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OPTIMIZATION OF METAL PROCESSING IN INDUSTRIAL WORKSHOPS

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Abstract

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Abstract

This thesis work is aimed at analyzing manufacturing processes in the metal fabrication workshop. Different methods of work organization and implementation of possible improvements with as few resources as possible are discussed in the thesis. This is an important topic because in this observed case this workshop is working without any strategic management and it is not efficient. The goal of this thesis work is to show how it is possible to improve production at this workshop with as less resources as possible. The study was commissioned by the St.Grad company.

For this work, the main research methods were observation literature study, reading specific literature, and consulting with the workers of the workshop. These methods were chosen to get the most encompassing view of the workshop.

Overall, the results show that optimization methods will improve the company's capacity by more than 2 times. This work is important to show how big of competitive advantage companies get when they have an organized and automated production. Unfortunately, this is only theoretical work, because the implementation depends on the owner of the workshop, but it can be assumed that this research is right and might help to optimize production not only in this specific case but also in many other companies.

Keywords
Optimization, Lean, Kaizen, 5S, Six Big losses, ERP, Layout plan, Production improvement.

CONTENTS

1 INTRODUCTION

After Henry Ford implemented the flow method which made a revolution in manufacturing, people started to think about and innovate different, more productive methods of manufacturing. They analyzed the productivity, collected the data, and improved their production. Nowadays with all of the available technology and information, it is possible to make an efficient production. As an example, this thesis studied metal fabrication workshops and develop an improvement plan. It includes not only the way how equipment is arranged but also a production step by step plan.

To develop an optimization plan for the workshop in this thesis the help of the internet, professional managers, and workers was used. Analytical methods such as mapping working conditions, examining employees, and interacting with the supervisors were utilized. This thesis work and study looked at the current metal fabrication workshop that the company has under its management, analyzed the equipment and technics that are used in a metal fabrication cycle, and made the best possible layout for the equipment.

The production plan was developed by collecting information from the workshop managers. The decision to do so was supported by them having more experience in organizing the production and their ability to tell the production process steps that are usually taken to manufacture a product that has been ordered. That production plan was also compared with different technical books and articles which were specifically written to help to understand and design a production plan.

The equipment layout plan was designed to fulfil the main objective of making the transporting time from one step of the production to another as fast as possible. To develop that plan several production methodologies were used and the whole facility plan was taken into consideration. It was also decided to include additional equipment such as lifting winch, transporting or shipping bands, and welding tables to make the most convenient working place layout possible.

The workshop which was studied is in size 24-9-4 m. It is a metal construction covered with a metal decking. Equipment there is the following: 2 metal sawing machines (automated and hand), rollers for metal bending, welding machines (both argon and arc welding), production line, guillotine for metal sheet cutting, plasma cutting machine in a separate area, milling machine. All of the equipment is arranged without any plan and was put where it fitted as it arrived at the workshop. Most of the equipment is out of order but requires only small repair works. Some require minor settings and some just need to be unpacked. By arranging all the equipment in a specific way and organizing the process based on methodologies the most optimal way of manufacturing can be achieved in the current situation.

2 MODERN MANUFACTURING PROCESS

2.1 Metal fabrication process.

"Metal fabrication" is defined as creating products or structures by cutting, bending, and/or assembling metal material. It's largely considered a value-added process as it consists of putting together actual products or structures from metal raw material." (Southern Metal Fabrication s.a.). Therefore a metal fabrication workshop is a facility where people with the help of equipment fabricate raw materials in the needed goods. The process of fabrication involves cutting, bending, welding and assembling. Equipment that can be involved in this process varies a lot and can be dependent on what type of production the company is creating and what criteria the product has. As an example, products made from specific materials such as carbon steel or aluminum are better welded with MIG welding. All these nuances which are gotten with the customer's orders make this production process rarely typical. (Dain Zimmerman, April 28.2021)

Usually, orders from customers vary a lot and one of the challenges in this job is to make a unique and the most optimized production plan which will be using the optimal amount of the resources available. Production plans are usually developed by the team or a person in charge of the production process and he or she commonly has an engineering degree. It is important for at least one of the people in charge to have an engineering degree because to fully develop a clear and efficient production plan person has to know in detail all of the production processes that are going to be involved in the manufacturing of the order. Therefore, it is the person in charge task to choose the best production methodology to fulfill customers' needs and workshop capabilities. (Betterteam s.a.)

For this task, most people use the job shop manufacturing methodology. Job production is a manufacturing process that involves the company making a unique customized product for a single customer. (Optessa s.a.) Depending on the customer's needs the product can be produced from start to finish as created in parts for future assembly by other companies. That all make this production method not suit the production in big quantities. Therefore it is used in most workshops and has proven itself usable and good. it is the best suitable methodology for such type of manufacturing because even though the work has universal technics in it, such as welding and cutting, still usually every order is unique and it is difficult to make a stable production line, that would fit everything. There are other benefits of Job production such as high customization of the product and the higher quality of the work if it has professional workers. Nevertheless, all the basic main principles were taken into consideration and were summed up and formed into a single plan that would help in the production assembly and development.

First of all, when starting manufacturing a production plan should be developed. It should be exact and clear so the workers who follow it would not have any uncertainty about what should be done.

