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Optimization of the maintenance workshop

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Institute of Logistics Engineering

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Affidavit

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources. The text document uploaded to TUGRAZonline is identical to the present master‘s thesis.

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Abstract/Summary

Title: Optimization of the maintenance workshop

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This thesis aims to investigate ways for optimization of the observed workshop, with a focus on the material and process flow and layout. Data and the rest of the records are collected by observation on the site, through communication with the company employees, and with allowed access to the companies data files.

Research is separated between three main parts - The theoretical section describes Material Flow Analysis followed by several *Lean* techniques and philosophy to get an overview of the tools which are used for the development of the optimization concept. The second consists of an introduction to the observed workshop, with explained performed process procedure step by step. Additionally, material flow analysis has been made to identify waste and bottlenecks, which are presented through the Value Stream Map and the Process Flow Map for better visualization and understanding. After the detection of the process's weaknesses, it is possible to investigate improvement suggestions, and with the combination of the optimization tools provide a possible solution for the workshop area work in efficient way.

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1 Introduction

One of the biggest challenges that many companies are facing nowadays is the need for production optimization, efficiency increase, and lowering costs with keeping the focus on reaching customer demand.
This thesis is made in collaboration with Primetals Technologies at their workshop in Tangshan, China. There are two main purposes of thesis research. Firstly, it is necessary to make a theoretical review of the optimization technologies, including analysis of the different activities performed in the workshop. The second purpose includes the definition of the weak points and investigation of a possible solution for the roller workshop maintenance workshop. To analyze the current situation and to suggest possible improvements, it is necessary to include each point, steps, and workstations and present them.

The material flow can be improved by reducing the movement and handling of materials and reducing the distance of movement. Improvements in the production area can be achieved through an efficient layout.

With proper analysis, it is possible to identify and remove non-value added activities (later NVA) and make optimization conclusions. If the improvements in material flow and handling suggest a change in layout, it is necessary to investigate the proposal and prove it.

1.1 Company background

The company Primetals Technologies Limited, established in 2015, is a joint venture of Mitsubishi Heavy Industries and Siemens AG. The company's headquarters is based in London, and its sub-offices are present around the world – Europe, America, Asia, and Africa. Primetals Technologies currently counts approximately 7.000 employes. [Lit. 1]

Primetals Technologies is recognized worldwide as one of the leading companies in the field of metallurgical plant manufacturing with a wide range of services. The company has close collaborations with partners and customers, with the main focus on both improvements of proven technologies and the development of new ones. [Lit. 1]

1.2 Problem description

There are four (4) maintenance workshops operated by Primetals Technologies in Tangshan, China. They are named after their location: Headquarter 12 (HQ12), Headquarter 34 (HQ34), Stainless Steel (SS), and Plate Mill (PM). Each of those provides maintenance services for continuous casters. With the start of lean implementation, to decrease costs, improve the quality of the work, better control, and overall customer satisfaction decision is made that all roller workshops should be moved to one roller workshop – HQ12. PTTS is facing now with a big challenge.

Firstly, from October 2018, HQ34 roller workshop, which was next to the workshop for HQ12, was moved to this workshop. Now, from the beginning of this year, 2019, SS workshop was joined to this workshop. Each plant requires different roller types. They differ in type, size, weight, number of parts, and order quantity. The orders are not completed as they are planned, and the main reason is missing material – roller jackets.
Currently, the roller jacket maintenance workshop is also under the optimization process, and RS-A managers cannot influence roller jacket delivery. Additional problems that are identified as those that can influence incomplete orders are coordination problems, warehouse organization, waiting, and storage time.

2 Theory section

2.1 Steel

Steel is the most popular and essential construction and engineering material. Steel does not consist of only one element, it is an alloy of iron mainly, carbon (2%), manganese (1%) and some small amounts of silicon, phosphorus, sulfur, and oxygen. Today, approximately 3,500 different grades of steel are known with various physical, chemical, and environmental properties.
Steel can be applied in almost every aspect of daily living: in cars and construction products, refrigerators and washing machines, cargo ships, and surgical scalpels. Moreover, in 2018, steel production reached 1, 808.6 million tones (MT), from where more than fifty percent is accounted by China production. Other important and large steel production sites are located in Japan, US, and India. [Lit. 2, Lit. 3]

2.1.1 STEELMAKING PROCESS

As shown in Figure 2-1, the steelmaking process consists of several steps:
In primary steel making, steel can be produced via main processes and their combination: the blast furnace basic oxygen (later BF-BOF) and electric arc furnace (EAF). The main difference between these two processes is the type of raw material that is used in the process. The raw materials used in the BF-BOF process are iron ore, coal, and recycled steel. At very high pressure, oxygen is blown through the metal. After the oxygen combines, unwanted elements are removed from the mold. The quantity of added scrap keeping the temperature under control. After this process carbon content is refined to 0.04%. The EAF process is using recycled steel, electricity, direct-reduced iron or hot metal, where metal is melt by sing high power electric arc.
Once when the molten metal is poured, it is necessary to make additional treatments to adjust the composition of the steel. Depending on the grade of steel that is required, several possible processes that can be used for secondary steelmaking: stirring, ladle furnace and injection, degassing, CAS-OB.
The principle of the continuous casting method is simple. The liquid steel in a ladle is transferred to the casting machine. When the casting operation starts, the nozzle at the bottom of the ladle is opened, and the steel flows at a controlled rate into the tundish and from the tundish through a submerged entry nozzle (SEN) into one mold or several molds. The molds are generally water-cooled copper molds. The first solidification takes place at the metal/mold interface - the thickness of the solidified shell increases progressively when it is withdrawn through the machine. At the mold exit, the shell must be thick enough to support the liquid pool. Below the mold, the shell is cooled by spraying water. The mold cooling is called the primary cooling and the spray cooling the secondary cooling. At the machine end, the strand is cut off and transferred to a rolling mill. The big challenge in continuous casting is to cast steel continuously without interruptions and many kinds of defects. Solidification control is important for surface and internal quality. Steel cleanliness is determined essentially already by the other opera-

tions in the ladle and the tundish but can be influenced even in the casting operation. Important control parameters in solidification are, e.g., steel chemistry, casting speed, mold level, mold powder, mold oscillation, liquid steel temperature, secondary cooling conditions, as well as parameters affecting the flow phenomena in the mold. The research and development work in the continuous casting field is continuing quite intensively today, and the main purposes being a better quality of cast product and to develop methods to cast extra difficult steel grades with particular problems and requirements. [Lit. 3, Lit. 4, Lit. 5]

Finally, at the last step, the secondary forming, final shape, and desired quality are accomplished by different technologies: shaping, machining, joining, heat, and surface treatments.

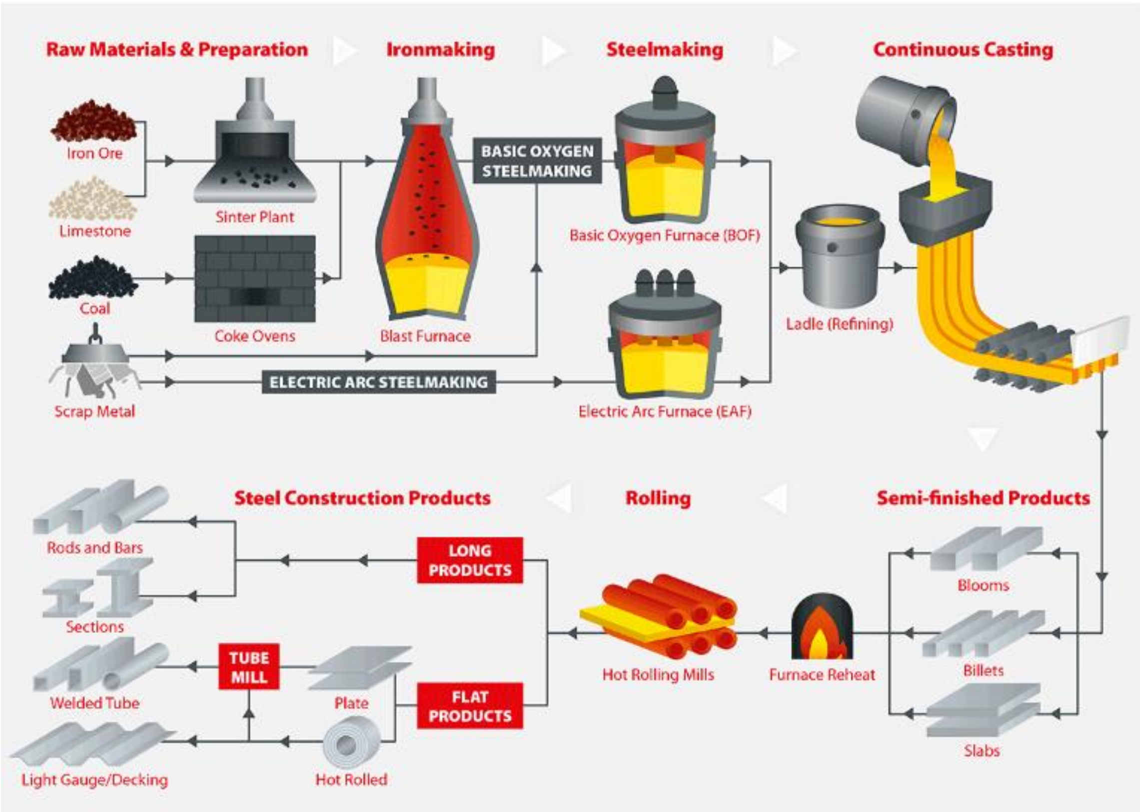


Figure 2-1: Steelmaking process [Lit. 4]

2.1.2 STRANDGUIDE ROLLER

The primary function of the strand-guiding rolls is to support and guidance of continuously cast metal strands. When strands emerge from a mold in a strand-guiding strand, they can reach a temperature of over 1000° C (in case of steel strands). A pronounced liquid core is the result of ferrostatic forces in the case of relatively thick strands. The strand guiding rolls have to resist all deformation forces. They are usually equipped with a cooling system with a design that is capable of handling mechanical stresses. Several types of strand-guiding rolls are used in Primetals Technologies:

The compact split roller (CSR) finds its application for standard casters that uses product of non-critical steel grades, and it is sufficient for casters with fewer unexpected loads (e.g., Tundish exchange) and low additional forces (e.g., soft reduction). It contains two or more separate rollers (where each of them consist two bearings). To form a single compact split, separate rollers need to be aligned in the lateral direction. [Lit. 6]

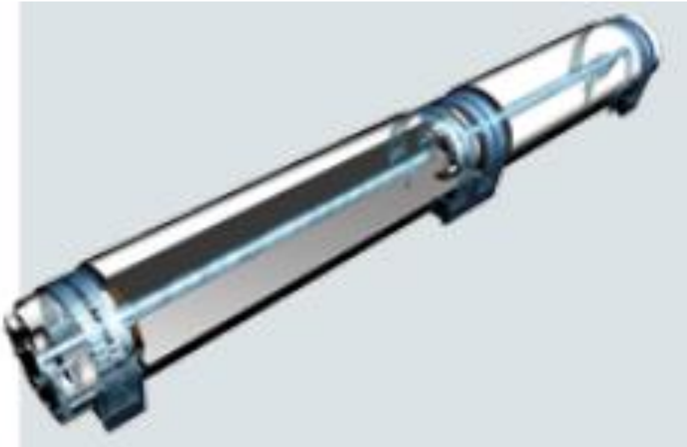


Figure 2-2: The compact split roller (CSR) [Lit. 6]

There are rollers with the same mechanical properties as in the CSR rollers but with the peripheral cooling system – PDR rollers. They serve as the right solution for the caster, which is having problems with a secondary cooling system, or unexpected loads. [Lit. 6]

Figure 2-3: The peripherally drilled roller (PDR) [Lit. 6]

The intermediately supported transaxle roller (I-Star) is an ideal roller for a secondary cooling or external machine cooling from the casting bow to the horizontal casting area. The base of the I-Star strand guiding roller is four or more bearing blocks and three and more roller bodies. The small unsupported strand is a crucial advantage of this roller because it helps in reduction off strand bulging. [Lit. 6]

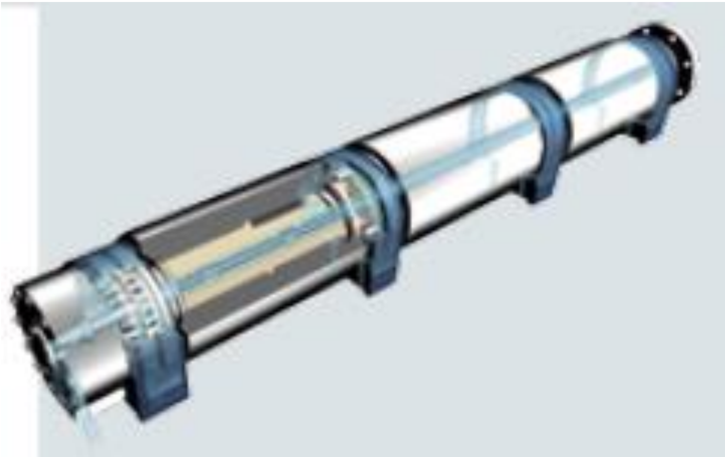


Figure 2-4: The intermediately supported transaxle roller (I-Star) [Lit. 6]

The ECO-STAR is the most used roller in slab casters. The main parts of these rollers are three or more roller barrels, four or more roller bearings that are mounted on four or more roller stumps. The advantage of the ECO-STAR roller is soft reduction and optimized maintenance concept. The ECO-DRI-STAR roller is a combination of the ECO-STAR and cooling by revolver bores (located along the circumference). The main advantages of this roller are: soft reduction, dry casting, and crack sensitive steel grades can be used. [Lit. 6]

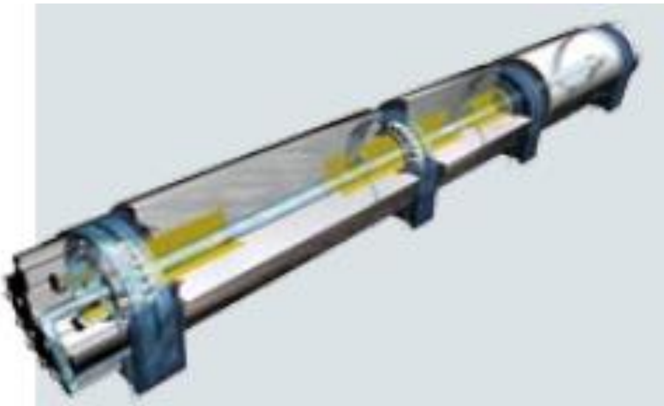


Figure 2-5: The ECO-STAR roller with water cooled axle & bearing block [Lit. 6]

Figure 2-6: The ECO-DRI-STAR [Lit. 6]

The Bend-Star roller is designed based on the ECO-STAR principle, and it has continued peripherally water-cooled roller bodies, which allow partial dry casting in the area of the slab corners in the bender segment. The advantage is the reduction of the delivery time and accordingly maintenance costs. [Lit. 6]

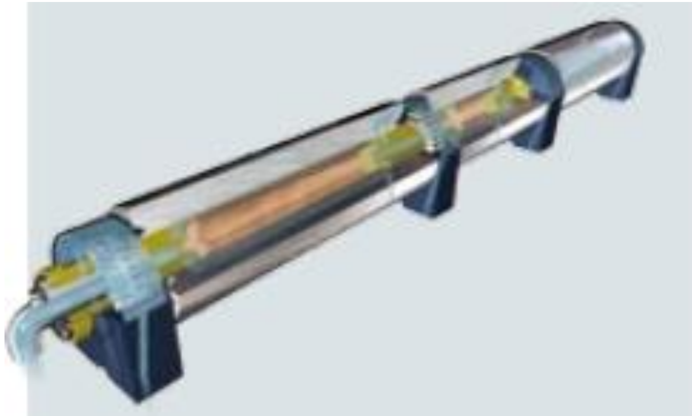


Figure 2-7: The Bend-STAR roller [Lit. 6]

The VAI Micro-STAR roller can be divided into two types: Foot and Bender roller. The Foot roller is the name for a compact and sturdy roller for a long lifetime, where the roller is supported intermediately by the fixed axle. The Bender roller is known as the roller used in high productivity caster and thin slab caster. It is also intermediately supported with a fixed axile, providing the strand shell support and high availability. [Lit. 6]

Figure 2-8: The VAI Micro-STAR roller [Lit. 6]

2.2 Material flow

Every production system can be defined by material, information, energy, people, and capital flow. According to VDI 3300 and DIN 30781, material flow (later MF) is a *spatial, chronological and logistical interconnection* of all processes related to manufacturing, processing, and allocation of goods within defined area and time. MF can be described with the following factors: material type and quantity, the direction of material movement, speed, allocation distance, and movement frequency.

The main characteristic of MF are:

- It represents qualitative and quantitative values for planning environment and process of the production system

- Costs of MF are an essential part of the overall production costs
- It represents steps for improvements and rationalization of the production system
- It is base for automation and mechanization of material handling

System optimization, increasing competitiveness, and decreasing the cost are some of the biggest challenges companies are facing. Optimization can be achieved with the reduction of the production cycle, lowering production cost, and MF optimization. MF optimization is crucial when talking about the possibilities of production rationalization. For example, MF in the metal industry depends the most on transport time, material handling, waiting time, and stop time at all levels of the production process.

The need for MF optimization is present at both: planning a new production system and at reconstruction/rationalization of the existing system – changes in production quantities and production layout and implementing new production resources. Jonson [Lit. 7] analyzed the impact of MF optimization on the production system. Results have shown that MF optimization provides better effect then investment in new system elements because the material flow has a more significant potential for system rationalization. He concludes that new investments provide only a suboptimal solution where significant investments are made for small improvements.

Visualization methods can be divided into two – dimensional representation, three-dimensional representation, and mathematical representations. Currently, the most popular methods of MF visualization are the Sankey diagram, flow process chart, operation process chart, flow chart, block flow diagram, and MF matrix.

