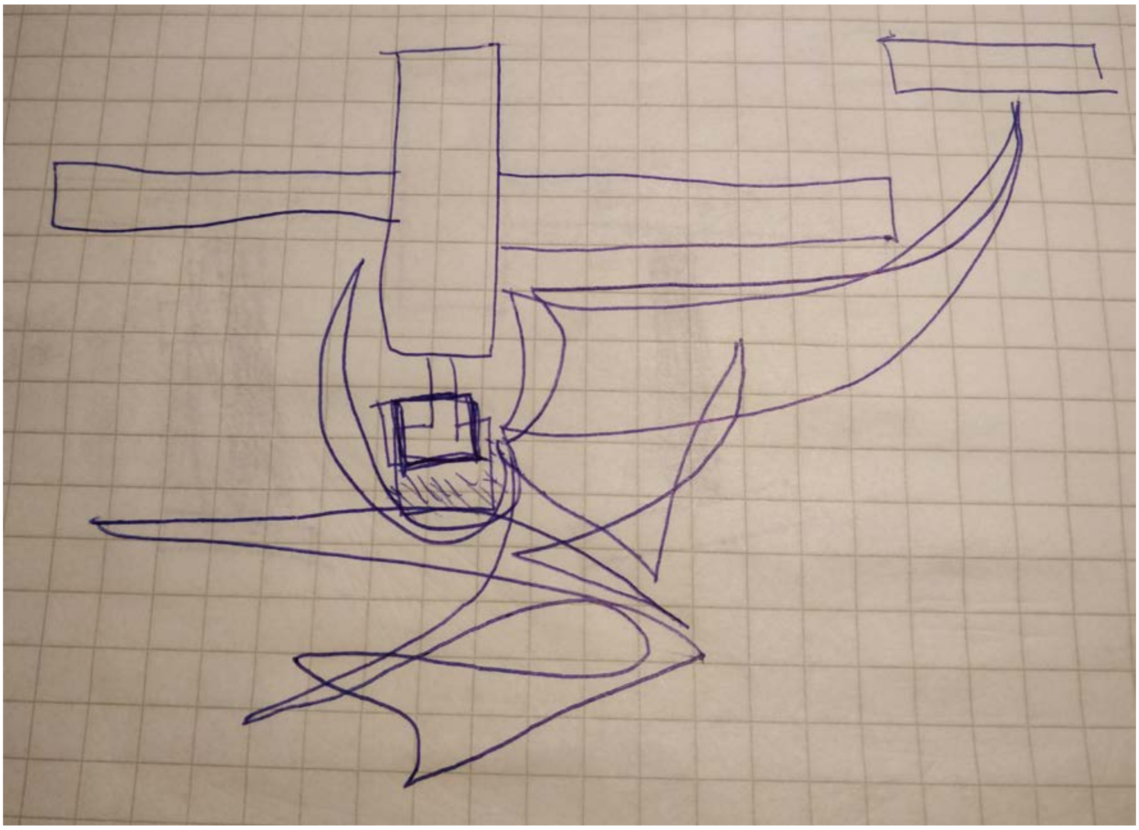

Figure 12

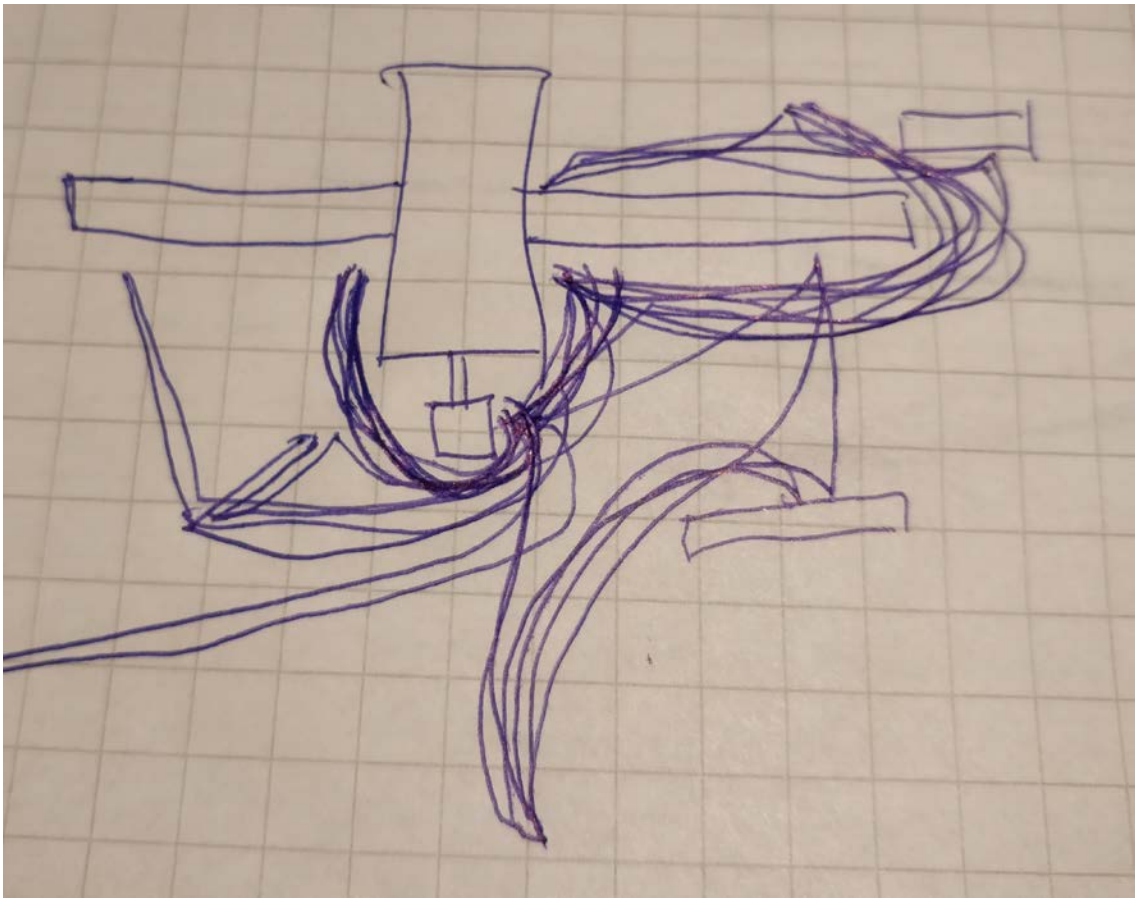