The production plan consists of several stages. The first is making a production schedule. It is important to have such a schedule for workers and customers to understand an estimated time that the product would be ready. The production schedule is created by taking into consideration the time of all of the fabrication processes and adding to it some reserved time in case of emergency or errors. Into the schedule also can be added the product delivery time, but that is discussed

separately with the customer. There should be made 3 types of schedules. Master schedule which shows the total amount of product that needs to be manufactured. Operation schedule, which shows how the production flow works. And daily schedule. It shows the exact steps and activities which should be done to accommodate a master schedule. (Indeed Editorial Team, 2021)

The second is material planning. In this stage of the plan, it is important to precisely calculate all the materials that would be needed in product manufacturing. Mostly the price of the product is calculated from how difficult the structure is and what are the volumes of the materials that should be processed. So, the product price depends on how precisely the amount of material is calculated. Another reason why it is important to have exact calculations of the materials it avoiding waste in the production. It is unnecessary to have too much extra material in the production. (MBA Skool Team, December 29, 2020)

The third is capacity planning. This stage directly correlates with the production schedule, because if the workshop has a big order it needs to calculate how much it can produce in a certain time and if it will meet the customer's demands. Capacity planning is divided into 3 categories: Product capacity planning, which ensures the company has enough material for production, workforce capacity planning, which checks if production has enough workers and time to finish the job, and tool capacity planning, which analyses if current equipment and tools are enough for the planned production. Capacity can be influenced by hiring more workers or buying additional equipment. But it is important to calculate if these spendings are necessary to the company and if it will bring more profit. (OptimoRoute, 2021)

And last, but not least is workflow planning. It is a very important stage because while calculating it, all the things above should be taken into consideration. Every part of the plan will directly influence the workflow plan, and a good workflow plan can even cover some of the production issues way so it will not influence the final time and quality of the product manufacturing. (TechTarget, production planning, internet publication by Ben Lutkevich, Technical Writer, last update November 2020)

Statistically speaking the main fabrication processes are cutting, welding, metal treatment, final technical hole making, and metal treatment with paint or similar chemical substances. (Investopedia, internet publication By Will Kenton Updated December 01, 2021) Consequently, based on these most common processes, this workshop has all the equipment needed and even more for a successful production cycle.

Usually, the production cycle at the fabrication workshop looks like this: After having a conversation with the customer about the needs and getting or making technical drawings workers get the raw materials that first are cut by the sizes they need. If it is sheet metal it is cut either on the guillotine or plasma cutting machine. Commonly if there is no need for precise cutting, the guillotine is preferred to save resources. If it is pipes or angles or even steel bars the sawing machine is used because the material can be piled up and cut at the same time. After that, all of the cuts are cleaned by the turbine if needed, sorted, and moved to the specially allocated place where it would be easily reached for production. Then the construction is assembled and welded. And the final stage is metal treating. Metal is usually cleaned either with sanding or turbines, depending on the amount of work, and then covered with Zn paint. Based on this production plan the position of the equipment can be

approximately assumed. But to finally determine where and how to put everything different manufacturing methodologies should be taken into consideration. (Sattler Manufacturing s.a.)

2.2 Lean Methodologies

When talking about the methodologies, it should be clarified in advance that Job manufacturing that has been discussed above is a method and lean manufacturing is a methodology. There is a big difference between them. Methodologies are used to save as many resources as possible, such as materials, time, and skills. And the method is the way how manufacturing works. In this thesis work, the lean methodology was analyzed and implemented in the optimization process.

There are 5 main principles in lean methodology, that help to better understand and therefore implement this methodology:

First is Kaizen or Continuous improvement methodology. Kaizen is a Japanese methodology and it translates as "good change" or "change for the better". Kaizen was born in 1950 when the Japanese government and management acknowledged that there was a problem with their current system and pending labor shortage. And to solve, these problems major companies introduced lifetime employment and benefits for the development of the company. The philosophy of kaizen gained popularity because it helped to increase productivity with minimum effort. (Sebin Mani 2009) The main point of the kaizen methodology is to make small changes in the work on regular bases. It is proven that an such approach helps to increase the effectiveness of the work. In the researched workshop Kaizen methodology can be implemented not only by workers to see how they can improve their work every day (Leanproduction, s.a.), but also by sending them once or 2 times a year for professional development courses where they can improve their qualifications and get more knowledge about the job they do. For example, welders can improve their welder's discharge, which will help them to do more responsible and better-quality work. And workshop managers should also be sent to additional courses because with that they would be able to better control and plan the work in the workshop. Needless to say, all of those improvements will only benefit the company that owns the workshop, because the more technically challenging and high-quality work could be done more efficiently.

The second is the 5S system. 5S stands for Sort, Set in Order or Straighten, Shine, Standardize and Sustain. This methodology is mostly aimed at having a workplace in order. It is statistically proven that people work better in a clean and comfortable environment, and for that, the Japanese invented the 5S system. The first stage is sorting. The workplace should be sorted and all the unnecessary things or even equipment should be disposed of. Because things that are not in use would only just distract and take up space that might be more useful for other things. The second is set in order or straightening. It means that all the equipment and tools should be arranged in a specific and systematic manner. It is important to have everything in order because that way the production flow will be smooth and efficient. The third is shine. Shine stands for having a working place cleaned and shiny. It should be always inspected because productivity rises in a clean workplace. It is also important from the customer's point of view. If customers come to the workshop and see that the

workshop is not in order and is dirty, that would mean that the work there is done poorly and with low quality. It would be better to have someone clean the working place after the work shift, it might be an additional worker or evening duty of the regular workers, or the best way would be for all workers to clean their workspace after their shift before heading home. It also should be checked and fined, if not done. The fourth is standardize. That means that there should be developed clear standards for the workplace organization. That should relate not only to the organizational standards but also to the work. When starting work at the workshop new worker should clearly understand what is demanded from him. There should be clear instructions on how productive the worker should be and how to behave in a working place. Not to mention the safety instructions which should be obligatory for companies to have and present to their workers. And the fifth is sustain. That means that the company should look that all of these points were followed. It is important to have everything sustained and implemented in for in a daily bases because the main point of the 5S system is to do everything systematically, or otherwise, all the efforts would be wasted. (Kaushik Kumar, Sanjeev Kumar June 2012)

Another one is the Six Big Losses methodology. Unfortunately, it is not rare for errors to happen in a production facility. But it is important to be able to predict and avoid such losses. And with that, the six big losses methodology is used. The Six Big Losses include Breakdowns, setups, Adjustments, small stops, reduced speed, start-up rejects, and production rejects. So, the breakdown or in other words the equipment failure is often thought of as an unplanned stop or downtime. There can be many reasons for equipment failure. It can happen because some part got accidentally broken or the machine has not been checked in a long time. This is an availability loss. As an example, in the current fabrication workshop, there are 2 pieces of equipment that are not working. And that makes them inaccessible and conclusively increases the production time. That could have been avoided by doing a maintenance check every year or two.