Material management is known as a coordinated function within an organization, which is responsible for controlling the MF. To look at material management, there are two approaches. The first approach deals with the maximization of the usage of the company's resources, and the second approach refers to the importance of providing the service level, which is needed [Lit. 8]. Material management is likely about to be the physical management, storage, movements, and packaging of the material within an MF, logistical system, or production process. To create a physical location advantage, different material management functions are needed. In most of the manufacturing organizations and companies, the significant part of the costs depends on the overall MF. It is efficient to implement improvements into the material flow or logistical system continuously, to minimize the costs of material management. Increased management capacity and more valuable MF with fewer bottlenecks can be achieved by implementing a well-developed material management system, which also has several positive effects [Lit. 9]. There should be a link between the functions within an organization, to get high flow quality within production. The flow-oriented approach helps us to achieve this by integrating our processes along with the MF. Within manufacturing, the lead time has a significant effect on MF and efficiency. So, to reduce queues in front of operations, it is recommended to avoid waiting time, which leads to an advantage [Lit. 8]. To analyze the MF and to illustrate how the material is being processed and transported through different activities and operations, MF chart are highly recommended. Before the MF chart is being created, it is crucial to study the processes involved, to know through which activities and operations the material is going through. Symbols are usually used to indicate different transportations, operations, buffers, and controls within the material flow chart illustration. Moreover, arrows are used to show the sequence between various activities [Lit. 10].

Manufacturing companies have pressure to optimize their production to increase productivity by lowering their costs [Lit. 11]. Costs can be impacted by the way the materials are managed and monitored [Lit. 12]. The company's productivity and manufacturing costs are affected by facility layout [Lit. 13], that can lead to devastation if there is a mismatch between the way materials are handled and moved and the facility layout [Lit. 14Lit. 15]. To maintain customer satisfaction and to meet customer demand on time, the flow of material in manufacturing processes has given great importance [Lit. 15], thus increasing the company's productivity and also to remain competitive [Lit. 16]. MF should be synchronous and continuous. The continuous MF means there is no unnecessary inventories and no interruptions. Furthermore, simultaneous material flow running smoothly at the same pace.

MF is going through the whole production line, starting from raw and processed materials to the final step as the finished product. MF analysis is used as a base for production optimization.

The determination of the ways of acquisition or maintenance of their position in the competitive environment is troublesome as a dilemma for most contemporary organizations in today's world [Lit. 17].

MF often stands for a significant part of the costs as it is a promoted part of the supply chain to evaluate within manufacturing organizations. The analysis and optimization of the MF that arises during the manufacturing of products are subjected to evaluation. Evaluation can focus on very different levels, such as material flow within a company's internal processes or MF in a region [Lit. 18]. The operations, transportations, and storage of materials are the main concerns of material flow. A well-organized MF enables organizations to increase productivity as well as lowering costs [Lit. 19].

2.3 Material flow planning

The need for planning material flow can be indicated for several reasons: the need for a new product, the change in production volumes of existing products, or the implementation of new technologies.

In dependence of combination indication factors there are several MF planning approaches: new planning, extension planning, reconstruction, and rationalization planning. New planning is the biggest and wider scenario of all, and it has an aim in the realization of long-term enterprise concepts. It contains a small amount of limitation and the highest variance of planning to compare to other MF planning options. Extension planning is an option when the existing production area requires a capacity extension, mostly because the current production system cannot handle additional production requests. Also, many companies are reconstructing the production system when they want to decrease production costs or in case of need for new products. Reconstruction of production systems with or without their extension occurs as a consequence of dynamic, variable environments where the actual state and requirements of production systems start to deviate significantly from initially imagined. Reconstruction involves the transformation of production flows and structures. It has an aim in qualitative improvement of the production conditions. Implementation of rationalization in the existing production system has the main goal in improving and expansion of the existing concept. Development of MFS is divided into four basic levels of planning:

- planning process
- planning method
- planning model
- planning tools

The planning process, however, has five process steps. The first step is problem analysis, where it is necessary to define system boundaries and boundary conditions and restrictions. The next step is data analysis that has its aim in a review of the current state and gathering of the actual data. The output of data analysis is system weaknesses and threats. Modeling is a powerful tool for illustration and a better understanding of reality. System parameter determination is possible with using calculation. To optimize the system, the variations of the system parameters are tested to see which combination provides the best optimization solution.

When describing the MF in production, there are several theories in place, such as Lean production, AM (Agile Manufacturing), JIT (Just in time), MRP (Material Requirements Planning), TOC (Theory of Constraints), supply chain management and so on. Many challenges will appear when the production volume increased sharply, which means that there will need to use all the above mentioned theories/modes to analyze and optimize manufacturing. However, enterprises can analyze their situation by selecting one or two of the methods, and then they adopt the corresponding approach to solve their problems and to enhance their production. Each of the optimization methods has an advantage in a particular field instead of an outstanding all-around.

The goal of a company is to use of its production resources with minimum state of the material, to achieve steady while the market requires assured fulfillment of the terms agreed and also short flow times [Lit. 19]. It is possible to maximize the economy by increasing the readiness for delivery and by reducing warehouse costs, flow times, bound capital, delivery terms, and delay costs. Materials are converted from one form to another through processing, thus adding value to them. The objective of a manufacturing company is to add value and to achieve this efficiently, they have to ensure the least amount of waste in terms of time, money, materials, space, and labor. When concerning productivity increase, the operations and processes should need to be properly arranged and selected to permit controlled and smooth material flow through the factory. The more efficiently materials can be converted and produced into desired products with prescribed quality, the higher will be the companies' productivity, the better will be the living standard of employees [Lit. 20]. The main fault of companies, which leads to uncompetitiveness, is caused by a too high net cost of the product. In other words it can be said that poorly organized MF results in irrational production. MF can show a lot more about whether the system is organized well or not, and also shows a pretty clear image of the technological preparation department's knowledge and quality. Thus it is beneficial for a company to hire an engineer who can be able to design, implement, and operate an efficient manufacturing system [Lit. 19Lit. 20].

2.4 Material flow analysis

Material flow analysis (later MFA) includes a review of MF – definition of moving/transport in the production process with planned and unplanned material storage included. Complate MFA documentation consist of the material, space, transportation, storage, and employee details that are observed directly on site. MFA uses different graphical and analytical methods, where graphical methods display MF in qualitative as well as quantitative way.
Main objectives of MFA are mechanization and automation of transport and storage, transport distances decrease, lowering transportation and storage costs, process bottleneck detection, cutting accident and disturbances percentage.
With MFA, it is possible to affect an existing condition that results in suggestions for MF improvements and optimization. The ultimate goal of MFA is to highlight weak points and threats and to divide costs to reach optimized material flow with minimized costs [Lit. 21].

2.5 Lean management

2.5.1 Contemporary ways for business process improvement

How to become and stay successful and what techniques or methods to use in the process? One part of the answer lies in improvements. There is no unique definition of improvement, but almost everyone agrees when it comes to one thing: improvements are changes for better, all of which is progress concerning the current situation, and they result in savings of either financial or functional type. Numerous innovation-related papers have also included improvements to a certain extent.
Bergek and Berggren talk about various types of instruments that help when it comes to the improvement of multiple types of innovation: general economic instruments encourage incremental innovations, general regulatory instruments encourage improvements based on modular innovations, while technological specific instruments encourage the development of radically new technologies [Lit. 22]. Other papers, especially the ones related to the car industry, talk about improvements in materials [Lit. 23], energy efficiency [Lit. 24], processes [Lit. 25], environment [Lit. 26] and similar. According to Schroeder [Lit. 27], continuous improvements are the key to sustaining the competitiveness, while, according to the financial dictionary, improvement presents a new condition that is better than the previous condition. How big exactly is the power of improvement is perhaps best visible in the following quote: "If we would improve every single process in our business for only 1%, or even 0,1%, and if we would do so every day – what effects do you think would be achieved in a month? A year? In 5 years?" [Lit. 28].
Although there is talk about improvements in almost every activity and segment of the business, the most significant improvement come from the automotive industry, and the high number of definitions and types of improvement comes from Japan. The reason for that lies not only in the fact that the Japanese nurture a particular philosophy of life and business, which is hardly applied in the western

world even today but also in their wish to be the very best. Although the car industry emerged in America, Japanese car manufacturer defined the most significant contemporary business process improvement methods known today.
The most relevant theoretical authors of various types of improvement are closely related to automotive manufacture in Toyota. Taiichi Ohno, the most pertinent of them all, continued to follow the dream of his ancestors, especially of Eiji Toyoda, and he successfully finished the implementation of the Toyota manufacturing system, and by doing so, he set the foundations for the manufacturing philosophy of "making things", from which numerous implementations known today had developed. Ohno significantly helped the expansion of the Japanese work philosophy and more accessible application by other manufacturers with his published work. In his well-known paper [Lit. 29] he states numerous cases of a successful switch of the mass production with lean manufacture applicable in various manufacturing processes. Some of the elements of Toyota manufacturing system were soon recognized by other manufacturers as well, especially by the ones on the west: Muda (waste elimination), jidokka (intelligent automatization) and Kanban (the usage of cards in "Just in time" manufacture application, which serves as inventory control devices). Edwards Demming, professor, engineer, and author of numerous books, is especially famous for developing statistical quality control and PDSA (Plan-Do-Check-Act) circle, which he thoroughly developed on foundations of W-Shewhart's paper. His most famous work is in Japan after WWII, where he cooperated with the leading men of the Japanese industry, intending to implement progress in manufacture. Demming remained remembered from that period by numerous ideas, which significantly contributed a strong takeoff of the Japanese industry, and he will be remembered the most by the 14 fundamental principles, which the management would have to follow to improve the business [Lit. 30]. Demming's studies greatly impacted Japan to be recognized as a country of innovative, high-quality products and strong economic force. That is why it is no wonder Japan is respected and recognized so much that there is a prize-awarding for quality with his name since 1951.
Alongside Demming, it is essential to mention Kaoro Ishikawa, who advocated the thesis that the improvement of quality is a continuous process, which can always be additionally improved. He is famous for his diagram of sample and consequences (Ishikawa diagram, i.e., fishbone diagram), with which many improvements of quality were achieved [Lit. 31].
This diagram enables the visibility of all possible samples and the consequences of a manufacturing problem in one place. The diagram was used by both Demming and Ishikawa, as one of the first tools in the process of quality management implementation. Ishikawa was a firm believer in creating standards, but he also thought the standards should be constantly examined and improved. Ishikawa updated Demming's PDCA circle and added two new steps to it.
Another one of the relevant theoreticians who described manufacture improvements is Shigeo Shingo. He had a significant impact on the development of the Toyota manufacturing system, Lean manufacture, and Kaizen, and he is one of the founders of the statistical quality control method. Shingo was the first consultant hired in Toyota, intending to help in the finalization of improvements that had started earlier and to help teach new generations, with his knowledge and visions. He is the author of many papers where he discussed topic of the manufacture improvements, and of his the most significant work is *New Japanese*

manufacturing philosophy [Lit. 32]. In this book, Shingo explains three types of development: Just in time (JIT), Single Minute Exchange of Dies (SMED), and Zero Quality Control. Today, this author is more famous in America than in Japan. The University of Utah awards Shingo a prize for excellence in manufacture since 1988. This award promotes successful work in manufacture and awards enterprises, which achieve high business results alongside happy costumers, and it is compared with the Nobel prize in manufacture.
Alongside the previously mentioned theoreticians, Juran, Oakland, Taguchi, and Crosby also contributed to the advancements and improvements of business and manufacture processes. Theoretical bases for all the later advancements were though set by Stewart, Demming, and Juran. Their philosophy summarized that all the improvements are useful, but that is necessary for everyone to be included in their implementation. In that sense, it is not enough to just work the best. It is necessary to know what needs to be done and to do that the best. As a result of the studies of the most famous quality and improvements theoreticians, Toyota and the other Japanese manufacturers didn't do the impossible. They simply adjusted the business to market conditions and creatively applied innovations in technology, which originate from American enterprises. Furthermore, looking for better solutions for basic problems, they set new standards of efficiency and started a revolution in manufacture. The previous insight in the definitions of improvement and the theoreticians, shows the importance of improvement as a research area.

2.6 Contemporary methods of business process improvement

Theoreticians who practice contemporary methods of business process improvement state various methods by which the improvements are achieved. In this paper, the most frequently used methods are being observed, such as Kaizen, Lean Manufacturing, Kanban, Line Balancing, 5S, Continuous Improvement, Value Stream Mapping. There are characteristics of each of the mentioned methods, briefly laid out below.

2.6.1 Kaizen

Kaizen (improvement, change for the better) defines philosophy or positioning towards permanent improvements of the business manufacture and management processes [Lit. 33] and it is accepted and applicable in a great number of sectors. The base of Kaizen is that there are constant advancements of business processes achieved with its application, with common action of knowledge and experience of all employees, and it is categorized as "a unique life philosophy," according to which every aspect of life should be constantly improved [Lit. 34].

2.6.2 Lean Manufacturing

The term Lean Manufacturing or lean manufacture was first described in the book "The machine that changed the world" [Lit. 35], which was the result of a research work of the IMVP (International Motor Vehicle Program), where the authors described the differences between the Japanese and the western car industry and used the expression "Lean" for Toyota's way of manufacturing for the first time. Lean means less of everything, less drive, fewer investments, work, and capital. Lean is a manufacturing philosophy that, when implemented, shortens the period from the buyer's order to the shipment of a final product, eliminating all sources of dissipating, i.e., the loss in the manufacturing process. The basic principle of Lean manufacturing is the production of the exact thing that the buyer wants, i.e., the quality and the quantity of the product directly dictate the market.

2.6.3 Kanban

Kanban (writing board, marker, card, mark) is the concept of improvement, which relies on the Just in the time manufacturing process, as well as on Lean manufacturing. Kanban is one of the ways of achieving JIT manufacture. This is "the method of approval of the production and the movement of the material" [Lit. 27]. Kanban is not a system that solely controls the supplies, but it is also "a system of manufacturing control, which also pulls JIT manufacture, allowing the production with small supplies" [Lit. 36].

2.6.4 Line Balancing

Line Balancing (later LB) is all about designing a smooth production flow as possible, to remove bottlenecks and all wastes. The objective of this process organization method is to meet production goals and divide the same amount of work in each operation. The basic rules of the LB are to have at least half of an hour of WIP for each process step, ensure each worker works on the maximum capacity, and solve problems on time (before they become more extensive). [Lit.37]

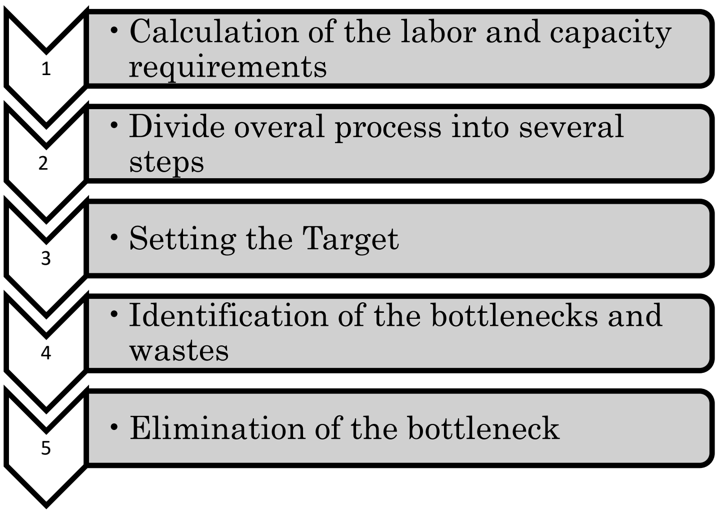


Figure 2-9: Five steps of Line Balancing

Relevant data of LB are cycle time, takt time, man, machine, and setup time. Takt time is a calculated value that describes the theoretical demand rate of the customers and answering the question of how fast production should be to meet demand. However, during the production process, downtime and unexpected failures are happening. That is why takt time is only an ideal time. The cycle time is a rate at which operation is producing the unit. Lead time is a measurement that describes how long one unit flows through operation, front to end. It starts when the unit enters the process, following it during the whole procedure and stops when it leaves the last step. Once when the takt time is determined, it is compared to the man, machine, and setup time. The comparison of the takt and the man time results in automation of the process (machines and equipment are monitored only when something went wrong) and work improvements – the entire procedure is tracked, wastes are identified and eliminated, and if it is possible operations are reduced or combined. When machine time is compared to takt time, it is possible to find out is any fixed cycle time in a process exceeds the takt time. The setup time is the time that shows how long does it take to change from one process to another, and which steps need to be taken to make changeover successful. The steps can be split into external and internal steps, where the focus is given on changing internal steps into the external because external step does not require stopping the process. [Lit. 38]

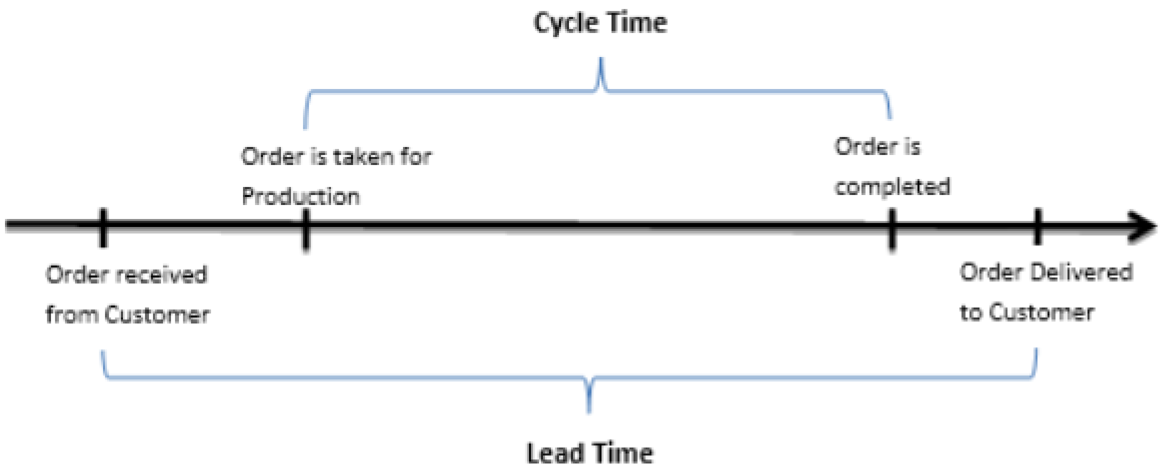


Figure 2-10: Difference between Cycle and Lead time [Lit.39]

2.6.5 5S

5S is a contemporary method of improvement of the business processes, developed in Japan, and it is based on an efficient and effective organization of the workplace, using five steps:

1) sorting (jap. sieri) – elimination of unnecessary tools, parts and material;
2) setting in order (jap. seiton) – everything should be in its place, and everything should have its place;
3) systematic cleaning (jap. seiso) – workplace should be clean, as well as the work suit and gear, and everything should be put back in its place;
4) standardizing (jap. seiketsu) – work activities should be consistent and standardized;
5) self-discipline (jap. shitsuke) – maintaining and revision of standards. The goal of the 5S method is to increase the productivity of workers, to improve the quality, health and safety.