Figure 13

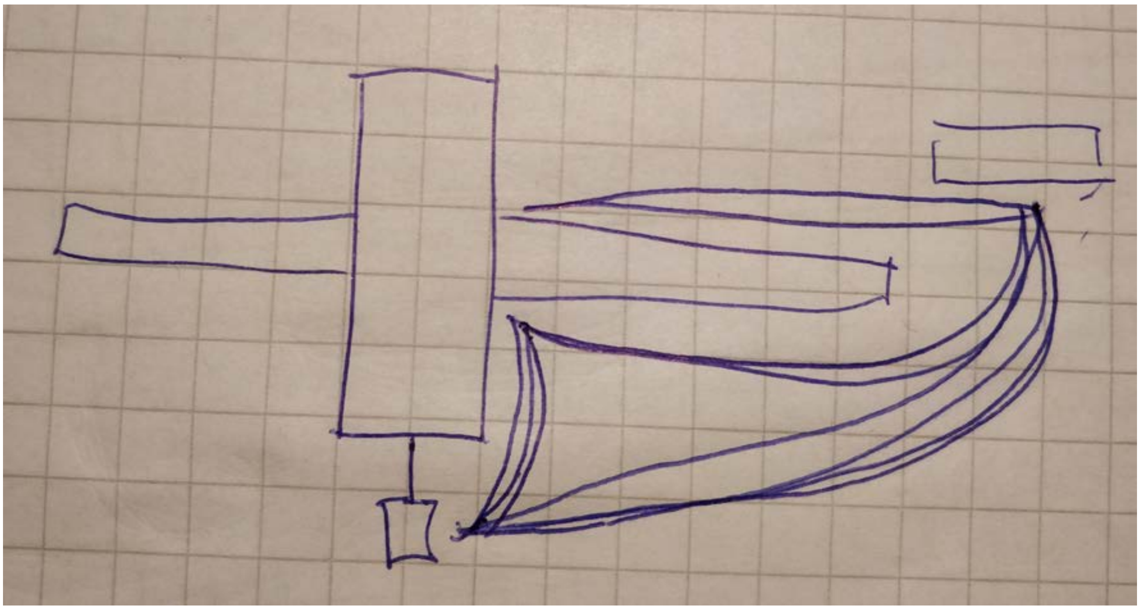

Figure 14

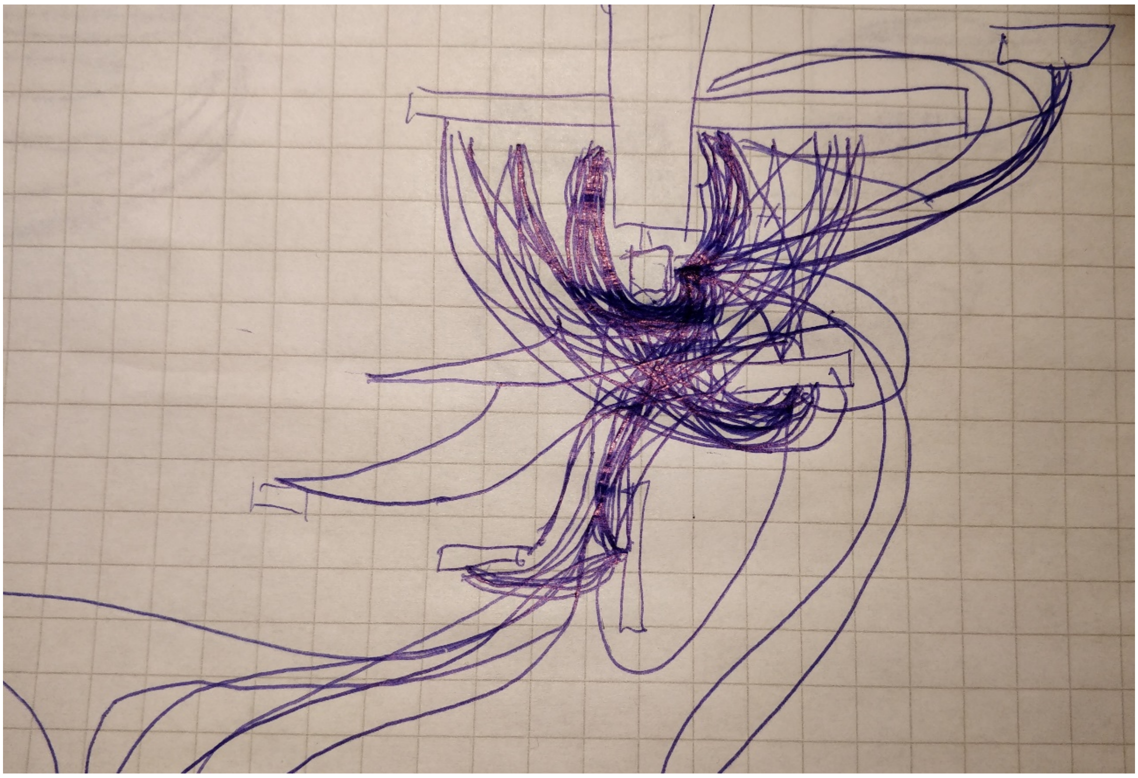