Next comes setup and adjustments. It can be also known as a planned stop. This is also an availability loss because it stops the work of equipment for an appreciable amount of time. Such stops mainly serve the purpose of cleaning, maintenance, or even adjustment work that helps the machines run better and smoothly. It is important to have such maintenance checks occasionally because with that many major problems can be avoided. That practice can help to prevent major errors and breakdowns which would hurt the production process. Not to mention that precisely adjusted equipment assures good quality of the work.

The fourth type of Six big Losses is reduced speed. That stands for production not working at its best possible speed and it is a performance loss. Things that affect the process in such a way are dirty equipment, poor setup, usage of incorrect materials, etc. Such an error can also occur if an unprofessional worker is working with the equipment.

The fifth is process defects. It is a quality loss and it is represented by the defects in manufacturing during a stable production. That can happen due to machinery errors such as poor calibration, or errors that affect performance loss. It can also happen if the worker is inexperienced and did not do his work correctly.

And the last one is a reduced yield type. This metric shows the number of defective products that were made during a normal run of the equipment. Such quality errors can occur during all the stages of the production cycle and therefore there always should be quality checks as preventing measures at each step of the production.

Another is the idling and minor stops category. This category includes all the small stops that can be happening due to material jams or equipment working incorrectly. Usually, the time of such stops is a minute or two. It is a performance loss because it makes the production run at less than the maximum possible speed. Such stops don't require maintenance personnel to help with the equipment and can be solved by regular workers. (Vorne s.a.)

Another lean methodology that fits current manufacturing is overall equipment effectiveness (OEE). This methodology identifies the percentage of manufacturing time that is truly productive. An OEE score of 100% means you are manufacturing only good parts as fast as possible with no stop time by measuring the equipment performance calculating the systematic improvement plan is possible. There are a few main points in this methodology. Availability is calculated by considering planned and unplanned strops during production. Performance, which shows the speed of the production. Quality, which shows the number of good parts. And OEE takes into consideration all the losses above and calculates the overall production performance. It is done by multiplying the number of Availability, Performance, and Quality. If the number is close to 100% it means that the manufacturer is working at its best performance. (OEE s.a.)

Of course, there is also a machine monitoring methodology. It includes different ERP techniques that help monitor and relocate resources to the place they are most needed. There are different types of ERP programs such as CAD, PDM, PLM, PIM, MRP, APS, MES, CRM, PCM, PRM, SCM, VCM, and BI. They all help companies to operate and serve different purposes. For example, some are used for technical drawing and some are used to help to have everything in order, others are used to collect data. There is a different data management app for any purpose in the company. The issue is that they are quite expensive to install and moderate. It would need a lot of additional equipment that will help it to collect, analyze data and successfully operate. There are still some companies that take such responsibility for themselves and install the ERP systems on the production sites and maintain them, but still, it is expensive. And not to forget that ERP systems are not fitting for everyone. Even though ERP systems are useful, they have a great conflict with the lean manufacturing methodology. Because the main principle in ERP is a push system and in lean manufacturing, it's a pull system. But despite that companies still find a way to combine both of these methods. For example, some of them can use ERP systems as a way to collect data about the orders, so it would be easier to know what products people buy. Even though the studied workshop uses different CAD programs, which are also considered an ERP and Data management programs but in the case of the observed workshop, it is still highly resource-demanding to implement other types of a machine monitoring methodology, and therefore at this point, it would not be necessary to include it in the optimization plan. (Aptean Staff Writer, 2021)

Not to forget about the lean methodology basic principles that help the manufacturing to work successfully and help to gain competitive advantage. The first is the value principal. Value is

determined by how much the customer is willing to pay for the service that he gets. And it is a company's task to fit in this price range and to eliminate all the costs to meet the price and get a profit. (Hansen, Jeff 2016)

The second is to map the value stream. The main point of this principle is to calculate the lifecycle of a product and to find a way to eliminate waste. (Lean Enterprise Institute)

The third is to create flow. In the current example of a metal forming facility, it is difficult to create a flow of products because this type of production works in a unique order. But it is possible, and it is going to be discussed further, to create a production manufacturing flow. When the equipment is arranged in the way that it creates a production line it is possible to create a smooth production flow where everyone will do their part. (Peter L. King 2019)

The fourth point is creating a pull system. Because metal fabrication is not stable in manufacturing it is almost impossible to create a push system, but the opposite pull system is commonly used in the production process. It is when parts are made as they are needed. This principle helps to control the amount of product produced and to eliminate waste.

As previously discussed, the Job methodology is the best suiting production type for the metal fabrication workshop. But it should be pointed out that the companies, should not stop on one lean method and try to consider as many different methodologies as possible and take what's best from each of them. For example, as previously discussed lean methodology consists of many different aspects and methodologies and all of them can be successfully implemented in a workshop to improve its production. For example, improving the work and process every day step by step and improving workers' performance through additional education can be adopted from the Kaizen methodology. Having a clean and standardized working environment comes from the 5S methodology. Setting and taking care of the equipment correctly is taken from the Six Big losses methodology. And overall performance control is checked by using OEE principles. All of the things above when followed help to significantly improve the performance and therefore income of a workshop.

2.3 Qualities of an optimized manufacturing process

Production is optimized when the product is made as fast as possible, without any waste or loss in quality and resources. Earlier examples of methodologies to use to optimize production performance had been provided, so now the methods of the data collection, decision making, and overall improvements of the company's work process are going to be observed.

The methodology is not just raw theory. It is based on data that people around the world collected and studied for many years. Therefore, to improve production besides using the methodologies, the information flow throughout the company and workshop should be checked. Usually, this is the most time-consuming part of the production. Because first managers need to contact the client, then he tells the conditions on which the project should be done, then the managers pass this information to the team of engineers who make their fixes and again and again until the project goes to production. And even there, all of the processes should be followed and controlled by the executive engineer. In this example, this is very time-consuming and unnecessary for the optimal production process.