2.6.6 Value stream mapping

Value stream mapping (later VSM) is a tool, which used to visualize material and information flows, which appear when a product goes through the value stream. The path of the product manufacture from buyer to supplier is followed, and a visual presentation of every process in the material and information streams is being drawn carefully. Then, it is necessary to ask specific questions and, with their help, to draw a new map of conditions, which shows how the new material and information streams would look like. Value stream mapping:

- Helps to see the sources of loss in value streams
- Visualizes the process in the manufacture
- Shows the bond between material and information streams

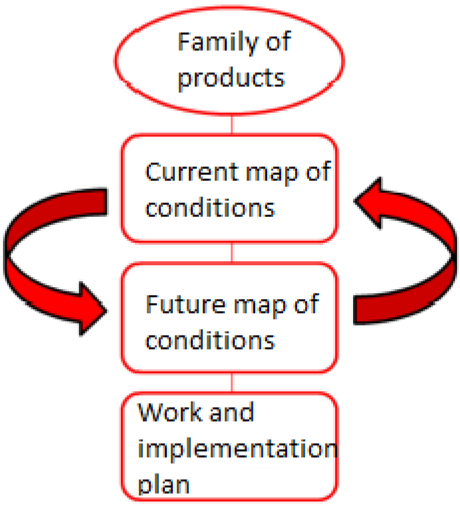


Figure 2-11: The steps of value stream mapping

The first step is choosing the family of products, i.e., the group of products, which goes through similar processes in the stream of its manufacture. VSM follows the steps shown in Table 1. from which is noticeable that the arrows between the current and the future map go in both directions, which means that the current and the future maps of conditions of mixed activity are created. The final step is the making of a plan of how everything that is suggested in the future map will be applied to the process in reality. To achieve the constant perfecting of the procedure and to ensure competitiveness, it is necessary to constantly repeat the procedure of making the future map after application of improvements from the previous map [Lit. 40].
When it comes to map creation, the symbols, which mark the parts of the process, are used.

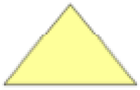
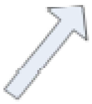
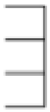
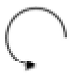
 Supplies	• Presents a warehouse of incoming material or final products, as well as the work in process (WIP)
 Shipments	• Presents a raw material stream from a supplier to a factory, or a final product stream from a factory to a buyer
 Truck	• Shipments from a supplier or to a buyer with the help of a truck
 Supermarket	• A controlled type of warehouse between the processes/operations • Low amount of supplies connected with the Kanban cards – pulling and replenishing of the supplies only when needed • Reduces the supplies and prevents excessive manufacture
 Pulling	• The symbol of pulling the materials between supermarkets and downstream processes in the value chain
 Pushing	• Presents pushing of the material from one operation to another • Pushing of material means that the previous operation in the value chain produces, regardless of whether the following operation requires it or not

Table 1: Some of the VSM symbols [Lit. 41]

2.7 Lean concept

2.7.1 Lean management

Lean is a process of managing, which is based on constant improvement. It is focused on identifying and removing so-called waste. By that, what this waste stands for are the activities that don't have any value, from customer's point of view, and are involved into the supply chain, such as fallout products, unnecessary steps of manufacturing, unnecessary movement of goods and men, waiting on material, supplies and similar. In business, lean doesn't present abandonment of something, but it can be considered a healthy way of business, which gives "energy and vitality" in conditions of a competitive, unstable, and challenging environment in which a company acts on the market [Lit. 42].

Lean is the term for rational, which primarily refers to the rational business of enterprises, on which lean management applies with the help of lean tools. To achieve its goals, lean applies through a longer period with persistent usage of lean tools. For the rational activities to achieve their maximum, the organization, on which lean management is applied, has to be completely directed towards the buyers and align all activities, which do not bring value to users. Lean management sets out from natural resources, and by that, there is a tendency of trying to avoid unnecessary elements in the production chain. It is an approach based on achieving as many results as possible, by using as little resources as possible.

Lean management is a business strategy on an enterprise level, which is based on satisfying buyers' needs and expectations by delivering quality service wherever it is the buyer wants it to be, with a reasonable price with minimal consumption of materials, equipment, space, work and time. For lean management to be fully implemented, it is necessary to include everyone who participates in a value-adding process within the enterprise, in the implementation, as well as suppliers and buyers. By applying lean management, the enterprise achieves high-quality services, lower expenses, more efficient usage of the enterprise's resources, and complete processes. The main goal of this quality managing strategy is a fast flow of a unit (materials, raw materials, client, information, and similar) through the process along with the elimination of all possible dissipations and losses (delays, jams, poor quality service and similar) [Lit. 43].

Alukal (2006) defines Lean as a production or management philosophy, which enables a decrease of the period between the buyer's order and delivery of the product or service by the elimination of all forms of waste or losses from the process. Lean management helps the companies in reducing the expenses, reducing the duration of a production cycle, and in the elimination of activities, which do not contribute to the creatine of added value. The companies, which apply the Lean concept, are efficient, flexible, and they understand the users' needs, which results in their competitiveness on the market [Lit. 44].

Lean management emphasizes the importance of defining and eliminating activities that do not create an added value. Processes become faster and cheaper. This is why this strategy is called Lean, and there is a desire to emphasize the importance of elimination of all unnecessary activities, so only the most important processes for the company are left. Lean is, among other things, based on principles that determine the value from the users' perspective, determine the consistent creation of the value flow, and on the *pull* production system as well as on the continuous progress [Lit. 45].

Lean management and manufacture are also called Lean thinking. Lean management is directed towards the identification and removal of waste from the process and the production of high-quality products with minimal expenses in given deadlines. After the precise definition of value and mandatory resources, everything else which isn't included presents the elements which don't create added value for the process, product or buyer and are considered excess or waste. The things that are called an excess or waste are usually activities in processes, which don't contribute to the creation of added value [Lit. 46].

Added value is defined with the service provider, and it needs to be accepted and approved by the buyer. In every process, there are three types of activity [Lit. 43]:

- *Activities that add value (VAT)* – the buyer is ready to pay for it, and those are the activities that present a direct work when operating the service, and they need to be done flawlessly.
- *Activities that don't add value* – they present a necessary loss, but they can't be eliminated from the process, although they don't create value (existing technology, business policy, work preparation, meeting the regulations and similar). These activities don't participate directly in

creating the buyers' satisfaction, but the producer considers that they should exist.

- *Activities that don't add value* – present a pure loss, and the buyer is not ready to pay for them (waiting, supplies, modifications, and similar).

The activity type share in a typical business process, which doesn't apply Lean or some other process upgrading strategy is shown in Figure 2-4.

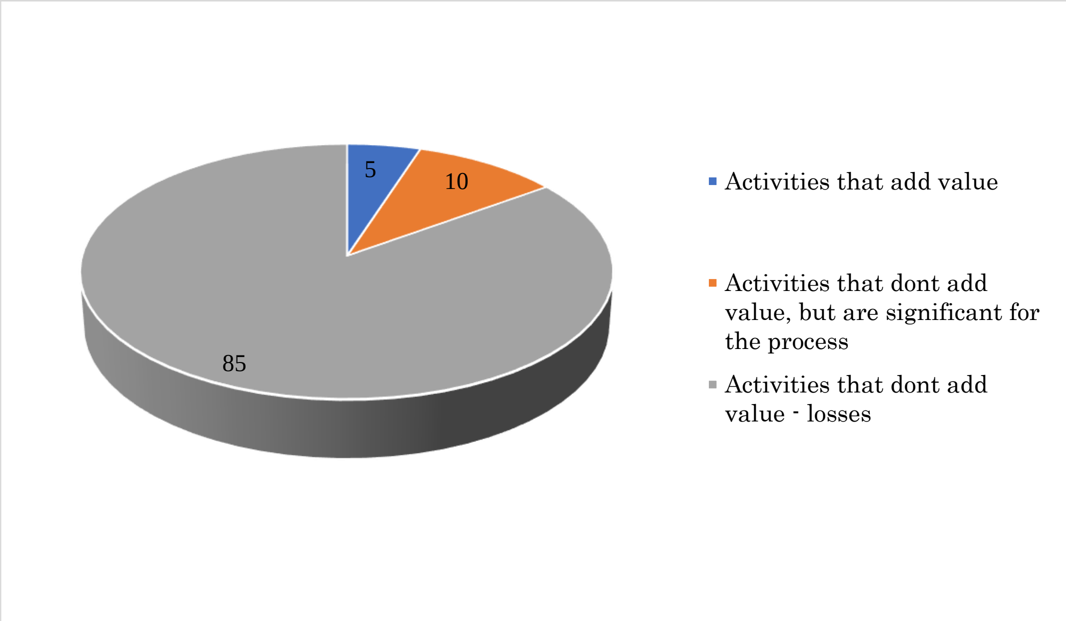


Figure 2-12: Typical business process

As the end goal is decreasing the lead time between order and delivery, the speed is considered a key in Lean management, but there is also a question about the amount of speed expected in the duration of the cycle after the losses in the process are detected and eliminated. The answer is gained by a comparison of the value-added time (a period which the user recognizes as necessary for the creation of a product or service) and the total amount of time necessary for completing the process from the start to the end, and it can be calculated via the following formula:

The efficiency of a process cycle = the amount of time spent on creating added value/Total duration of the cycle (lead time)

The lean process is considered a process in which the time spent into creating added values goes over 25% of the total time spent in that process [Lit. 47]. The speed in Lean process enables a large variability of products, small series, a small number of supplies, flexible manufacture, and high quality [Lit. 48].

The philosophy of Lean management is based on the manufacturing system of small series, i.e., the course of one piece. The term *pull* is used to indicate that nothing is produced before the voice of the users is examined or before the demand for a certain product or service is achieved. *Make-to-order* (MTO) is another term used in the context of Lean thinking, and it means custom manufacture, whenever possible [Lit. 49].

The experiences of the application of Lean management showed the following results [Lit. 43]:

1. 20-50% increase in work productivity,
2. 30-40% increase in equipment capacity availability,
3. 80-90% decrease in time necessary for product delivery,
4. 40-50% decrease in waste expenses,
5. 50-90% decrease in supplies,
6. 30-40% decrease in needed space.

These results are achieved because the employees do only those activities which contribute to the creation of added value with the removal of all possible dissipations and losses. Also, there is an important part of the process of Lean transformation, and they gain higher authorities in the processes and participate in creating their solution. In Lean processes, there are small series, and it is relatively easy to discover irregularities and mistakes in that way.
For Lean philosophy to be fully implemented into an organization, Lean management rests on the following principles [Lit. 50]:

- In a manufacturing sphere, Lean management should decrease the resource engagement, by which the product range should stay the same, which doubles the productivity.
- In the organizational sphere, there is such an organizational structure that should be established, which will be "shallow" with short communication channels, short decision-making processes, and which will be orientated towards the associates and the production process.
- In the management sphere, managerial functions are shifted into operative areas, emphasizing teamwork, and development of the cooperative relations within teams.

With the consistent application of Lean principle, the shortening of the production cycle and the decrease of capital binding are achieved, but one of the main innovations of Lean is that it enables the employees for problem solving.

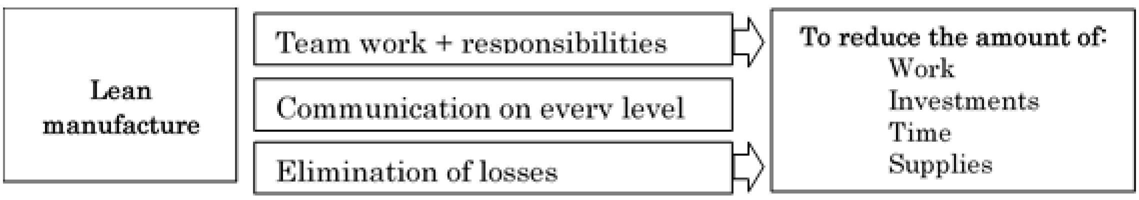


Figure 2-13: Features of "Lean"

The term "Lean" is first applied in a book "The machine that changed the world" by J.P. Womack and D.T. Jones, within MIT *International Motor Vehicle Program*, where the authors described the differences between the Japanese and the western car industry and used the term "Lean" for Toyota's way of production, both for the first time [Lit. 51].

2.7.2 The history of Lean concept

The first person to spot the losses in the work mode was Frank Gilbreth, by studying the work of bricklayers. Henry Ford continued the development by focusing on the losses during the development of the assembly system for mass production. It is considered that he set the key grounds and principles of the "Lean" system in 1913. He managed to achieve the first real "mobile production," i.e., the integration of business processes. The parts, standard work, and assembly line are the three elements that made the mobile production. The mobile assembly (production) line presented a turning point in the production way, which he created at that time [Lit. 52].
Henry Ford managed to divide the production process into steps and then align those steps into manufacturing lines. He uses special-purpose machinery wherever possible, with the goal being a faster production and assembly of the correct parts in only a couple of minutes. Also, he uses control devices, which do not allow the passage of defect products onto the next step of the process. It was a revolutionary step in the manufacture, compared to classic workshops. Classic workshops consisted of general-purpose machinery, grouped by the type of processing, and they produced great amounts of equivalent parts, which then waited in the storage, for the production of other components, so they could finally be assembled into a final product. That kind of production resulted in a significant number of defected final products and with the overload of unfinished manufacture. "Henry Ford company's warehouses were emptied every few days, so he didn't have any problems when it comes to inventory turnover and the production flow. The impossibility of providing diversity and variability of the produced cars, depending on market demands, was the main problem of such a way of production, so Ford started to fall behind the competitors for that reason.
Beginner and early forms of Lean production originate from Toyota Production System, a production philosophy, whose pioneers are Japanese engineers Taiichi Ohno and Shigeo Shingo from the early 60s of the past century. After having analyzed the situation in Ford, they saw that it is possible to ensure continuity and fast flow of production and simultaneously provide the market with diversity and variability of products with the series of small and simple innovations in the production process" [Lit. 53] formulation of TPS is based on three key principles: "do it quickly," i.e., the importance of speed in doing critical tasks: non-stop activity flow exemplified by an assembly line from the car industry and on the *pull* concept, which grew based on Taiichi Ohno's supermarket work studies [Lit. 54].
Also, the term "Lean" production comes from the United States as well, i.e., it is a result of the analysis conducted on the Massachusetts Institute of Technology, which is executed for the American car industry to find the key to success of the Japanese manufacturers. For many years, Lean manufacture presented a typical form of Japanese production, with all specifications of that area, and it was thought that it refers to the mass production and exclusively production processes. But such thinking soon turned out to be wrong. Lean also referred to shaping, development, and other processes.
The methodology is based on the idea that every industrial process consists of "useful" and "needless" activities, that it should be directed towards the elimination of "needless" activities and that it needs to enable uninterrupted flow

of processes and dedicate a significant amount of attention to buyers' demands. It is a success to achieve a production system in which all the "unnecessary" activities, which don't add value to the outcome of a certain production process, are eliminated. The methodology is conceptualized in a way where it is used for planning and managing in stages, necessary for the realization of defined goals of a business system [Lit. 50].

The experts from Toyota, inspired by thoughts that it is possible to ensure continuity and fast flow of manufacture and simultaneously provide market diversity and variability of products, they adjusted and revised Ford's original concept of manufacture to their own needs and the market's needs. Transfer of the focus of activity of production engineers from individual machines and their use, as well as individual processes, to a wholesome process of production and the flow of products through said production was one of the basic characteristics of that production system. In Toyota, there was a conclusion that, with the help of a few simple solutions in production, they would be able to ensure a very short time period from the order to delivery, with the goal is a fast and quality reaction to unstable, i.e., variable market demands, low product expenses, high variability of the product and high quality of the product.

Some of the solutions in production are: achieving short preparatory-final times to enable the manufacture of small amounts, i.e. series of different parts or products, precise formation of machine schedule and productive equipment according to productive steps in production process (technological processes), with the goal of ensuring the continuity of production processes, implementation of the "pull" production systems, which means that every step of the production process informs the previous step about the current need for materials or parts, formation of machines and equipment, i.e. their adjustment to the volume of necessary production, implementation of machines and productive equipment, which contains devices and sensors for self-control (Andon systems, i.e. devices with visual warnings about irregularities in the process) with the goal of ensuring the production without fallout.

With this way of production, there is no unnecessary piling up of the material or parts, i.e., only a required amount of components is produced for every following step of the production process. In the Japanese automotive industry, which dominates the world car market, the strength of the "Lean" enterprise management system is proven. "Lean" philosophy is spreading across the globe and is coming to almost every country. The managers and the owners of companies are perfecting the techniques of lean management, which are starting to be applied even outside the same production, so in project leading, maintaining, logistics, distribution, service companies, healthcare, and even bureaucracy [Lit. 55].

At the beginning of the 1980s, the Japanese car industry, led by Toyota, took over the power in the car industry and completely won the American car industry on a global, but also the American market. On this occasion, a group of scientists from MIT started to examine the work of Toyota and are achieving better results. They spotted that in Toyota, they achieve the desired amount of production capacity and quality with fewer investments, that the production process is done with fewer mistakes, that it takes less amount of time for key production processes, that they have fewer providers and don't have a lot of supply stocks (JiT). The leader of this team, Jim Womack, Ph. D., described such a way of business as “Lean.” Jim Womack and Dan Jones later became the founders of the Lean Enterprise Institute and the academy, which is the global carrier of Lean thinking. So, it can be concluded that Lean is not entirely a Japanese privilege [Lit. 48].

Toyota is a global example of a manufacturer that produces high-quality products, i.e., high-speed vehicles, and it got through to a leading position in its production sector (it got ahead of GM when it came to market in 2007). The lean concept got developed the most by the mutual investment of Toyota and its biggest rival, GM, into the research about the implementation of Lean concept into European and North American companies. Namely, Toyota was never hiding the bases and the principles, which were the reason for its business success. This is visible from two examples, which show how Toyota didn’t try to hide its production system, but it tried to share it with others and expand it. The first example is the founding of the New United Motor Manufacturing Inc (NUMMI) program in 1982. when the presidents of the Toyota company were Shichiro Toyoda and Eiji Toyoda. NUMMI program was made to transfer and teach the “Toyota Way” to General Motors, by which Toyota shared its famous production system with its main rival.