Figure 15

Figure 16

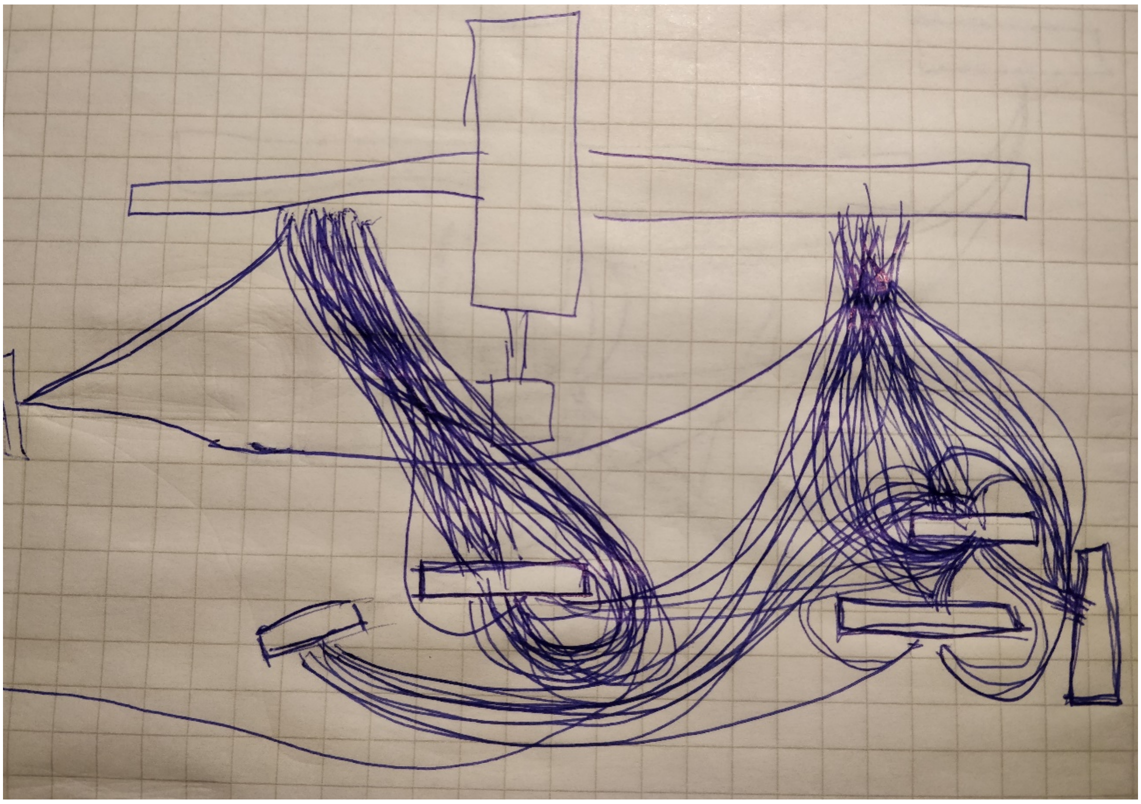

Figure 17