Nowadays modern education gives a variety set of skills in any profession so to improve the production process, strait after the customer is found engineer should take place in the discussions about the project directly with the customer, there is even a job position called sales engineer. They can consult as on their own as in a team with a sales manager or project manager. It will avoid time waste and misunderstandings during the communication part of the process. It will also save time because engineers would be able to directly ask questions and suggest solutions to fit the customer's desires. (CareerExplorer, s.a.)

Also, to improve the production head engineer in the workshop should search for the bottlenecks in the production process and try to improve them. Ideally, this should be done already in the product production planning stage. One of the main methods to do so is the Theory of Constraints.

The theory of constraints focuses on the identification of constraints in production systems and their proper management to achieve the maximum throughput (Łopatowska, 2017) The constrain is the most important element in the TOC method. It determines the capacity of the production system and limits its success (Wieslaw Urban, Patrycja Rogowska 23 July 2020) overall there are three types of constraints: resources, materials, and management. The most often type of constraint is the third one because companies commonly make the mistake of not hiring more people or buying additional equipment that would improve their productivity. But on the other hand, they are the cheapest and easiest to solve. Second, more often is the resource constraint. It is when production is exceeding its assumed capacity. "An excess of production capacity is characterized by a surplus of stock of finished products and work in progress." (Wieslaw Urban, Patrycja Rogowska 23 July 2020) And the material constraint of quite rare because nowadays if materials are finished it doesn't take much effort to make a new order from a supplier and they would be available soon. Identifying the current constraint in a production cycle is already half of the work. The other half is fixing the issue by doing all the necessary means. It is important to have this search process running all the time to always improve the efficiency of the production.

One of the other good things to improve the production is also making an end analysis after the work is done. It will help to find the problems and the ways to improve the production in the future. One of the main problems in a not optimized production is the waste of time and resources in the lack of automatization. As an example, one automatic metal saw can work as fast as the 4 workers at the same.

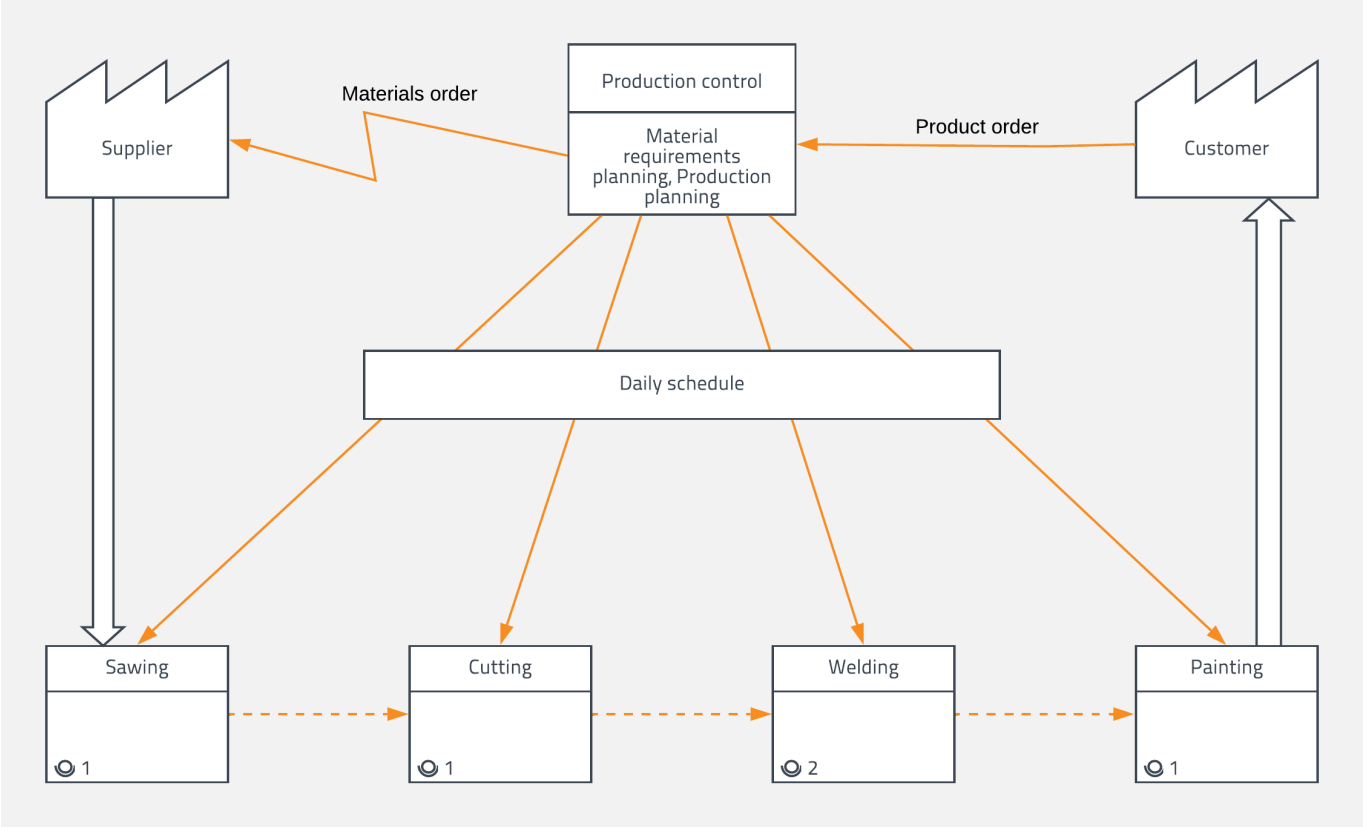
Some companies do not see the benefits of automatization and they think that it is an unnecessary investment, but to further improve the capacity and productivity of a company it should go on the road of automatization, because automated processes are much easier to handle and control and improve.

Another massive waste of time in a workshop is logistics. If equipment is placed as it arrived at the workshop (as it usually is) then a lot of time is wasted on the transporting working piece from one place to another. Not to say that heavy pieces require more workers to participate in the transportation and therefore more effective time is wasted. Therefore, it is highly important to properly

arrange equipment into a well-designed production line. The time saved in transport can be a significant competitive advantage in metal fabrication.