The other event happened more recently, and it refers to the creation of Toyota Supplier Support Center (TSSC) in 1992, which was founded to teach and transfer knowledge and experience in Toyota’s possession to American production enterprises, through the establishment of work models in the industrial facilities of those enterprises. Mutual researches and investments of Toyota and GM had shown that the Lean concept could be implemented into all organizations, regardless of their activities and the culture they function in [Lit. 56].

2.7.3 The foundations of Lean philosophy

There are two basic concepts in the background of Lean philosophy – value and waste (jap. Muda). Value is considered what the buyer is ready to pay for, while waste is every activity in the process, which doesn’t add value for the buyer (Thetoyotasystem.com). The Lean philosophy requires a faster process operation through the elimination of waste/losses, so all the process activities could create value. Constant efforts focused on waste reduction and the tendency to continuous improvement are called *Kaizen* [Lit. 49]. Lean philosophy is based on waste elimination, continuous improvement, variety reduction, and Zero Quality Control access.

Identification of waste and losses

Lean management is directed towards the identification and elimination of waste from the process. According to Taiichi Ohno, there are eight groups of loss appearance, towards whose elimination one must be directed [Lit. 46]:

1. Hyperproduction – the production greater than customer demand, which demands more storage space and l raw material consumption. Hyperproduction is caused by the *push* system of production, which is contrary to Lean’s *pull* principle, i.e., production according to the buyer’s desire;
2. Jam – the expense caused by waiting for the material, information, equipment, tools, etc., while contrary to that, Lean philosophy advocates JIT, i.e., “timely” system;

3. Transport – material should be delivered to a place where it is used so that it wouldn't demand any extra workforce, storage or cycle duration time prolonging expenses;
4. Processing without added value – when the process is full of unproductive steps like reprocessing (the product or the service should have been realized the right way the first time), removing the "excess" (the products should be manufactured without "excess", with adequately designed and maintained tools), and control (the products should be manufactured with the use of techniques of statistical process control, to minimize or remove the needed control). Lean value flow mapping technique helps with identifying the activities which don't participate in added value creation;
5. Increased supplies – are related to hyperproduction and impact negatively on the financial flow of the company;
6. Flaws/mistakes/Processing – downsides of manufacture and mistakes in services needlessly spend human resources and material;
7. Too much movement – additional and unnecessary activities are caused by bad flows. To eliminate this defect, the value flow mapping is used;
8. Underutilization of human potentials – refers to the underutilization of mental, creative and physical skills and possibilities;

Kaizen or continuous improvement

Kaizen is a combination of two Japanese words (*kai*+*zen*), which means, in literal translation, "change for the better," although it is translated into English as "continuous improvements." The term *kaizen* presupposes a continuous improvement, which involves all the employees in a company. The basic value system of the kaizen approach is integrated into the core of the Lean concept [Lit. 44]. According to kaizen, an old saying "if something is not broken, it doesn't even need to be fixed" is transformed into a saying because something is broken, it doesn't also mean that it can't be improved. The elements of the kaizen approach include the focus on customers, teamwork, Just-in-time, quality circles, the cooperation between management and workers, and maintaining the total productivity [Lit. 57]. The conceptual base of continuous improvement for taking action in that direction is in the "plan-do-check-act" cycle, which is also called the Stewart circle according to the inventor or the Deming circle, according to the man who affirmed it in the application. The Deming circle provides a systematic approach for the implementation of continuous improvement. The elements of Lean, which make up the core of its concept, significantly overlap with the elements of kaizen, and they are [Lit. 44]:

- Creativity over the capital. Instead of more significant investments into the company's property, the framework of Lean philosophy consists of team brainstorming and finding the solution to detected problems. The employees responsible for a certain process are called to share their own experiences, skills, and knowledge, to generate an action plan, by which the waste is removed, and the process itself is improved.
- Not so perfect solutions, implemented today, are better than late perfect solutions. *Just do it now* is the basic idea of this Lean element.
- The supplies don't present property, but the expense, i.e., waste.
- The PDCA methodology is used to implement improvements.
- Once started, Lean management becomes a never-ending journey.

Lean philosophy in practice is implemented through two types of teams, work teams are in charge for everyday task completion through regulated activities, while the other type, the kaizen teams, are also called the process improvement teams. Kaizen teams are formed because of the special kaizen event, and after it is finished, the teams fall apart to be assigned with new kaizen tasks. Both types of teams are characterized by versatility of their members, but they are different when it comes to the members of working teams, who cooperate in "work cells", which consist of experts for a certain area (Engineers, managers, operators, etc.), while the members of the kaizen team are specially trained for the application of lean and kaizen techniques.

Variability reduction

The next element of Lean management is demand, production, and provider related variability reduction. Production variability refers to not only the variability in characteristics but also on the variations in the duration of the task completion. Lean management tries to reduce detected variations by defining standardized work procedures. The provider related variability means inequality in time delivery or delivered quality. For that type of variation to come to a minimum, the establishment of a partner relationship with the providers needs to be achieved [Lit. 49].

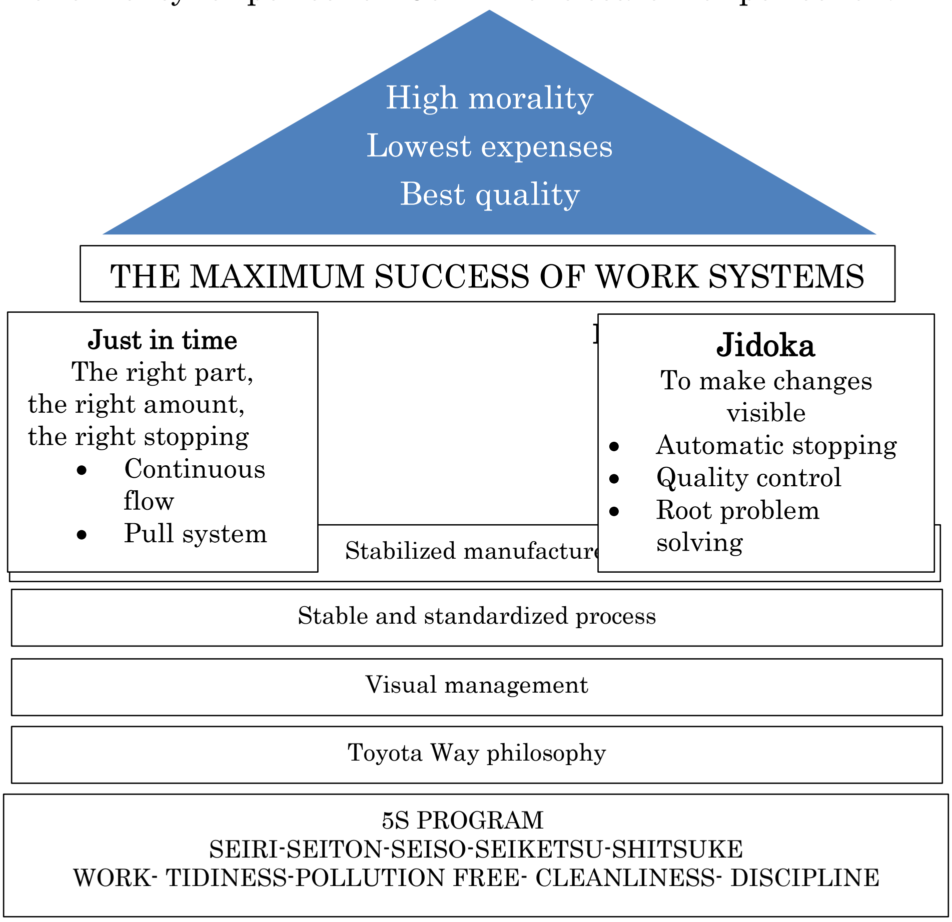
„Zero Quality Control“ (ZQC)

„Zero Quality Control“ concept is implemented through the Lean technique – Poka Yoke, but it is necessary to mention ZQC in the context of philosophy because it presents a framework of Lean. ZQC presents the philosophy of removing the mistakes from the process when they are spotted. This approach enables the establishment of surveillance over the process in a way that the mistakes in the other parts of the process are prevented with the help of surveillance spots, and there is a desire to prevent the mistake made the first time [Lit. 49]. So, ZQC enables achieving the perfection the Lean organizations strive to achieve. Lean philosophy or way of thinking is based on the continuous process improvement to detect and eliminate unnecessary activities, reduce the time necessary for product or service delivery, and by that to increase the customers' satisfaction with the expense efficiency for the company. For the Lean philosophy to live, the engagement of all employed is necessary. Lean philosophy of continuous improvement and waste removal is based on principles and techniques of Lean management, which help to implement philosophy in business.

2.8 Lean principles

Lean principles are based on the clients' recognized value ground, and as such, they can be applied in many productional and distributional situations. The application of techniques based on Lean principles enables expense reduction and ensures the dedication of rivals. Lean uses include process steps reduction, inventory turnover increase, capacity increase, faster operation of the cycle and customer satisfaction increase [Lit. 58]. Five basic principles of lean manufacture are recognized:

- Defining value. Only that, which the buyer sees as valuable, matters. Determining the product characteristics is done by the intern and extern buyers. The value is expressed by how the product satisfies customer needs at a certain price at a certain time. Specific product or service are evaluated based on characteristics which add value. Determining the value is based on the perception of the final user or the later process.
- Value stream. After identifying user value, the next step is the analysis of the business process to determine the activities, which contribute to the creation of added value. If the lack of contribution of an activity to the value creation for the buyer is recognized, it should be eliminated from the process.
- Standardization of production flow. When activities, which add values are identified, the next step is to ensure the uninterrupted activity flow through the system to the user. The main inhibitors of the flow are sequences, groups of products in processes, and transport. Such buffers slow down the delivery of a product or a service. Buffers also connect money as supplies, which could be used for other business purposes.
- Production pull. After the loss/waste is eliminated, and after the flow is established, further efforts are directed towards the establishment of pull systems, which enable the buyers the pulling off of a product or a service when they need it, not sooner nor later.
- The tendency for perfection Continuous search for perfection.



First principle "*Value*" or defining value

Defining value is considered a starting point of a successful Lean transformation. The value can be defined exclusively from the perspective of a client or a buyer, and it is one of the critical points of lean business. It is crucial to determine the value from the aspect of a buyer, i.e., it is of extreme importance to understand what does the buyer think of a service or a product he is offered. This implies that the value is connected to a certain product or service, which fulfills its basic function to satisfy the desires and needs of buyers and clients. Such defined value presents a base of successful manufacture and business. However, practice shows that the companies neglect the real desires of buyers, and produce and offer what suits them best on the market. This is about the final price of a product or a service, which the market could accept, which creates the dependence in which all the other processes are formed. This way of thinking is limiting, and it directly impacts product quality. Long-term speaking, such a situation results in the discontent of the buyers and facing rivalry products and services, which have more quality and are better adjusted to their desires and needs. During such product or service development, the production and business process should be formed in a way so it does not contain losses, and it is possible to achieve that by the precise formation and the definition of the value chain.

The second principle "*Value stream*" or added value stream

(Added) Value stream presents a group of all activities in an enterprise that directly or indirectly participate in the creation of an added value to a product or a service that is offered on the market. Every product or service of every enterprise can go through three basic groups of processes, which are:
Problem solving processes (which refer to the development of the concept project), construction, and design (projecting the technological process and similar), then the processes of informational management among which are the most important ones are order processing, production, business, and delivery organization and the processes of transformation of the raw materials or starting materials into final products. The precise definition of value streams is considered a crucial step in spotting and then removing losses in production.
From the aspect of adding value, the analysis of the business process point out the necessary activities which directly create value (processing and material formation processes, material protection, assembly, and heat treating), activities that are necessary for operation of the whole process, but do not create value directly (quality control, transport, storage, etc.), and the unnecessary activities, which don't add value, so they can be removed immediately.

The third principle "*Flow*" or the equality and continuity of production flow

The equality and continuity of the production flow refer to the reshaping of the remaining steps and associated activities, with the goal of an equable and uninterrupted production process flow. It can begin when the value of the service or the product, which wants to be ensured, is precisely defined and when the analysis of the value stream is done and when the unnecessary activities are removed from the process. This most frequently includes the reorganization of the whole production facility, i.e., people and production equipment. The most important thing is to be directed towards the object of the analysis, i.e., the product which goes through the process of adding value from the procuration of raw materials, through production, and in the end to the delivery to the buyers. The surveillance or the control over the product must not be lost at any moment, and the phase of the process in which the product is in and the reason for it being in that phase must be completely clear.

The fourth principle "Pull" or the pull of a production

The pull of production is one of the basic principles of lean production and business. The pull of production starts with the buyer by buying or ordering a certain amount of some product, which is important to emphasize. The value stream of every product is made by certain processes and acquired specific activities in an enterprise. Every step in the value stream transfers the information to the previous step in the process, that there is a need for a certain amount of material, parts, or products, after the buyer's demand, i.e., the need for the product is initiated. The information travels along the value stream and starts a process in which all the specific activities are operating (the ones that add value and the ones that don't, but are necessary for the whole process operation) necessary for gaining the final product from raw or starting materials, and for delivering it to the buyer, i.e. for changing it with the one that was bought. In this way, the need for planned manufacture is lost, and the unnecessary supply piling is prevented.

The fifth principle, "*Perfection.*"

"Perfection" presents continuous perfecting ("kaizen") of all processes and activities in the company or the enterprise. Continuous perfecting in the "Lean" system of management is a process, which must not stop because it ensures the advantage over rivals. Lean management system states that the "kaizen" workshops are being held continuously to perfect various processes in an enterprise, which points to the conclusion that there is always more space for subsequent improvement of current ways, i.e., work methods [Lit. 48].

By applying the lean concept, many advantages are achieved, with the expense reduction due to the decrease of investments into storage space, standing out the most. The total production time is shortened, the work effect and the machine utilization degree are increased, the engagement of unemployed is increased, the quality is increased, and the company becomes more flexible to the changes in market demands. Due to numerous advantages, Lean principles found their application in all types of production enterprises, regardless of their size or production type.

Service enterprises also apply these principles to increase their efficiency and business excellency [Lit. 48].

3 Maintenance workshop (RS-A)

This section has its purpose of giving a comprehensive overview of the workshop building, where every part concerning the material flow is described. Information is collected with process observation and interviews with white and blue-collar workers.

The first step of the MF analysis is the determination of the current situation. It is essential to get an overview of the actual state and procedures that are characteristics of the observed production system. Recognition of an existing state is essential for the determination of the pros and cons of the production system. One of the main factors that effects this analysis is data gathering. In the case of processing a large volume of data, it is necessary to compress and reduce them to avoid long data processing time and leading of investigation in an unwanted direction that results in questionable results. There are several ways to gather data like the observation of the process, review of technical documents, and talking and interviewing employees. In this analysis, data is gathered by a combination of the mentioned methods

There are four (4) maintenance workshops operated by Primetals Technologies in Tangshan, China. They are named after their location: Headquarter 12 (HQ12), Headquarter 34 (HQ34), Stainless Steel (SS), and Plate Mill (PM). Each of those provides maintenance services for continuous casters. With the start of lean implementation, to decrease costs, improve the quality of the work, better control, and overall customer satisfaction decision is made that all roller workshops should be moved to one roller workshop – HQ12. PTTS is facing now with a big challenge: From October 2018, HQ34 roller workshop, which was next to the workshop for HQ12, was moved to this workshop. Currently, from the beginning of this year, 2019, SS workshop was joined to this workshop. Each plant requires different roller types. They differ in type, size, weight, number of parts, and order quantity (Shown in Table 2). Currently, orders are not completed as they are planned, and there is a problem with huge inventory increase.

Table 2: Product types

#	CUSTOMER	SEGMENT TYPE	ROLLER UNIT	ROLLER Ø
2	HQ3	Bender	Idle	120-130
3	HQ3	Bow segment	Idle	130
4	HQ3	Bow segment	Driven	140
5	HQ3	Straightener segment	Idle	165
6	HQ3	Horizontal segment	Driven	175
7	HQ1	Bender	Idle	150
8	HQ2	Bender	Driven	150
9	HQ1	Bow segment	Idle	200
10	HQ1	Bow segment	Idle	200
11	HQ2	Bow segment	Driven	200
12	HQ2	Bow segment	Idle	200
13	HQ1	Bow segment	Driven	230
14	HQ1	Bow segment	Idle	230
15	HQ2	Bow segment	Driven	230
16	HQ2	Bow segment	Idle	230
17	HQ1	Straightener segment	Idle	250
18	HQ1	Straightener segment	Idle	250
19	HQ2	Horizontal segment	Idle	250
20	HQ2	Horizontal segment	Driven	250
21	SS1	Bender	Idle	150
22	SS1	Row segment	Idle	230
23	SS1	Row segment	Driven	250
24	SS1	Straightener segment	Idle	300
25	SS1	Straightener segment	Driven	300
26	SS2	Bender	Idle	150
27	SS2	Bow segment	Idle	230
28	SS2	Bow segment	Driven	250
29	SS2	Straightener segment	Idle	300
30	SS2	Straightener segment	Driven	300
31	SS3	Horizontal segment	Idle	300
32	SS3	Horizontal segment	Driven	300

3.1 Maintenance workshop area - Layout

The visualization of the micro-locations of the production system in different process areas are shown in Figure 3-1. The workshop is divided into the following areas:

1. Assembly line
    a. Preassembly
    b. Final assembly

2. Disassembly line

3. Storage area
    a. Storage area 1 (assembled roller units)
    b. Storage area 2 (parts waiting to be assembled)

Other areas that are part of workshop functions but are located in different locations are:

1. Segment workshop that is being used for the cleaning process. The cleaning process that is part of the disassembly process is partly performed in the RS-A facility and partly in the segment workshop.

2. The workshop has a warehouse with additional storage areas around the assembly and disassembly area and their workstations. The warehouse is supplied by the central warehouse, called "temporary warehouse," which is located a few minutes driving from RS-A. Another warehouse area, located outside the RS-A on the west side, is known as the "west warehouse," where roller units that need to disassembled are stored and waiting to be delivered to the workshop.