2.4 Current production analysis.

By observing the current production at the metal fabrication workshop, the conclusion was made that it works inefficiently. This conclusion is made because on the production site workers use old tools that lack maintenance. Also because most of the industrial machinery is either broken or is not adjusted it is not possible to provide quality work with it. Therefore most of the work in a workshop is done manually. Current production process looks like this (Picture 1)



Picture 1. Production process

Even though on picture 1 the production process is well developed, it is clearly seen that for big production jobs this workshop is not fit because it lacks workers and proper equipment. But with the advancements that will be shown further it would be possible to improve production so it will have enough capacity for a bigger production.

3 RESULTS

3.1 Statistics

The main goal of this thesis was to show how implementing statistical analysis, specific methodologies and proper equipment can significantly improve the production performance of the metal fabrication workshop. To do so several methods of analysis were used. Starting with regular observation after the workflow of the workshop and continuing to the system analysis of the collected data. Analysis was made by calculating the average work time with and without the specific equipment. Some of the data was collected from the internet and the equipment characteristics.

Here is provided information that shows how important automatization and proper use of equipment are. Table 1 shows the differences and benefits of manual and automated processes.

Table 1. Data analysis of the hand and machine work.

	Hand	Machine
Sawing	25-35mm/min	20-100mm /min
Transporting	max weight ~ 40kg	max weight 250-1000kg
Plasma cutting	25,4 cm/min	35/min
Arc welding	75 to 150 mm/min.	
Semi-automatic welding		720mm/min

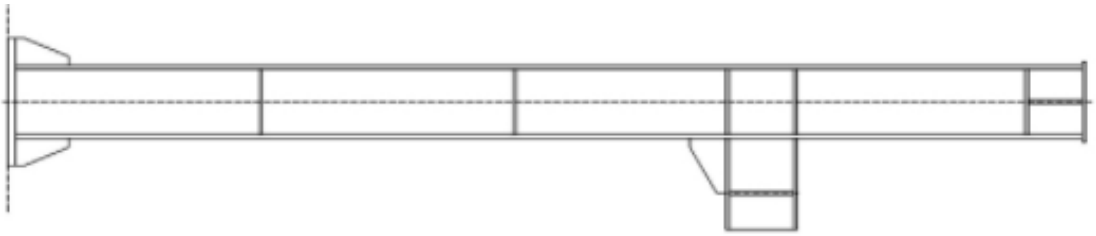
For example, regular hand sawing takes almost twice the time, that automatic band saw for metal. Also, the benefit of the automatic is that it is possible to put a bunch of material and it will not have any problems with cutting it. Rather than when sewing by hand, it is possible to hold only a few beams without the excessive risk of injury and/or downgrade in quality.

Another piece of equipment that is essential in an optimized workshop is an electric Lifting Winch. It is an additional piece of equipment that was not in the original list of materials. The decision to add it was done because it is small, cheap, and can pull up a weight from 250 to 1000kg in one go. It will sufficiently improve the transporting speed and reduce the waste of human resources.

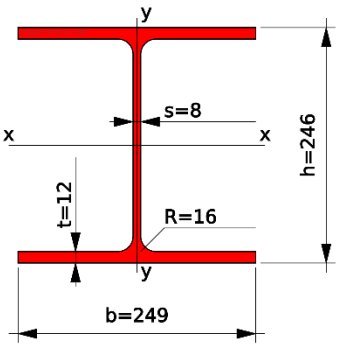
One of the things that is also often needed in the workshop is metal cutting. When talking about plasma cutting metal manually, it is already assumed for it to have lower quality, speed, and precision of the cuts. Rather the automatic plasma cutting machine does not have such minuses and its cutting speed is much higher. Additionally, the work of the CNC plasma cutting machine is much simpler than the manual. In hand plasma cutting, the worker has to manually adjust the flame each time before the work and therefore from the professionalism and experience of the worker depend the speed and quality of the work, whereas on the other hand to operate a CNC machine worker does not have to be such a professional. The only thing needed is to upload the technical layout to the system, which can be drawn by the engineer working at the facility and wait until the program is finished.

Welding in the workshop is another complicated topic. Its efficiency can vary starting from the professional skills of the welders and finishing with the quality of the equipment. Also, the working machinery depends on the type of metal construction being welded. But despite all of that it can be confidentially concluded that according to data collected semi-automated welding is more efficient than regular arc welding almost in 20 times.

As another example, the amount of time that is needed to produce one metal 6m column which is made from 1 I-beam 25K1, and metal sheets thickness 5 mm is going to be calculated. The number of ribs is calculated based on a formula, but now as an example, a work plan is going to be based on the current technical drawing. (Picture 2.)

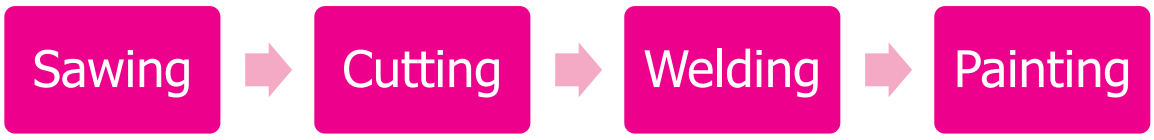


Picture 2. Technical drawing of the column.



Picture 3. I-beam dimensions

By observing the drawing, it can be safely assumed that the column has 4 triangle ribs and 6 rectangular. Part of another column will not be considered. There is also one rectangular basement of a column which is going to be assumed a 10mm metal plate. Dimensions of the column 25K1 are 246*246mm. Inner distance (hi) is 222mm. And inner width (wi) is 119mm *(Picture 3). Based on these numbers the dimensions of the ribs are going to be calculated. Rectangular ribs (R1) will be 222*119mm. And triangular (R2) will be 123* 250mm. The rectangular basement (R3) is going to be assumed to be 500*400mm. These numbers are approximate and may vary considering the real needs in construction and assumed only for an example. Now the production process is discussed.



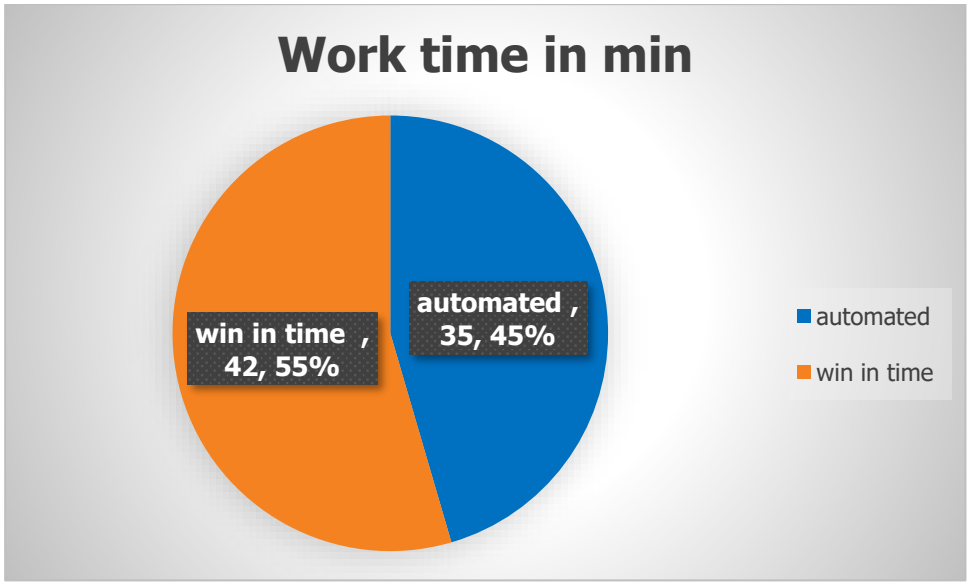
Picture 4. Production process.

The regular production process goes like this. (Picture 4.) First the I beam should be cut in half because the usual beam length is 12m. At the same time, metal sheets should be cut out to fit in the middle to make hard ribs. And then all the ribs should be cleaned and welded. The process of cleaning of the column is to be ignored because in the current production plan is not considering the sanding and treatment of the metal is not considered, because those processes are done the same in both ways as in automated and as in manual production in this workshop and the work time will not be affected by them. After all, the sending machine is expensive and is not considered a necessary investment, for now, so the cleaning time will not affect the production process. But in the future, it will be a great opportunity for company development.

Based on this arrangement plan and assuming that metal sawing will be automatic and all the metal ribs will be cut in a plasma cutter and welded with a half-automated welding machine, it can be calculated that the average production time is 35 min. And when everything is done manually 77 min. It was done by dividing the amount of work by the capacity and then adding everything up. Cutting length is calculated by this formula (222*2+119*2) *6+ (123*2+250*2) *4 +500*2+400*2=8876mm. And welding length is calculated by this formula (119*2+222) *6+ (123+250) *4+ 246*2+222*2 = 5188 mm. sawing is calculated by dividing 246, which is the thickness of the column by 35mm/min and 100 mm/min. which are sawing speeds of hand and machine saw respectively. And the numbers are 7- and 2-min. Same operations were done with plasma cutting 8876/350=25 and manual cutting 8876/254=35. And the final Arc and half automated welding is calculated by 5188 divided by 150 and 720. This gives us 35 and 7 working min.

This pie chart shows the win in time that is gained when using tools and necessary equipment.

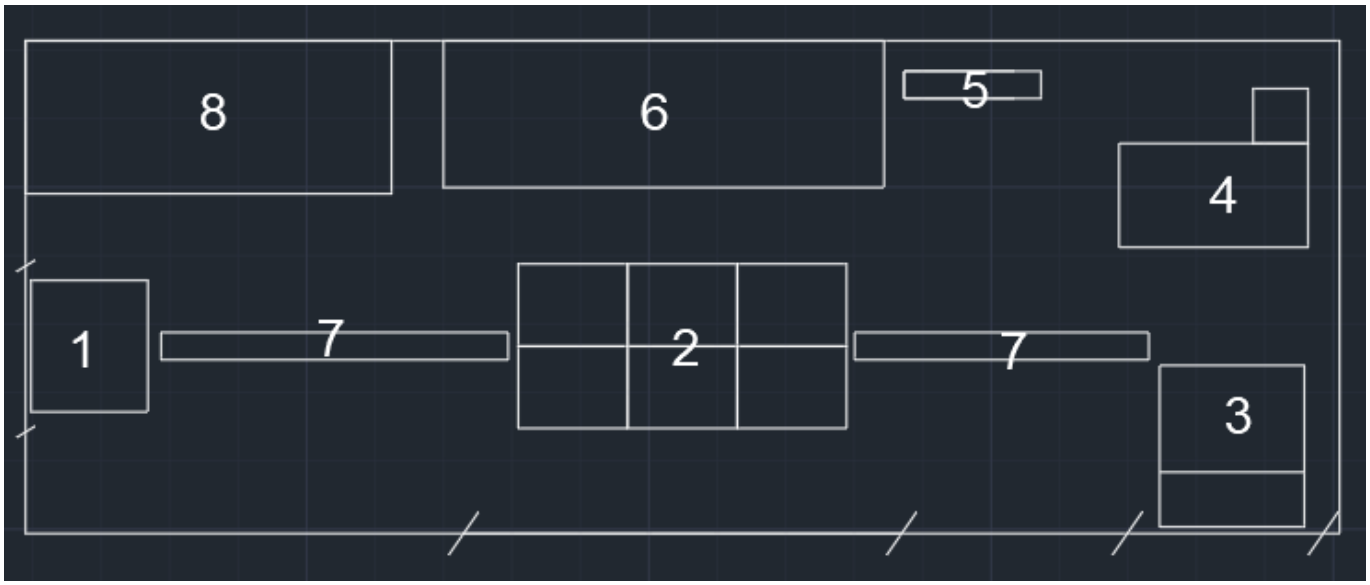
Chart 1. Work in time in min.