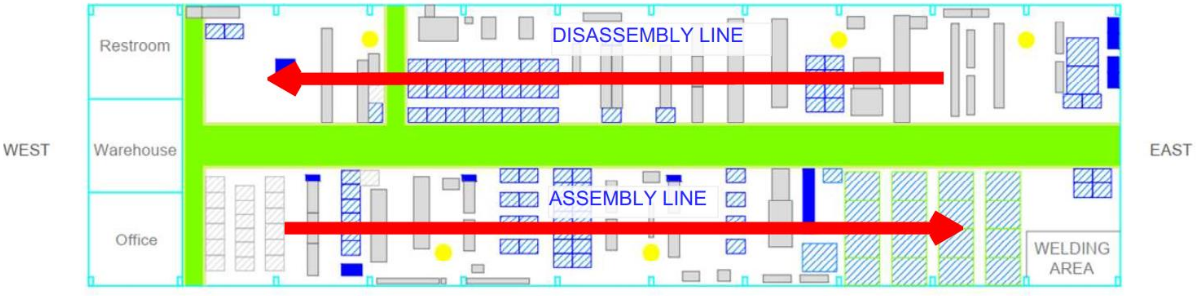


Figure 3-1: Layout

3.1.1 Assembly line

- ASSEMBLY STATION 1 – PREASSEMBLY

The pre-assembly step is related to the assembly of the bearing block. Depending on the type of the roller following parts must be prepared: bearing block, bearing, sealing ring, laminar ring, and ring. There are three workplaces at this workstation with one worker at each workplace, where all of them are working independently from each other. Sometimes, when the order requires a large quantity of the bearing blocks, some of them are preassembled on the opposite side of the facility, at station D8 (next to the roller jackets preparation workstation).

- ASSEMBLY WORKSTATION 2, 3, 4 – FINAL ASSEMBLY

There are four final assembly stations through the assembly line – A2, A3, A4, and A5 (see Figure 3-2). The workstation A2 is equipment with a working table, pneumatic machine, and standing JiB crane that is shared with workstation A3. This workstation is used for assembly or roller units for SS, diameter (Ø) 300. The roller units are assembled unit by unit, and the total demand of A2 workstation is fifty-six (56) roller units per month. The following workstation is A3, with total demand of 110 roller units per month. The roller units are assembled in a series of four. The workstation is equipped with a shared JiB crane, tool closet, induction heater, shelf with small parts, and equipment for grease filling and water test. The workstation A4 is reserved for assembly of HQ34 roller units, which are assembled in a series of four. The workstation is equipped with tools and water test/grease filling tables. There is one JiB crane between A4 and A5 that is shared between those two stations. The monthly demand for the A4 workstation is 116 roller units. The last final assembly station is workstation A5, reserved for HQ12 bender roller units only, where monthly demand is 128 roller units. At this workstation, preassembly is performed in the same area as the final assembly. It is equipment with the heating machine, and it has storage of related parts around the workstation.

Table 3: Assembly stations and items

#	WORKSTATION	ROLLER UNITS ASSEMBLED
1	A2	SS roller units Ø300
2	A3	SS2 idle roller units Ø230, Ø300 HQ12 idle roller units Ø200, Ø230, Ø250
3	A4	HQ34 roller units
4	A5	HQ12 bender rollers

- TESTING - A5

After assembly, each bearing block needs to pass a water test to make sure there is no leakage. Workstation A3 has equipment for testing, and rollers from workstation A4 need to be transported to the next station, A5, where the test is performed on the testing table. After passing the water test, bearing blocks need to be filled with grease. Last thing that needs to be checked before packaging is a roll-out test. Quality inspector checks roll out at three positions – on both edges and in the middle.

- QUALITY CHECK

The quality check should be done at the following stages:

1. Inspection of roller jackets on receiving
2. Measuring parts dimensions directly at the final assembly stations
3. Roll out at the testing workstations – A6
4. Testing (Water and grease test) by using testing equipment at the final assembly workstations.

If the roller fulfills criteria, it is ready for storage, where is awaiting shipment to the customer.

PACKAGING

If assembled roller fulfills all dimensions and quality criteria, it is ready for delivery to the customer. To secure the roller surface and protect edges, each qualified roller needs to be packed in the right way. Workers are using an overhead crane for roller lifting, and then they protect the roller with a transparent plastic foil.

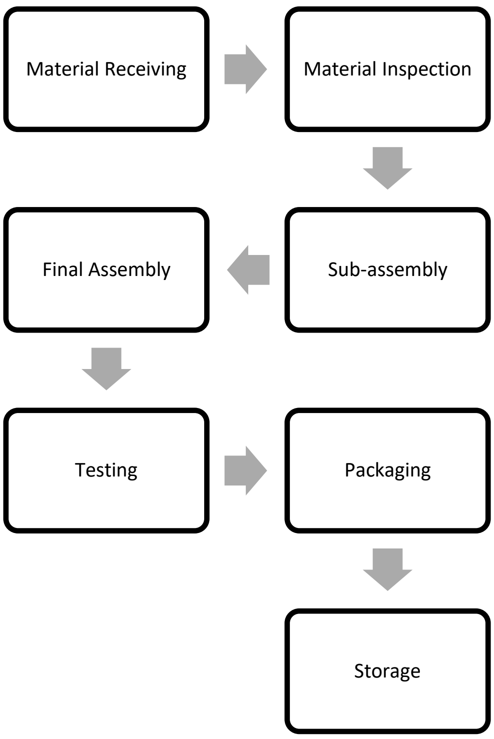


Figure 3-2: General assembly process

3.1.2 Disassembly line

The general disassembly process is shown in Figure 3-4, and it is described through the following steps:

- INPUT OF GOODS

The rollers are transported from the customers by the truck in the batches or without them, depending on the roller size. For the truck, unloading workers are using the overhead crane. One worker stays at the truck and secures the position of the crane and put chains at the pallet (in case that rollers are delivered in the pallet) or around the roller (in case of unloading of each roller separately). Another two workers secure a position in the storage, and one controls and manage the crane. After all batches with a certain number of rollers inside or rollers that are unloaded separately are transported from the truck in the storage, the truck is leaving, and the disassembly process can start. Depending on the available space, input of roller units can be stored in the west warehouse from where they are delivered to the workstation with the forklift.

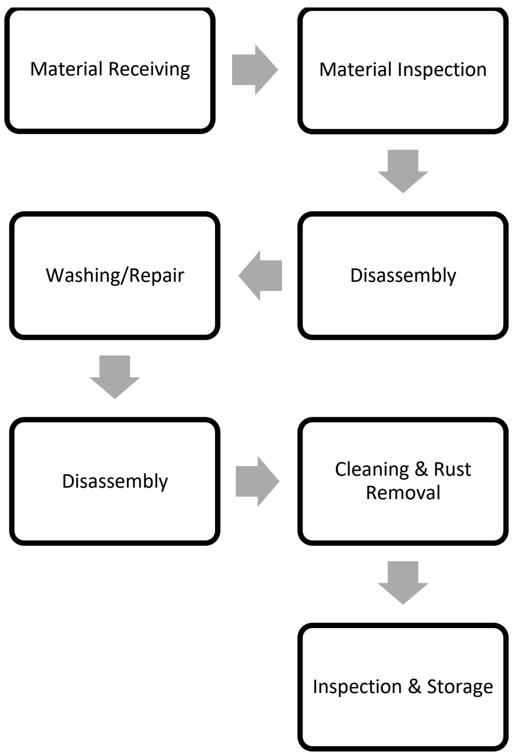


Figure 3-3: General disassembly process

- DISASSEMBLY STATION D1 – D6

First, it is necessary to move the roller from the storage to the workstation. The process of disassembly starts with bringing roller units to the workstation. First of all, it is necessary to remove bearing blocks, which are moved to the next table or area around the workstation, where they are disassembled separately. During disassembly of the roller and bearing block, parts are immediately divided into two categories: cleaning and scrap. The pieces that are classified as scrap (standard parts) are put away into the scrap box, and parts that need to be clean are sorted into the batches or on the trolleys. Scrap box stays at the current place until it is full, and batches and trolleys with dirty parts are transported outside the workshop, to the cleaning station at the segment workshop that is located in the next building. Shafts are excluded from high-pressure cleaning, so they are transported and cleaned manually at station D8 or D2. Each disassembly station, except D5, is equipment with pneumatic machines that are used for easier disassemble of roller units.

Furthermore, there are three standing JiB cranes at disassembly stations. The first one is shared between D1 and D2, and the second one is shared between D3 and D4, and the third is used at D5 and D6 workstations. The first disassembly station, D1, is used for bender roller unit disassembly only. Currently, the D2 workstation is used for shafts cleaning, and it is equipped with two pneumatic machines for different roller units dimension. At the second disassembly station, D3, SS idle and driven rollers diameter Ø300, are going through the disassembly process. D4 area is used for disassembly and assembly of SS2 Ø230,300 and HQ12 Ø200,300,250 idle rollers and their bearing blocks. Rollers from HQ34 and their bearing blocks are disassembled at station D5.

Table 4: Disassembly stations and items

#	WORKSTATION	ROLLER UNITS
1	D1	HQ12 bender roller units
2	D3	SS roller units Ø300
3	D4	SS2 driven roller units Ø230, Ø300 HQ12 driven roller units Ø200, Ø230, Ø250 Assembled and disassembled
4	D5	SS2 idle roller units Ø230, Ø300 HQ12 idle roller units Ø200, Ø230, Ø250
5	D6	HQ34 roller units

- D4 – CLEANING AREA

The parts that require cleaning are transported to the segment workshop for high-pressure cleaning. High-pressure cleaning is performed at the segment workshop two days per week, defined by segment workshop manager. Once the parts are finished with high-pressure cleaning, they are returned to the roller workshop, and they are ready for ultrasonic cleaning, rust removing, and neutralization (D4). Again, the employee uses a small crane to lift the batch and transport it to the machine, and later from machine to machine. After the washing process is completed, parts are transported to the inspection station, where it is necessary to inspect and test all parts (D8, D9).

- D5 – INSPECTION AREA

Before storage, cleaned parts need to be qualified by categories: storage, scrap, or refurbishment. Different parts have different quality control (see Table 2). Dimension measure, hardness, gap measure, and run-out test are performed using inspection devices. The water test, shown in Figure 3-4, is performed on the inspection machine that is constructed specially for the inspection of bearing blocks. First of all, bearing blocks are mounted and sealed on the testing machine. Then, employees release water under pressure, and bearing blocks are filled with water.

The water is kept inside approximately 15 minutes. If the leakage is detected at any time during the test, the bearing block will be classified as a damaged one, and it will be marked with red color and send to refurbishment or scrap (depending on defect type). Qualified bearing blocks are marked with green color, and they are ready for final storage.

Table 5: Different quality control test for different parts

PART	QUALITY CONTROL					
	VISUAL CON-TROL	DIMEN-SIONS MEASURE	HARD-NESS	GAP MEAS-URE	WATER TEST	RUN OUT
Small parts	×	×				
Roller jacket	×	×	×			×
Shaft	×	×				×
Bearing block	×	×			×	
Bearing	×			×		
Rotary joint	×				×	

Figure 3-4: Water test table for the bearing blocks

3.1.3 Warehouse

Currently, the roller workshop is supplied from a temporary warehouse, which is located a few blocks away from RS-A.
One day before or on the day of order execution, goods are delivered into the roller workshop. This warehouse is still in a setting phase. Parts from the previous workshops (maintenance workshops at HQ12/34, and SS) are moved to this temporary warehouse and parts are mixed. Sorting and labeling of the parts are in progress.
There are different storage areas across the workshop, shown in Figure 3-2.
The location of rollers that require maintenance is at the workshop entrance on the east side of the building, blue hatched area. The light blue area represents the storage area of assembled rollers that are ready for shipping. Also, this area contains some of the dirty rollers that are waiting for disassembly and cleaning. Orange area is a storage area of bender rollers, and the purple area includes roller jackets. The yellow area represents the storage of different bearing blocks, and the red one is the storage of bearings in different sizes that are needed for roller preassembly. Parts that are delivered from the temporary warehouse have their place across the green area. On the opposite side, inside the coral red area, washed pieces are waiting for inspection and testing (bearing block).

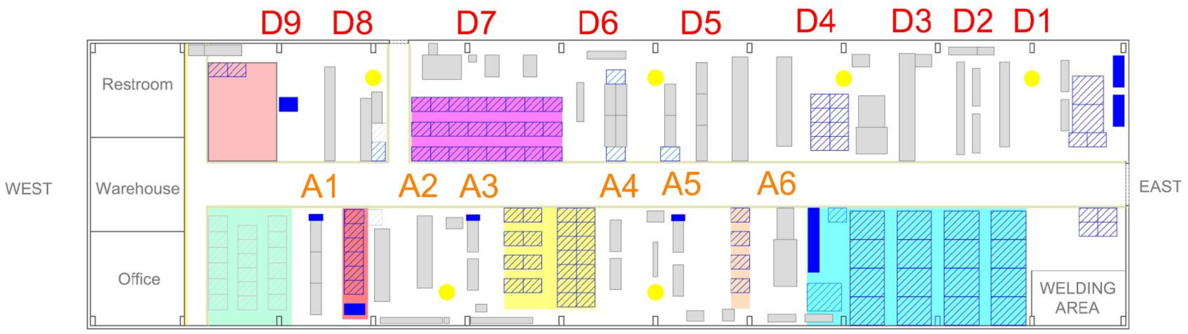


Figure 3-5: Storage areas in the workshop

3.2 Ordering process

Since the assembly and disassembly processes are separated, the ordering process is described for each type of order

- **Assembly process**

The roller workshop is receiving orders from the customers every 10th of the current month for the coming month. The workshop manager is ordering material/parts needed for next month's orders and then from 15th until the end of the month material is coming to the central warehouse. Depending on the customers that send the order request order can vary in the roller type, quantity, urgency. Regarding all these factor order execution time can vary too.

- **Disassembly process**

Since orders are coming the day before the execution, there is no exact plan for this process. Planning is based on assumption, and it is forecasted on previous experience. In the ideal case, each roller should be replaced every four months, but there are many factors that increase or decreases roller lifetime (intensity of the usage, position of the installation, etc). At the workshop, assembly orders are scheduled every day, but in opposite disassembly, orders aren't scheduled every day.Furthermore, there is no guarantee that each week's disassembly process will be performed on the same days or in the same quantity. This fact affects inventory increase. Since high-pressure cleaning is performed in another workshop schedule, days are assigned by segment workshop manager, and those days are not fixed – they can vary every week.

3.3 Type of containers and material handling equipment

Currently, several different pallets have different purposes at the observed roller workshop. They are used for material transport, storage, and handling. The pallets differ in type, dimension, and handling load (see Table 6).

Table 6: Pallet types

#	TYPE	DIMENSION	MAX. LOAD [kg]
1	Pallets for roller sets	2160×1700×735	10000
2	Pallets for roller jackets	1200×800×1300	2000
3	Pallets for other parts	1200×800×756	2000
4	Batch		

Cranes used in the workshop have different purposes, and they can handle the different loads (Table 7). There are two overhead cranes in the observed workshop. They are used for pallet and massive parts transport in case of significant distance, delivery (input and output), and transport from station to station. Depending on the type of transportation, an overhead crane is connected with belts, chains, or magnet.

The freestanding JIB cranes are located on the workstations, two of them are on assembly and four of them on disassembly line. They are shared between the workstations, and they are used for easier material handling.

The wall traveling JiB crane is located at the cleaning machines area, D7 (Figure 3-2), and it is used for pallet transportation from one cleaning machine to another two cleaning machines.

Other handling equipments are forklift, picker, and trolley. The forklift and picker are used for transportation of pallets and parts inside and outside the workshop. The trolley is used for transportation of the small, less heavier parts between the workstations. The forklift can handle maximum 5t, picker 2t, and trolley approximately 500 kg.

Table 7: Transportation and handling equipment

#	TYPE	PURPUSE	MAX. LOAD [kg]	PICTURE
1	Overhead crane	Transportation and handling of pallets and parts all over the workshop	5000	
2	Free-standing JiB crane	Material handling and transportation at the workstation A2-A4 and D1-D9	1500	
3	Wall travel-ing JiB crane	Batch transportation and handling at work-station D7	1000	

4 Process flow study

Demand and machine mapping analysis is done to identify two rollers which are taken into consideration for process flow study, observation, and analysis. Chosen roller units are HQ12 Ø150 Bender roller and SS1 Ø300 I – Star roller unit (See Appendix). For both observed roller units, a process flow map and graphically representation of MF (VSM) have been made. Different types of wastes can be identified by process flow study and VSM, which includes wastages like transportation, unnecessary motions, waiting, defects, overproduction, overprocessing, inventory, and the waste of human creativity.

4.1 Assembly process

- HQ1 Ø150 Bender Roller

MF of the observed roller is visualized in Figure 4-1. VSM (see Figure 4-3) is being done to analyze the VA and NVA activities that are being performed during the assembling process. To create the VSM, a cycle time study is being done to identify NVA. Cycle time is being taken based on regular observations with time studies on the shop floor. Figure 4-4 represents a detailed time study for a particular roller.

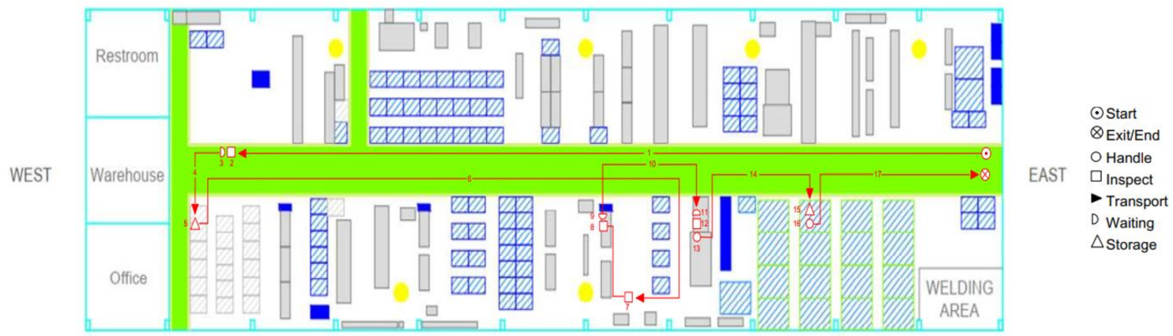


Figure 4-1: Material flow of HQ1 Ø150 Bender Roller

The production process of the bender roller unit consists of five operations:

1. preassembly
2. assembly
3. grease filling
4. testing
5. packaging

The first three operations are made at station A5, test, and packaging at A6 (See Figure 3-1 in Ch.3-2). Before the process starts, workers are using an overhead crane to move pallets with required parts for assembly. During the first observation, on assembly day, but before assembly starts, employees were taking a batch across the workshop and collects material needed for that day order. After two months, during the second observation, the material needed for this roller order is prepared in advance at the temporary warehouse and delivered to the workshop as a kit of required components. Each batch consists of components needed for assembly of six rollers. The goods are delivered to the storage area on the west side of the workshop and later moved by overhead crane to the A5 workstation. Like other rollers, HQ1 Bender also needs to be preassembled before the final assembly. The pre-assembly is performed at the final assembly station, on the floor, near the final assembly table. It starts with the heating of the roller jacket by using an induction heater that enables smoother pre-assembly. After roller jacket preheating, a worker installs other parts – bearings, sleeve, rings – through both sides of the roller jackets. Preassambly is then moved to the table where it should wait until it is cooled down. The final assembly includes assembly of the shaft with bearing blocks, preassembled roller jackets, pins, sleeves, and ring and cover on edge. At this point, the roller is ready for a water test and grease filling. In case that water test and grease filling finish without detected leakage, the roller is available for final testing and packaging.

Figure 4-2: Preassembly at A5 workstation

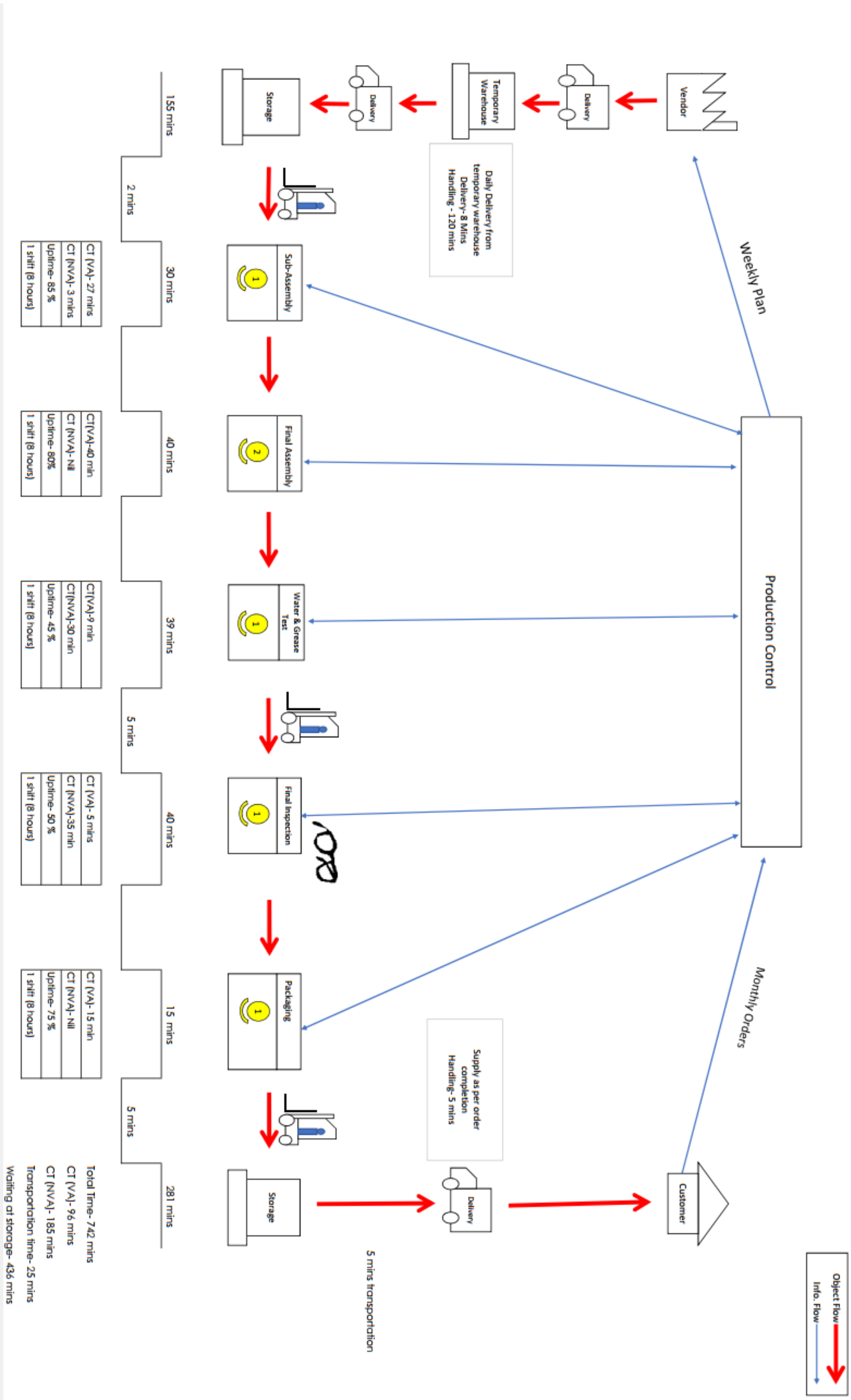


Figure 4-3: VSM of the assembly process - HQ1 Ø150 Bender

Company / Plant / Cost Center:	VDI/ AWF-Materialflow - HQ1_B_I_ Ø150	Page Nr. / made by:
Reviser / Datum	Subject of the investigation: ASSEMBLY LINE MATERIAL FLOW	Current procedure / Suggestions

Lfd. Nr.	Process	Bearbeit. + Form chang	Bearbeit. + Condition c	Bewegen o Handle	Bewegen > Transport	□ Control	D Waiting	Δ Storage	Output Nr.	Output Unit	Distance in m X	Distance in m Y	EQUIPMENT	Work force	Progress time	Individual times in mins – move – Handle	Individual times in mins – move – Transport	Control	Waiting	Storage	Remark
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	INPUT OF MATERIAL					□	D			2956	900	15	Forklift	2	120			60	60		
2	STORAGE OF MATERIAL				>			Δ		2956	720	72			155	60	60			35	same person as at step 1
3	TRASPORT TO FINAL ASSEMBLY STATION				>					1871	315	256	Crane	2	2	2					
4	SUBASSEMBLY			o						1137	88	176	Heating machine	2	30	30					same person as at step 3
5	FINAL ASSEMBLY			o						1871	176	176	Tools		40	40					same person as at step 4
6	BB FILLING WITH GREASE			o			D						Equipment with grease	1	39	9			30		same person as at step 3&4
7	TRANSPORT				>					1871	132	132	Crane		5		5				same person as at step 6
8	FINAL INSPECTION					□	D				66	164	Inspection tools	1	40			5	35		
9	PACKAGING			o									Crane		15	15					same person as at step 7
10	TRANSPORT				>						176	132	Crane		5		5				
11	STORAGE							Δ							281					281	same person as at step 14
12	SHIPPING			o	>					1871	121	132	Crane, Truck	2	10	5	5				
	Sum			7	8	2	1	2		1085	2694	1255		10	742	161	75	65	125	316	Nr.
	Sum [h]														12.367	2.7	1	1	2.08	5.27	
	Sum [day]														0.5153	0.1	0	0	0.09	0.22	

Figure 4-4: Current Process Map - assembly process of HQ1 Ø150 Bender Roller

The total cycle time of the assembly process for this roller is approximately 12,5 hours, where only 1,40 hours is classified as value added (later VA), and 3,10 hours is recognized as nonvalue added (later NVA). Additionally, 25 minutes are spent on transportation, and more than 7 hours is detected as waiting time. During the process observation following wastes are identified:

Transportation: Even though movements of material are activities usually classified as no NVA, in this process, some transportations are classified as nonvalue added but necessary activities (later NNVA). For example, when the delivery truck comes, and the truck needs to be unloaded. However, even though material for this order is already prepared at the temporary warehouse and it is delivered to the workshop as prepared set for planned assembly, it is delivered first to the storage area at the west side of the facility. With the delivery directly on the workstation, it is possible to save eighty minutes per truck.

Unnecessary movement: The employees are preparing the material before the assembly process starts, but often they forget some tools or part what causes around five minutes of unnecessary movement per roller unit.

Waiting: According to the process map (See Figure 4-2), the total waiting time was more than 7 hours. These times have the most significant effects on total cycle time. Of course, that time includes storage time and waiting time between steps, and they vary depending on many factors. For example, the material is always delivered at least the day before, often more (that depends on delivery schedule). Sometimes inspectors are not available for an inspection right away, and during observation, some rollers were waiting for almost two days to be packaged and stored after inspection. This waiting time can be easily removed by transportation immediately after inspection and packaging. Furthermore, there is a waiting time identified after bearing block grease filling, where employees wait approximately thirty minutes to transport roller to the inspection workstation. This activity would be classified as NNVA in case that two or more rollers are transported together at one time to the final inspection, but since each roller is transported separately, it is classified as NVA.

Waste of human creativity: After roller unit assembly, bearing blocks need to be filled with grease. Currently, two employees are working on this workstation, but for this step, one employee can easily manage the grease filling process. In the case where only one worker works on bearing block grease filling, another worker can prepare workstation for the next assembly – prepare material and preassembly (five minutes per shaft), move the shaft to the table (two minutes per roller). This kind of process flow can save seven minutes of next roller cycle time, and it can be seen as reducing waiting time. Also, both employees are transporting the rollers to the next station. That movement lasts for five minutes, but in case of demand of sixty-eight (68) rollers, that is 340 minutes. If the employee that works on grease filling, transport the finished roller to inspection table by himself, another employee that already prepares parts for the next roller can preassemble shaft and bearing block. In this way, the reduction of the cycle time of the next roller can be up to ten minutes. One more possible way for the cycle time reduction is to set employees on the inspection station. Currently, employees that work on final assembly stations are in-charge for the packaging and transport to storage, which is performed on the inspection table, so they need to stop with their task. That stopping time at the assembly station is twenty minutes per roller, and 1360 minutes in total for whole demand.

- SS1 Ø300 I-Star Roller

In January 2019, demand for this roller set was 24 pieces, and by the end of the month, RS-A delivered only 11. The main reason for unreached demand is missing material, especially of roller jackets. MF, shown in Figure 4-5, starts with the material delivery to the west storage area. Before transportation to the workstation, material needs to be grouped. At least the day before the final assembly, roller jackets need to be prepared and inspected as well as bearing blocks need to be preassembled. Roller jackets are taken from storage and transported (with overhead crane) to the inspection area (D8) where dimensions and surfaces are checked, and in case of need, they are polished. Preassembly of bearing block is performed at workstation A1, in a series of four pieces. Bearing blocks are moved to A2 workstation with trolley, approximately six pieces per one transport. The final assembly requires different tools, crane, preheating, and hydraulic machines. The JIB crane helps with material handling at the workstation, overhead crane transports roller jackets, shafts, and finished roller units by using crane belts. Once when it is assembled, the roller unit has to be tested. In this case, the roller is tested and packaged at the workstation A2, from where it is directly transported to the storage on the east side of the workshop. Inspectors are coming to the workstations with the inspection tool. For this particular roller, it is necessary to test roll-out and dimensions. The packaging is performed by a collaboration of the two blue-collar workers. It is necessary to lift rollers from the table surface with the crane. The crane belts are wrapped around roller edges so that workers can wrap roller into the plastic film. The process flow is made for this type of roller too, and it is shown in Figure 4-6.

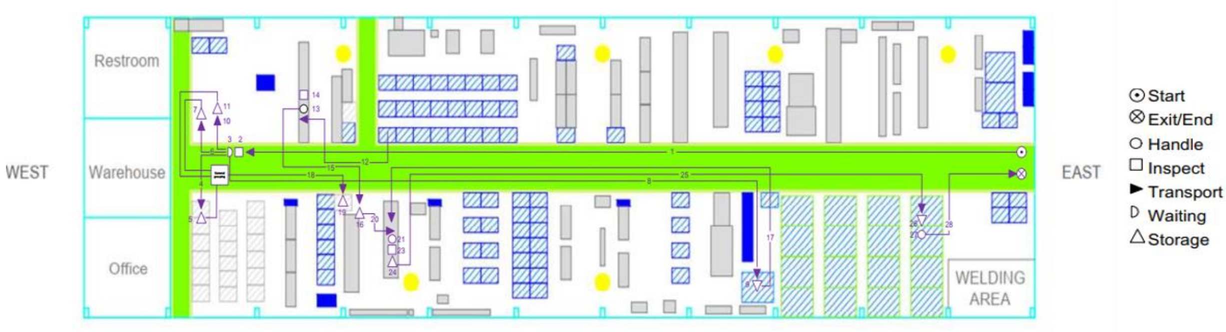
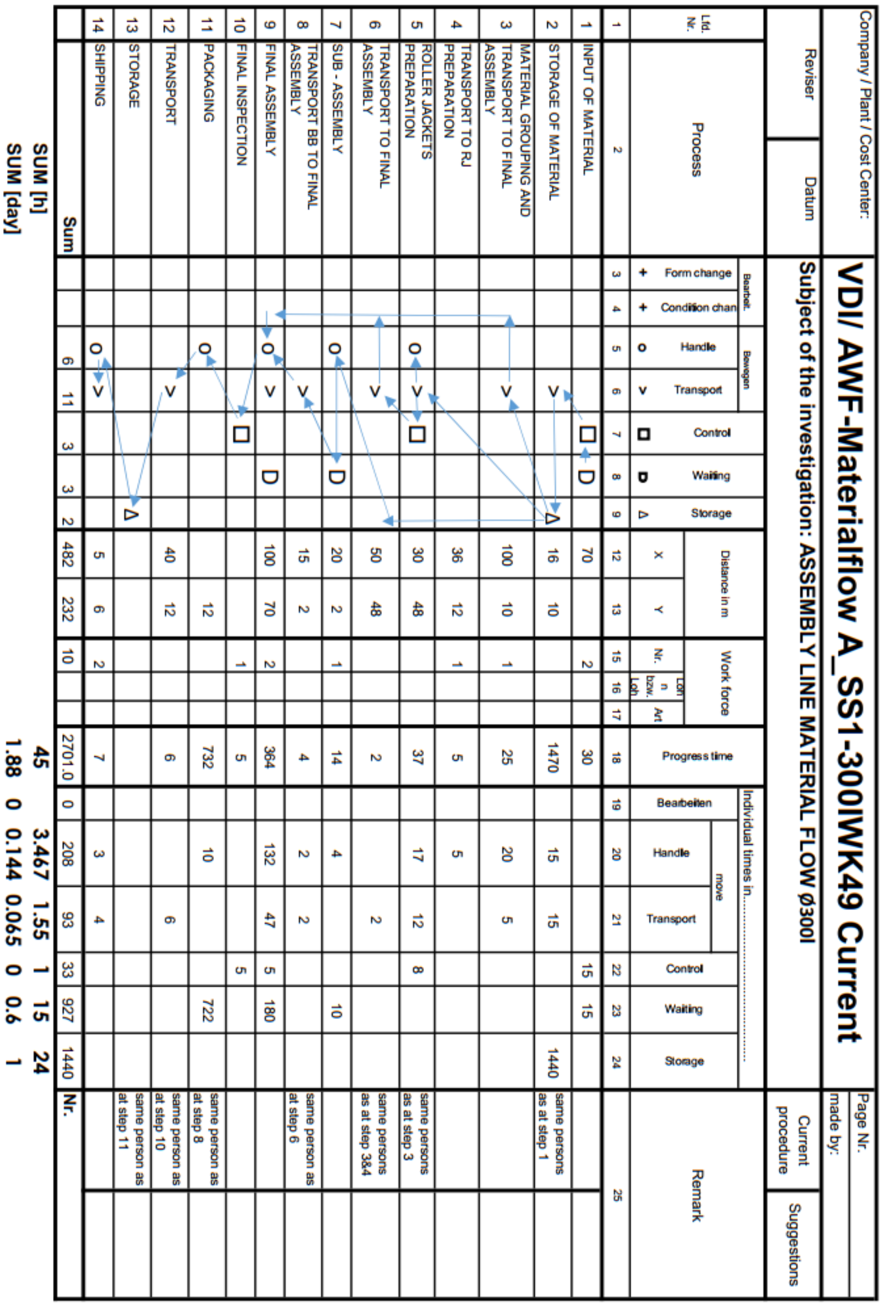


Figure 4-5: Material flow of SS1 Ø300 I-Star Roller



Company / Plant / Cost Center:

VDI/ AWF-Materialflow A_SS1-300IWK49 Current

Subject of the investigation: ASSEMBLY LINE MATERIAL FLOW Ø300I

Reviser | Datum | Page Nr. | made by:

Lfd. Nr.	Process	+ Form change	+ Condition change	o Handle	> Transport	□ Control	D Waiting	∆ Storage	Distance in m X	Distance in m Y	Work force Nr.	Work force Lohn bzw.	Work force Art	Progress time	Bearbeiten	Handle	Transport	Control	Waiting	Storage	Remark: Current procedure	Remark: Suggestions
1	2	3	4	5	6	7	8	9	12	13	15	16	17	18	19	20	21	22	23	24	25	
1	INPUT OF MATERIAL					□	D		70		2			30				15	15			
2	STORAGE OF MATERIAL				>			∆	16	10				1470		15	15			1440	same persons as at step 1	
3	MATERIAL GROUPING AND TRANSPORT TO FINAL ASSEMBLY				>				100	10	1			25		20	5					
4	TRANSPORT TO RJ PREPARATION								36	12	1			5		5						
5	ROLLER JACKETS PREPARATION			o	>	□			30	48				37		17	12	8			same persons as at step 3	
6	TRANSPORT TO FINAL ASSEMBLY				>				50	48				2			2				same persons as at step 3&4	
7	SUB - ASSEMBLY			o			D		20	2	1			14		4			10			
8	TRANSPORT BB TO FINAL ASSEMBLY				>				15	2				4		2	2				same person as at step 6	
9	FINAL ASSEMBLY			o	>		D		100	70	2			364		132	47	5	180			
10	FINAL INSPECTION					□					1			5				5				
11	PACKAGING			o						12				732		10			722		same person as at step 8	
12	TRANSPORT				>				40	12				6			6				same person as at step 10	
13	STORAGE							∆													same person as at step 11	
14	SHIPPING			o	>				5	6	2			7		3	4					
	Sum			6	11	3	3	2	482	232	10			2701.0	0	208	93	33	927	1440	Nr.	
	SUM [h]													45		3.467	1.55	1	15	24		
	SUM [day]													1.88	0	0.144	0.065	0	0.6	1		