This pie chart shows that manual work takes more than twice as much time as automated. Therefore, statistically speaking the workshop can earn twice as much money as it does now because it can do the work two times faster. And considering the tools arrangement plan that would be discussed further, it can be safely added the win in time with transporting the materials around the workshop.

3.2 Workshop layout plan

One of the main important things in workshop optimization is the arrangement of the equipment. Usually in most workshops equipment is placed as it arrives at the workshop and put where it fits. But this way of panning isn't optimal and can lead to a significant waste of time which comes from moving parts from one place to another. As discussed before the production process consists of such stages: sawing/cutting, welding, and painting or final processing. Therefore, the most optimal workshop equipment layout should look this way:



Picture 5. Workshop equipment layout

This layout is planned that way so it will be the most convenient to receive, fabricate, and hand out the production.

By /-/ sing on the plan shown doorways. There are 3 doorways on the plan. One in front of the sawing machine (1) (Picture 11) another in front of the welding tables (2) (Picture 7.) and the last gates are in front of the guillotine (3) (Picture 10.). It is made in such a way that the material can be divided into 2 parts: beam type and sheet metal. Therefore, it would be easy to receive raw materials. And the gate in front of the number 2 is made for easier handing our ready product.

Number 4 is a plasma cutting machine, it is put near the guillotine so it would be easier to put sheet metal on the machine. And it is also situated near the shipping tape which decreases the delivery time of freshly cut pieces.

Number 7 is manual shipping tape (Picture 6). Its purpose is for simpler material delivery. On to the working zone which is made from 6 welding tables size 2000x1500. All the welding machines and equipment will be stored under the tables.

5 is bending rollers (Picture 8.). They are near the PCM because more often sheet metal is bent rather than tubes. Zone 6 is a special milling and drilling zone for small size manufacturing. Zone 8 is a small storage zone for materials that would be soon needed or for already done production. It is not made for long-term storage. Also, it is important not to forget about the small lifting winch is situated near the sealing. It helps to transport the material around the workshop. This layout was

developed by analysing the production plan and worked out with all the lean methodologies described above. It can be claimed that this layout is the most optimal layout which shortens the amount of time spent on transporting and fabrication of the material.

4 DISCUSSION

Nowadays at the highly competitive times when all the resources are growing in price, many companies search for the cheapest and most functional products. That is why a lot of companies are interested in optimization. There are many pieces of research made on this topic, therefore it is highly recommended to use statistics and methodologies for the improvement of the production.

This thesis work describes one of the ways to optimize and eliminate the waste of time in the metal workshop. By using more advanced equipment it is possible to get a win in speed and quality, by having more qualified and professional workers better quality is reached. Also, that decreases the mistake chance which always leads to the win in time. And by having all the equipment arranged properly delivery time is decreased and a win in time and resources is achieved.

Not to forget about the different lean methodologies and guidelines for optimization of the workshop's work arrangement. From Kaizen methodology, the always improvement principle was taken and additional professional courses are suggested. From the 5S methodology, the workshop structure and standards were borrowed. Also, the 5S principle was taken into consideration while developing the workshop layout plan. As shown on a plan everything is in its place without any useless equipment in a workshop. From the Six Big Losses methods of taking care of the equipment were learned. And OEE method shows the standard for understanding if production is well designed and optimized. Unfortunately, main ERP programs and manufacturing execution systems are hard to implement because in job type of production each manufacturing process is unique and mostly done half manually therefore it is almost impossible to gain a stable data flow from the production site. But such programs can and should be used as data storage systems for reports and manufacturing instructions instead of paperwork.

All these parts together are responsible for the improvement in the production cycle. And even if used individually each part will still lead to the improvement of the fabrication. Unfortunately, there are still several risks in implementing this plan for example if all the investments into the improvement of the workshop would be returned. Therefore, it is suggested to implement all these improvements step by step by using the income from the orders made.

Through the data shown above, it can be concluded that the improvement in production will be twice as much as before. Therefore, by improving production speed the income will rise because workshop capacity will improve in 2 times. Unfortunately, even with all these improvements, it is still important to have qualified workers in their places. So, the kaizen methodology is highly suggested in manufacturing. There are still risks of the workers leaving the job after all the courses that the company has sent them to, but they can be nullified by making a work contract that would make them work for some time after their qualification improvement.

The aim of this thesis was to analyze the current work of the workshop and suggest optimization technics and plan for it to work more efficiently. By analyzing different methodologies and improvement technics, this thesis work showed that it is possible with the usage of the proper equipment to increase the production capacity up to 2 times. This work was done successfully because even with raw numbers the results are explicitly better than was expected before. And that was even despite

that the productivity improvement by methodologies and equipment layout is impossible to calculate without implementing this work in real life. It would have been a great opportunity to implement all these improvements in real life and to do an actual research-based analysis of all the described technics.

To sum up, it is important to always improve production and to always think about how to eliminate as much waste as possible. With a strong team of professional workers and the right working and up-to-date equipment, it is proven that it is possible for the companies to work with great profit and benefit. This study was made for the specific metal fabrication workshop that belongs to the St.Grad company but it is possible that it will help people develop and improve their productions in other facilities in the future.