Figure 4-6: Process Map of the assembly process of the SS1 Ø300

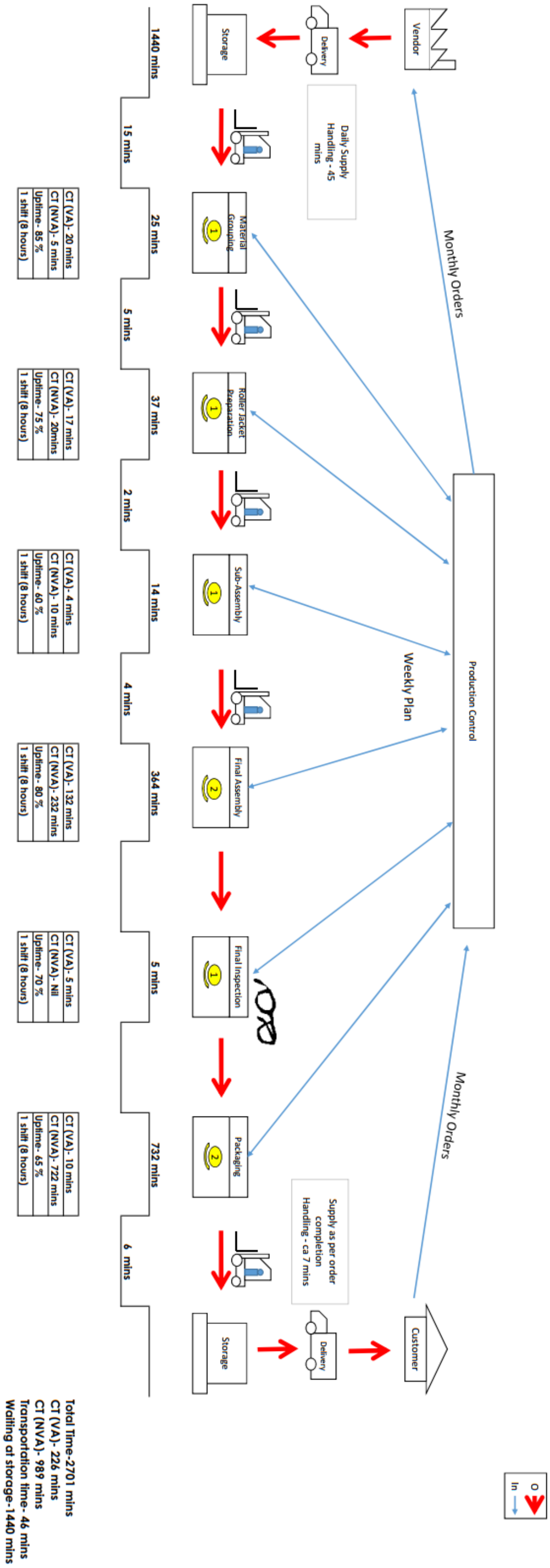


Figure 4-7: VSM current state of the assembly process of the SS1 Ø300

The process map helped to identify different kinds of waste:

Transportation: If the material can be delivered in the sets, total cycle time would be decreased for one whole step, material grouping, that is around 25 minutes per roller. Roller jackets that are inspected and qualified in advance are usually sent back to the workshop storage, and then from storage are sent to the workstation. In case they are prepared according to schedule, there won't be a need for transportation back to storage. Instead, they will be delivered directly to the workstation. This improvement is implemented during the observation, and because of that process, flow is shown with included improvement.

Unnecessary movement: Unnecessary motions are identified at preassembly (A1) and final assembly station (A2). NVA activities at A1 are mostly related to unnecessary movements, like when the employee goes to the storage area for parts even though he already spent five minutes on material-gathering before he starts with assembly. With a complete collection of material and tool preparation, it is possible to save at least four minutes per series. During the first observation of the preassembly station, employees used old, manual tools for the screw tightening. Meanwhile, they start to use pneumatic drills, that improved process for a few minutes, so process map is made according to that time. During the process, the bearing must connect with the bearing block. Since connecting doesn't go smoothly, employees are using a hammer to push bearing more easily. They need around two minutes per piece. One possible solution to preheat bearing block before connecting and bearing would get in more easily, where only a few seconds will be enough. One heating machine is installed at workstation A1, but it doesn't work correctly. There are preheating machine at the workshop, at the final assembly station, where it is measured that bearing block needs around fifteen minutes for heating. Even though the preheating machine seems like the right solution, with the installation of one properly working heating machine, there will be a long waiting time between bearing block preparation and bearing block heating – four blocks can be prepared while one bearing is heated. Because of the long waiting time, the RS-A manager secured four more heating machines.

At A2 station, bearing blocks and sleeves need to be preheated before assembling. Currently, each sleeve and bearing block is heated separately. The sleeves can be heated together, and in that way, it is possible to save two times per five minutes (3 minutes for heating and 2 minutes of movement) that is ten minutes in total per roller unit. In the case of installation of the second induction heater, two bearing blocks can be preheated at the same time, with savings of 20 minutes per roller unit.

At A2 workstation, before assembly, employees are checking the roller jacket surface. In case that surface does not satisfy parameters, workers need to do keyway grinding. Here, they are losing two minutes per roller jacket, which is six minutes per roller set. Roller jackets are delivered from RS-WM, where they should be machined, welded and inspected so that only qualified roller jacket can be delivered to the RS-A. Unfortunately, RS-A cannot influence on the surface quality of the delivered roller jacket. However, during the observation, some roller jackets are taken back from the final assembly workstation for additional keyway griding. Roller jacket preparation step is qualified as the NNVA step, but any additional keyway grinding is qualified as the NVA. The additional keyway grinding can be easily removed by radical quality inspection at the roller jacket preparation step.

Furthermore, there is a waste of time on the preparation of nuts for installation. It takes six minutes per each nut to be prepared, and even if it is earlier satisfy quality inspection. Removing this step can reduce cycle time for twelve minutes per roller. Again, at A2 station, there is a waste of motion for material reaching, ten minutes in total for one roller set.

Waiting: At A3 station, there are 220 minutes of waiting per roller units. Forty minutes is waiting time during the assembly process, and 180 minutes is waiting time until the finished roller is inspected and packaged. The waiting time till the next step (in this case, testing and packaging) can be almost entirely removed if inspection and packaging step is completed immediately after assembly.

Waste of human creativity: At A3 workstation, employees are using a hydraulic machine that helps to settle different parts in the right positions. During the assembly process, roller units are moved three times from the table to the machine. Here employees are spending almost fifty minutes: 15 for preparation, 14 on transportation, and 20 waiting for the machine to finish. For now, there is no other way to fix parts together, so this can be classified as NNVA. However, two employees are not needed during the whole process, so one worker can transport, prepare, and observe while another can take sleeves and bearing blocks to preheating machines. The same thing is happening during the preheating of bearing blocks. One worker transports the bearing block to the machine and waits until it is finished. As already said above, each bearing block needs approximately 15 minutes to be heated, and every roller set contains four bearing blocks. That results in one hour where the worker is waiting instead of preparing or

4.2 DISASSEMBLY PROCESS

- SS1 Ø300 I-Star Roller

This section describes the current state of disassembly of SS1 Ø300 I-Star Roller. The analysis made for the quantity of the 11 rollers. Cycle time study, VSM is being done for the disassembly process similar to the assembly process of roller diameter 150. Disassembly process runs through ten steps:

1. Roller disassembly
2. Bearing block disassembly
3. High pressure cleaning
4. Ultrasonic cleaning
5. Neutralization
6. Rust removal
7. Drying
8. Bearing block water test
9. Final Inspection
10. Painting

The current process flow is presented in the process map (see Figure 4-8), and MF is presented in Figure 4-7. A detailed analysis of each step is being done to map and sketch the VSM for the roller disassembly process is shown in Figure 4-9. Observation, datasheets, historical data, time motion study, layout study, interaction with operators, and workers are being carried out to know all facts of the current state.

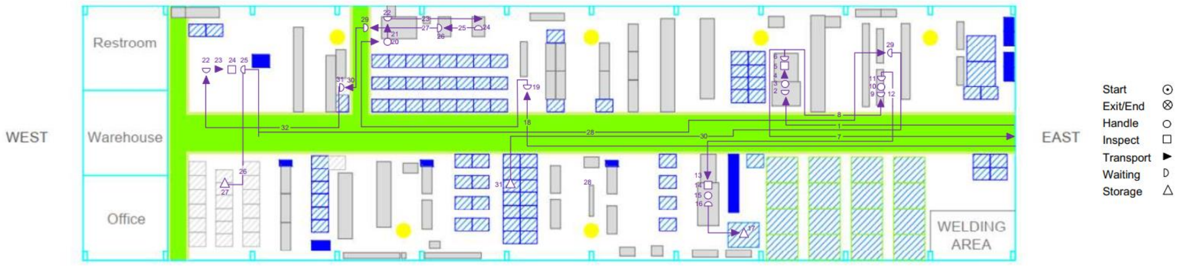


Figure 4-8: Material flow of disassembly process

The current state for roller disassembly is based on roller disassembly and cleaning with chemicals and machines. Another process is being also followed, which is completely manual. The process involving cleaning with chemicals is taken into account for this current state study, and future state is also mapped on the same pattern.

Time study is being classified into the following types for this study:

1. Value added time
2. Non-value added time
3. Transportation time
4. Waiting at storage

Sum of all these times gives total time, which is time for completion of end to end disassembly process. Time study (Figure 4-6) and VSM (Figure 4-7)are depicted in the diagram below, where is the MF, along with cycle time, manpower details, and material movement is presented for each step.

Company / Plant / Cost Center:		VDI/ AWF-Materialflow D_SS1-300IWK49 Future																					Page Nr. / made by:
Reviser	Datum	Subject of the investigation Disassembly Line Material Flow																					Current procedure / Suggestions
Lfd. Nr.	Process	earbeewege: Form chan +	Condition (+	Handle o	Transport >	Control □	Waiting D	Storage Δ	Distance in m: X	Y	Funding	Work force: Nr.	Lohn bzw. Lo	Art	Progress time	Individual times in mins: Bearbeiten	move: Handle	Transport	Control	Waiting	Storage		Remark
1	2	3	4	5	6	7	8	9	12	13	14	15	16	17	18	19	20	21	22	23	24		25
1	TRANSPORT				>				325	5	Truck	1			12			12					
2	ROLLER DISASSEMBLY			o			D				Crane, maschine	3			1380		292	8		1080			
3	TRANSPORT				>				7	2													
4	BEARING BLOCK DISASSEMBLY			o		□					Tools	5			35		35						
5	TRANSPORT TO SEGMENT WORKSHOP				>				75	5	Forklift	1			10		5	5					
6	HIGH PREASSURE CLEANING			o											20		20						Performed at Segment workshop
7	TRANSPORT TO RS-A				>				75	5	Forklift, trolley				10		5	5					
8	ULTRASONIC CLEANING			o			D		5	5	Machines, crane				123		120	3					
9	TRANSPORT				>				3	3	Crane				2			2					
10	NEUTRALIZATION			o						5	Machines, crane				120		120						
11	TRANSPORT				>				3	3	Crane				2			2					
12	RUST REMOVING			o						5	Machines, crane				15		15						
13	TRANSPORT				>				16	6	Truck, forklift,crane				5		2	3					
14	BEARING BLOCK WATER TEST			o		□					Machine	1			34		4		30				
15	FINAL INSPECTION					□			2		Testing tools	1			60				60				
16	TRANSPORT				>				2	2	Trolley	1			5			5					
17	PAINTING			o					24	2	Brush	1			12		7	5					
18	TRANSPORT				>				20	2		1			5			5					
19	STORAGE			o				Δ	20			1			10		10						
															0								
	Summe/ Übertrag			9	8	3	2	1	577	45		15			1860	0	635	55	90	1080	0		Nr.

Figure 4-9: Process Map of the disassembly process - current state

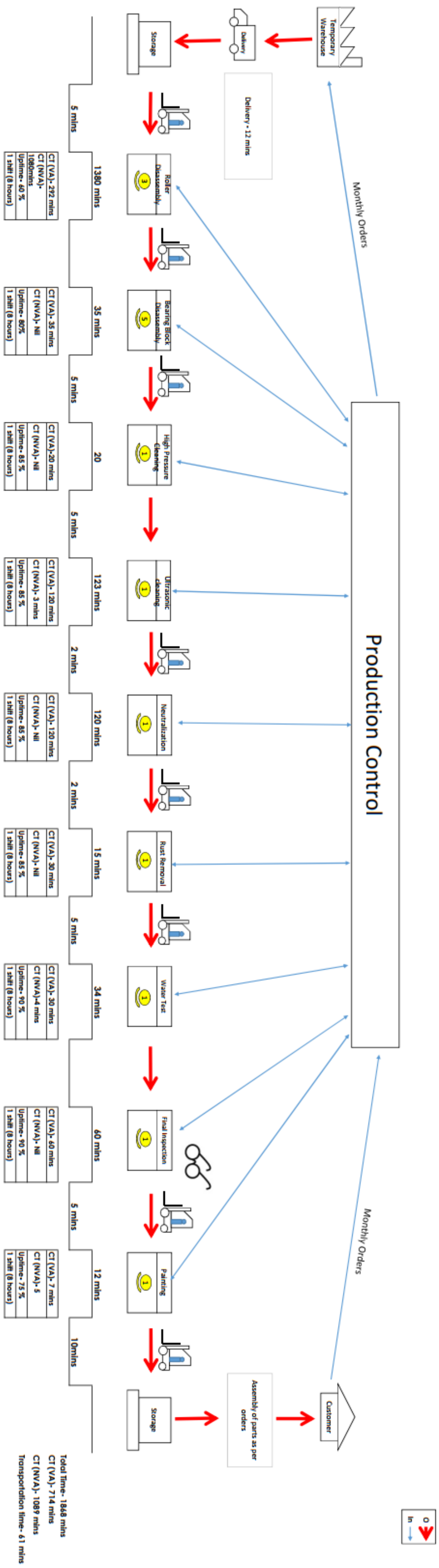


Figure 4-10: Value Stream Map of the current state for the disassembly line

The longest waiting time is the waiting time at the “roller disassembly” step. The main reason that is causing this waiting time is the fact that SS Rollers used to be assembled and disassembled in another workshop according to different techniques that include welding (shaft and roller jacket). Even though the new process is adopted, the workshop is receiving the rollers that are assembled according to the previous technology.
At some point in the disassembly process, the roller requires an old technique to be disassembled until the end. Since the roller workshop has no welders employed, they are called when several rollers are ready for disassembly. Sometimes they are coming every week, sometimes rarely, depending on roller number. This waiting time is in contradictions with a description of the assembly process (see Chapter 3.1.2) firstly because there are no welding steps mentioned in the assembly process. As already mentioned before (chapter 3.1.2) roller workshop received first orders from plant SS1 in January 2019, and the assembly process is upgraded. Now, in a new assembly procedure, there is no welding included in it.

Another step that is taking a lot of time in comparison to the other steps is cleaning. Currently, the cleaning process is slowed because it is performed manually in one of the areas of the roller workshop, D2 (Figure 4-8).

Figure 4-11: Manual cleaning station

During the first workshop visit, the cleaning process was performed within a different procedure (Figure 4-9). Firstly, parts were taken to another workshop, segment workshop, for the high-pressure cleaning. After high-pressure cleaning, parts are transported back to the workshop and washed using three ultrasonic cleaning machines, which were used for cleaning. In this way, it was possible to improve the cleaning step. Unfortunately, the workshop doesn’t provide safe conditions for the usage of the ultrasonic machines, so cleaning is switched to the previous procedure – manual cleaning (for a detailed explanation, see Chapter 5.2).

Another waste identified with cleaning is the quantity of the washed parts, or in other words – the increased quantity of unwashed parts. It is possible to clean parts for only six rollers that are being disassembled. According to collected data, 541 rollers were disassembled in January. In a comparison of the number of disassembled rollers with several washed roller parts, it can be concluded that RS-A required 75 working days to wash all parts.

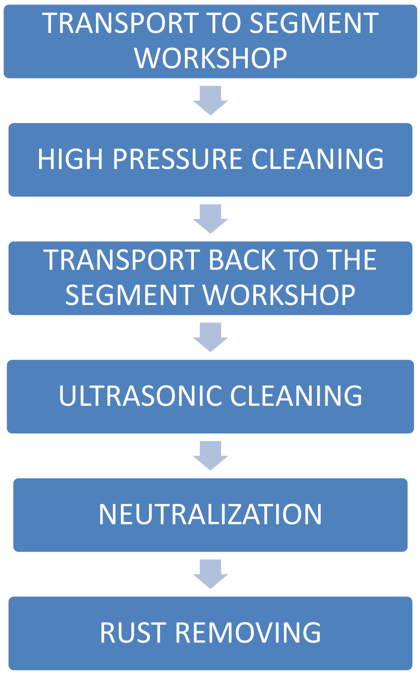


Figure 4-12: Cleaning process from January

Bearing block water test is a mandatory test, and it is performed on the testing table (Figure 4-11). Although there is capacity for eight blocks testing at the same time, the water test is performed of only four blocks at the same time. Depending on the result, the bearing block is marked with yellow mark (at the top of the block) or with the red one in case there is leakage recognized during the test. The usage of a full table capacity, testing time will remain the same, thirty minutes, but instead of four blocks, eight blocks would be inspected.

Figure 4-13: Water test table for the bearing blocks

Quality inspectors are in charge of quality checks. Many parts are sent to the storage and don’t satisfy quality criteria. Also, there are some batches where the controlled, qualified parts are mixed with dirty parts.
Painting is performed on tables at disassembly stations D1-D6, which means that blocks are sometimes moved from one side of the disassembly line to the other, causing unnecessary movements.

5 Improvement suggestions

5.1 LAYOUT

RS-A optimization started more than two years ago when Primetals Technologies went into a joint venture with HBIS TANGSTEEL. The workshop layout has been changed several times during these two years. The observation for the thesis started from the beginning of the current year, and since then, layout and material flow are continually improving. The layout, observed in January, stayed almost the same. As shown in Figure (see Chapter 3-1), assembly and disassembly lines are having nearly continuous straight flow. The assembly line had discontinuous flow only during the material gathering, but as already mentioned in Chapter 4.1., during the second observation, a temporary warehouse delivered required material already prepared a set of goods ready for assembling. However, the disassembly line also had some changes between the two site visits. Since government inspection forbade to use ultrasonic machines for cleaning, and now manual cleaning station is returned for usage. It is currently located on the D2 workstation (Figure 5-1).

Moreover, ultrasonic machines are still in RS-A, even though they cannot be used anymore. Except for space occupancy, manual cleaning station increases cleaning time too. Currently, only six roller unit parts can be washed during one shift. That is at least 50% less compared with the US machine.