REFERENCES

1. Southern Metal Fabrication. S.A. What Is Metal Fabrication? Internet publication. https://www.southernmetalfab.com/blog/what-is-metal-fabrication/#:~:text=Simply%20put%2C%20"metal%20fabrication",structures%20from%20metal%20raw%20material. Accessed 14.05.2022

2. Laserfab. by Dain Zimmerman. What is Metal Fabrication? Internet publication April 28. 2021. https://laserfab.net/blog/what-is-metal-fabrication/ Accessed 14.05.2022

3. Betterteam. S.A. Production Engineers Job Description. Internet publication. https://www.betterteam.com/production-engineer-job-description#:~:text=Production%20engineers%20are%20responsible%20for,to%20improve%20efficiency%20and%20profit. Accessed 14.05.2022

4. Optessa. S.A. 5 Types of Manufacturing Process. Internet publication. https://www.optessa.com/types-of-manufacturing-process/ Accessed 14.05.2022

5. Indeed Editorial team. Indeed. Guide to Production Planning: Benefits and Steps. Internet publication. June 17, 2021. https://www.indeed.com/career-advice/career-development/production-planning Accessed 14.05.2022

6. MBA Skool Team, Material Planning Meaning, and Factors. internet publication. Last Updated: December 29, 2020 https://www.mbaskool.com/business-concepts/operations-logistics-supply-chain-terms/15614-materials-planning.html Accessed 14.05.2022

7. OptimoRoute, Types of Capacity Planning and How It Keeps Your Products Stocked and Customers Happy. Internet publication. December 30, 2021. https://optimoroute.com/capacity-planning/ Accessed 14.05.2022

8. TechTarget, production planning, Internet publication by Ben Lutkevich, Technical Writer, last update November 2020 https://www.techtarget.com/searcherp/definition/production-planning#:~:text=Production%20planning%20is%20the%20act,process%20as%20efficient%20as%20possible. Accessed 14.05.2022

9. Investopedia By Will Kenton, Internet publication. Updated December 01, 2021 https://www.investopedia.com/terms/m/manufacturing.asp#:~:t ext=Manufacturing%20is%20the%20process%20of,tools%20before%20the%20Industrial%20Revolution. Accessed 14.05.2022

10. Sattler Manufacturing S.A. The 7 Basic Steps of Metal Fabrication. Internet publication.https://sattlermanufacturing.com/metal-pro-guides/7-steps-metal-fabrication Accessed 14.05.2022

11. Sebin Mani 2009 Internet publication https://d1wqtxts1xzle7.cloudfront.net/36988672/7_rew-with-cover-page-v2.pdf?Expires=1652638956&Signature=fBcnTJCS0T6ilVSoKcqqPz9dUMtJPBK-spJx-TdoGv0598N9bYVpBzh-OV1utQLw3s4AcPUZO36IpJqW15t7VQPqiLbvbjWe6RIpih-DOnbW0V4EI4PIuyYQMGHTQeTyF77VpsjzlC-oVfLqNobBN7ekZdl9NsR2y8GLYaA7IpyynBiW6-cYpG32TcVBc9GrTlQcoug1BHvi1xZ0Bnlpsvwy9gxAK2qoF-F8OMKKMGOpSWXK6ne-rQ6DlXzeZ-CHo5tES6DLHk5J1ttBRTEiDpb-i9I8CxkgT-T6p24jmBKHFCpC9MGUxR3Av-DNME4EnL9bPURYRKRDNIDPizZYBvBToQ__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA Accessed 14.05.2022

12. Kaushik Kumar, Sanjeev Kumar , internet publication, June 2012 https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.375.914&rep=rep1&type=pdf Accessed 14.05.2022

13. Vorne. S.A. Internet publication. Six Big Losses. https://www.vorne.com/learn/tools/six-big-losses/#:~:text=The%20Six%20Big%20Losses%20are,excellent%20target%20for%20improvement%20actions. Accessed 14.05.2022

14. OEE. S.A. Internet publication. Overall Equipment Effectiveness. https://www.oee.com Accessed 14.05.2022.

15. Aptean. The Complete Guide to Metal Fabrication ERP Software. Internet publication. 3 September 2021. https://www.aptean.com/en-AU/insights/blog/complete-guide-to-metal-fabrication-erp Accessed 14.05.2022.

16. Eric Fogg September 02, 2016. Internet publication. 5 lean Techniques that will improve your manufacturing process. https://www.machinemetrics.com/blog/5-lean-techniques-that-will-improve-your-manufacturing-processes Accessed 14.05.2022

17. Łopatowska, J. (2017). Planning the implementation of projects in multi project environment using a critical chain. Zeszyty Naukowe Politechniki Śląskiej: Organi-zacja i Zarządzanie, 114, 303-316.

18. Wieslaw Urban, Patrycja Rogowska 23 July 2020. Methodology for bottleneck identification in a production system when implementing TOC. Internet publication. https://sciendo.com/article/10.2478/emj-2020-0012 Accessed 14.05.2022

19. Lean for the Process Industries: Dealing with Complexity, Second Edition by Peter L. King 2019

20. CareerExplorer, S.A. What is a Sales Engineer? Internet publication. https://www.careerexplorer.com/careers/sales-engineer/ Accessed 14.05.2022

21. Lean production. Internet publication https://www.leanproduction.com/kaizen/#:~:text=THE%20KAIZEN%20PHILOSOPHY-,WHAT%20IS%20KAIZEN%3F,a%20powerful%20engine%20for%20improvement. Accessed 14.05.2022

22. Lean Enterprise Institute. S.A. Value stream mapping. Internet publication. https://www.lean.org/lexicon-terms(/value-stream-mapping/ Accessed 14.05.2022

23. Manufacturing engineering and management. Book by Hansen, Jeff, toimittaja 2016

24. Band saw. https://www.directindustry.com/prod/knuth-machine-tools/product-27150-2230393.html . Accessed 14.05.2022

25. Electric winch https://eur.vevor.com/electric-wire-rope-hoist-c_10453/2200-lbs-electric-wire-hoist-winch-hoist-crane-lift-1000kg-220v-overhead-pro-p_010207978675. Accessed 14.05.2022

26. CNC Plasma cutting machine https://www.cnc-cut.com/product/Gantry-cnc-plasma-and-flame-cutting-machine.html?gclid=Cj0KCQjw4PKTBhD8ARIsAHChzRK_GWUENNO6rCAWxhg0uz1iT-R64OHn1aXMS3IQPq5uav8MDedpeogaArsdEALw_wcB . Accessed 14.05.2022

27. Welding machine. https://www.directindustry.com/industrial-manufacturer/semi-automatic-welding-machine-203794.html . Accessed 14.05.2022

APPENDIX 1: PICTURES

Picture 6. Transporting band

Picture 7. Welding table

Picture 8. Bending rollers

Picture 9. Lifting Winch

Picture 10. Guilutine

Picture 11. Sawing machine