However, since RS-A already owning US cleaning machines, which work correctly, they should be in use. Three possible suggestions can be observed:

- Moving USM to the TW and use them there
- Moving USM out of RS-A and use manual cleaning
- Ensure legal requirements and use USM in the RS-A(move manual cleaning station from RS-A

The first option refers to the transfer of machines to TW. The main advantage is the additional free space in the workshop (see Figure 5-2). The new free space can be used for additional storage area or workstation. On the other hand, after washing, parts need to be inspected and qualified, which means they should be sent back to RS-A for inspection. Quality inspectors are responsible for control also at the assembly line, so in case of cleaning in TW, they would be needed in both facilities.

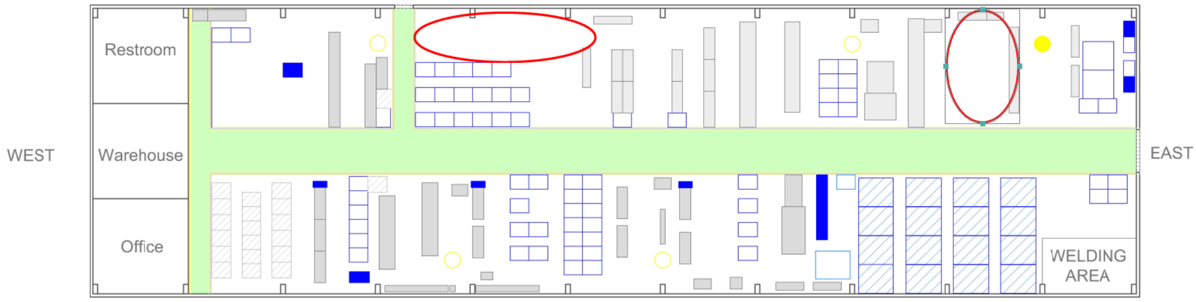


Figure 5-1: Current layout without cleaning machine and washing station

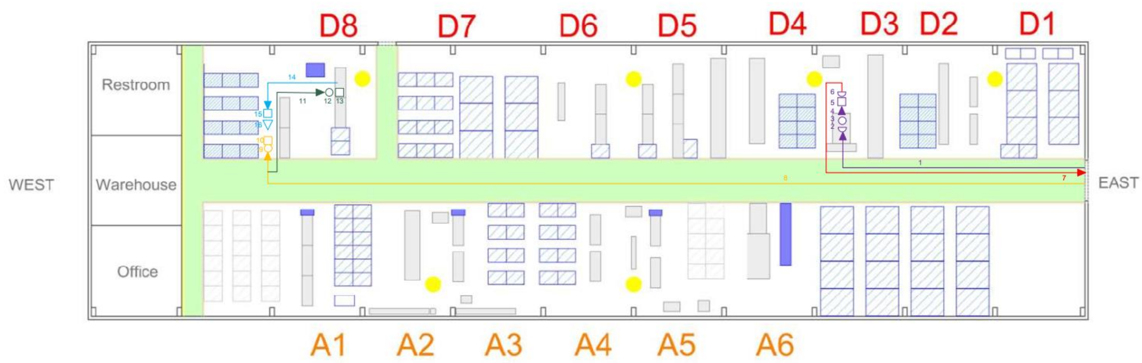


Figure 5-2: Future material flow – option 1

Company / Plant / Cost Center: | **VDI/ AWF-Materialflow D_SS1-300IWK49 Future** | Page Nr. | made by:

Reviser | Datum | **Subject of the investigation** Disassembly Line Material Flow | Current procedure | Suggestions

Lfd. Nr.	Process	Bearbeitewege: Form change +	Condition +	Handle o	Transport >	Control □	Waiting D	Storage Δ	Distance in m: X	Y	Funding	Work force: Nr.	Lohn bzw. Lohn	Art	Progress time	Individual times in mins: Bearbeiten	move: Handle	Transport	Control	Waiting	Storage	Remark
1	2	3	4	5	6	7	8	9	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	TRANSPORT				>				325	5	Truck	1			12			12				
2	ROLLER DISASSEMBLY			o			D				Crane, maschine.	3			300		292	8				
	TRANSPORT				>				7	2												
3	BEARING BLOCK DISASSEMBLY			o		□					Tools	5			35		35					
4	TRANSPORT TO SEGMENT WORKSHOP				>				75	5	Forklift	1			10		5	5				
5	HIGH PREASSURE CLEANING			o											20		20					Performed at Segment
6	TRANSPORT TO TW				>				800	10					30		20	10				
7	ULTRASONIC CLEANING			o			D		5	5	Machines, crane				63		60	3				Performed at TW
8	TRANSPORT				>				3	3	Crane				2			2				Performed at TW
9	NEUTRALIZATION			o						5	Machines, crane				60		60					Performed at TW
10	TRANSPORT				>				3	3	Crane				2			2				Performed at TW
11	RUST REMOVING			o						5	Machines, crane				15		15					Performed at TW
12	TRANSPORT BACK TO RS-A								800	10	Truck, forklift,crane				30		20	10				
13	BEARING BLOCK WATER TEST			o							Machines	1			34		4		30			
14	FINAL INSPECTION					□					Tools	1			60				60			
	TRANSPORT				>				2	2												
15	PAINTING			o							Brush	1			10		7	3				
16	STORAGE			o				Δ	2			1			10		10					
															0							
	Summe/ Übertrag			9	7	2	2	1	2022	55		14			693	0	548	55	90	0	0	**Nr.**

Figure 5-3: Process Flow Map – Option 1

Figure 5-2 represents material flow in the case of Option 1. The total transportation distance of one observed roller is 2022m, and total cycle time is 693 minutes (11 hours).

The second option is to move to USM and use manual cleaning only. In this way, there will be no transportation outside the RS-A needed. For the new material flow illustration, cleaning station is moved to the D7 workstation (See Figure 5-10). After roller disassembly, parts are transported to the manual cleaning at D7, and after they are moved few meters to the D8 (testing and inspection station). Even though this option results in approximately the same distances and cycle time, additional space is saved, and it can be used as additional storage of roller jackets and shafts for assembly line (Figure 5-3)

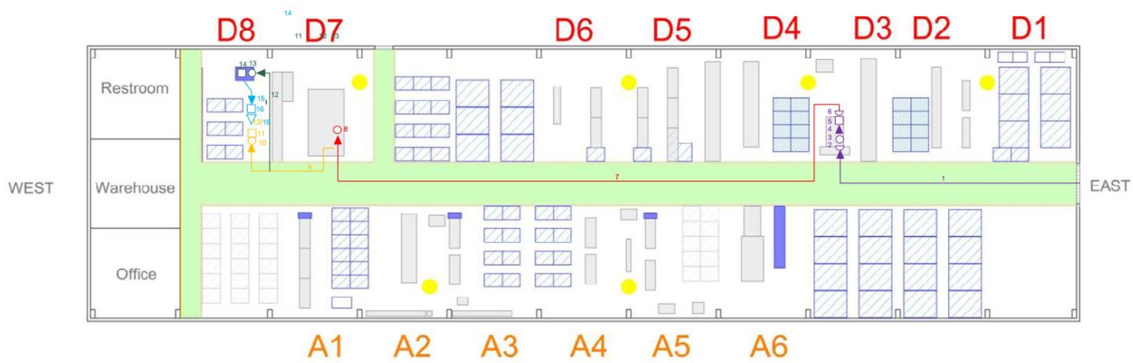


Figure 5-4: Material Flow – Option 2

Company / Plant / Cost Center:	VDI/ AWF-Materialflow D_SS1-300IWK49 Current	Page Nr. made by:
Reviser / Datum	Subject of the investigation Disassembly Line Material Flow	Current procedure / Suggestions

Lfd. Nr.	Process	Form char +	Condition +	Handle o	Transport >	Control □	Waiting D	Storage Δ	Distance in m X	Distance in m Y	Equipment	Work force Nr.	Work force Lohn bzw.	Work force Art	Progress time	Bearbeiten	Handle	Transport	Control	Waiting	Storage	Remark
1	2	3	4	5	6	7	8	9	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	TRANSPORT				>				325	5	Truck, forklift	1			12			12				
4	ROLLER DISASSEMBLY			o			D				Crane, maschine.	3			270		262	8				
	TRANSPORT				>				7	2	Trolley	1			3			3				
5	BEARING BLOCK DISASSEMBLY			o		□					Tools	5			35		35					
6	TRANSPORT TO CLEANING STATION				>				22	4	Forklift	1			5			5				
7	MANUAL CLEANING			o								1			120		120					
8	TRANSPORT				>				50	5	Forklift, crane	1			5			5				
9	BEARING BLOCK TESTING			o							Machine	1			34		4		30			
10	FINAL INSPECTION					□					Inspection to	1			60				60			
11	TRANSPORT				>				2	2	crane, trolley	1			5			5				
12	PAINTING			o								1			7		7					
13	STORAGE			o				Δ	20	5		1			10		10					
	Summe/ Übertrag			6	5	2	1	1	426	23		7			566	0	438	38	90	0	0	Nr.

Figure 5-5: Process Flow Map – Option 2

The third option is to secure legal requirements, which will allow the usage of machines in the RS-A facility, as shown in Figure 5-6. In this way, efficient cleaning would be possible without a significant increase in transportation distance. After high pressure cleaning in the segment workshop, parts are delivered to the RS-A for machine cleaning. Process Flow Map showed total transportation distance for this option is 535 minutes with a cycle time of 655 minutes.

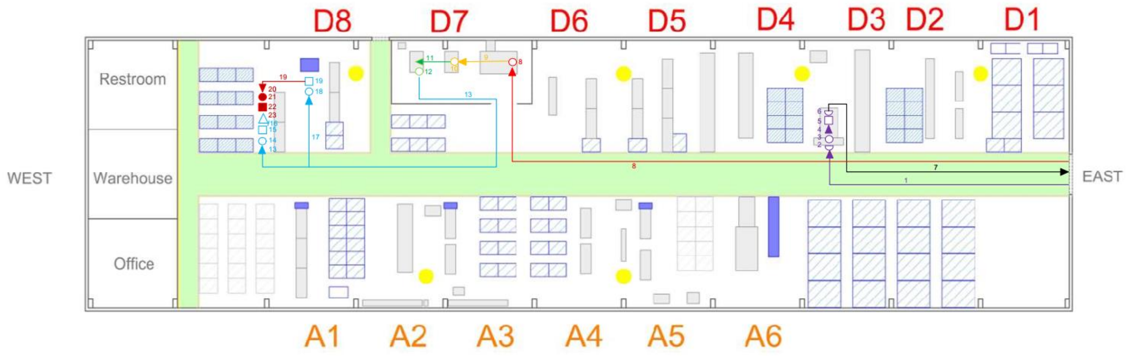


Figure 5-6: Material Flow – Option 3

Company / Plant / Cost Center:	VDI/ AWF-Materialflow D_SS1-300IWK49 Future	Page Nr. / made by:
Reviser / Datum	**Subject of the investigation** Disassembly Line Material Flow	Current procedure / Suggestions

Lfd. Nr.	Process	Form char +	Condition +	Handle o	Transport >	Control □	Waiting D	Storage Δ	Distance in m X	Distance in m Y	Funding	Work force Nr.	Work force Lohn bzw. Lohn	Work force Art	Progress time	Individual times in mins Bearbeiten	Handle	Transport	Control	Waiting	Storage	Remark
1	2	3	4	5	6	7	8	9	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	TRANSPORT				>				325	5	Truck	1			12			12				
2	ROLLER DISASSEMBLY			o			D				Crane, maschine	3			300		292	8				
3	TRANSPORT				>				7	2												
4	BEARING BLOCK DISASSEMBLY			o		□					Tools	5			35		35					
5	TRANSPORT TO SEGMENT WORKSHOP				>				75	5	Forklift	1			10		5	5				
6	HIGH PREASSURE CLEANING			o											20		20					Performed at Segment workshop
7	TRANSPORT TO RS-A				>				75	5	Forklift, trolley				15		5	10				
8	ULTRASONIC CLEANING			o			D		5	5	Machines, crane				63		60	3				Performed at TW
9	TRANSPORT				>				3	3	Crane				2			2				Performed at TW
10	NEUTRALIZATION			o						5	Machines, crane				60		60					Performed at TW
11	TRANSPORT				>				3	3	Crane				2			2				Performed at TW
12	RUST REMOVING			o						5	Machines, crane				15		15					Performed at TW
13	TRANSPORT				>				16	6	Truck, forklift,crane				5		2	3				
14	BEARING BLOCK WATER TEST			o		□					Machine	1			34		4		30			
15	FINAL INSPECTION					□			2		Testing tools	1			60				60			
16	TRANSPORT				>				2	2	Trolley	1			5			5				
17	PAINTING			o					2		Brush	1			7		7					
18	STORAGE			o				Δ	20			1			10		10					
															0							
	Summe/ Übertrag			9	8	3	2	1	535	41		14			655	0	515	50	90	0	0	Nr.

Figure 5-7: Process Flow Map – Option 3

Transportation distances and cycle times of all variants are shown in Figure 5-8. Blue column represents the distance (in m), and orange represents cycle time (in minutes). It can be seen that the first option takes the longest cycle time, and it requires the longest distances. Another two options are both related to the performed process inside RS-A, and according to the graph (Figure 5-8), the third option has both – lowest transportation distance and cycle time.

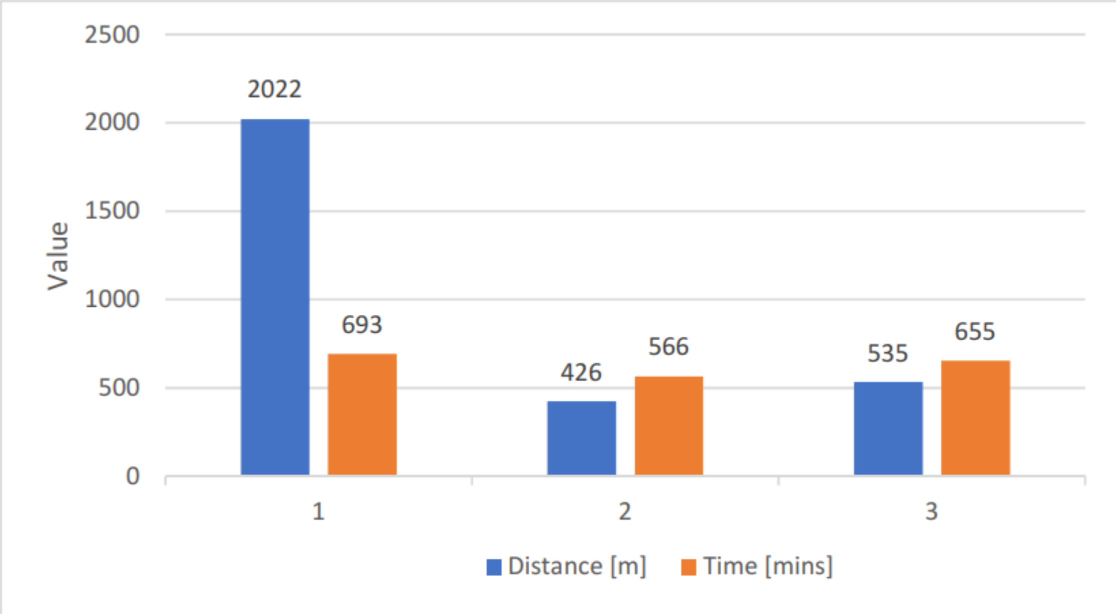


Figure 5-8: Comparison between variants

To make a detailed comparison between the variants evaluation table has been made (Figure 5-9). Several criteria are taken into consideration: Cycle time, cleaning effect, flow, and transportation distances. The weighting factor is distributed between criteria, and the total sum of the weighting factor must be an equal one. Furthermore, each option gets the point (grade) for each criterion, and it is multiplied with a weighting factor. The sum of these grades represents option value. The absolute variant value, which is accountable for option comparison, is calculated from divination of the sum of variant value with the maximum variant value.

As shown in Figure, the highest value is given to option 2. However, since cleaning machines are preferable cleaning approach, the third option will be considered in the future state.

Criteria	Factor (g_i)	Option 1		Option 2		Option 3	
		V_{i1}	$V_{g1} = V_{i1} * g_1$	V_{i2}	$V_{g2} = V_{i2} * g_i$	V_{i3}	$V_{g3} = V_{i3} * g_i$
Transportation distance	0.2	3	0.6	8	1.6	7	1.4
Flow	0.2	5	1	7	1.4	7	1.4
Cycle time	0.3	3	0.9	8	2.4	7	2.1
Cleaning effect	0.3	8	2.4	7	2.1	8	2.4
$V_{max} * n = 10 * 4$	$\sum V_i = V$	19		30		29	
	$V_g = \sum(g_i V_i)$	4.9		7.5		7.3	
	$V_{aps} = V/40$	0.475		0.75		0.725	
	$V_{gaps} = V_g/10$	0.49		0.75		0.73	

Figure 5-9: Evaluation table

$$g_i = Factor; \sum g_i = 1$$

$$V_i = Grade\ (1:10)$$

5.2 Process flow

5.2.1 ASSEMBLY LINE

- HQ1 Ø150 Bender Roller

The current state cycle time study is made to identify value-added and non-value added activities for all the steps involved in MF. In the future state, analysis focus is given to the reduction of the NVA cycle time so that that waste time can be eliminated from the process. Elimination of the waste time will result in a smoother flow of the process. Line balancing is also being done to improve the output and reduce waiting time in the process, which leads to a reduction in overall process time for roller assembly. The balanced and continuous line has numerous advantages compared to unbalanced and batch line assembly or production.

Improvement in time is being reflected in timesheet and VSM. The explanation of improvements is listed below:

1. Transportation of material is required from a temporary warehouse to storage in the workshop. With the elimination of transportation of material from a workshop storage area to the workstation, the workshop will be able to directly receive the material, and there will be saving of time in terms of transportation and handling. There will provide savings of 188 mins in total, which includes two times handling of material in loading and unloading and transportation of material from TW to RS-A.

2. Unnecessary movements can be avoided with better preparation of workers. If they prepare all the tools and parts that they need there will be savings between 3-5 minutes per roller.

3. As the assembly is a bottleneck process, it needs to be debottlenecked. There will be one workstation for sub-assembly of the roller diameter 150, two workstations for final assembly and testing, and one for inspection and packaging. The following tables are a demonstration of roller movement with times and workforce.

Table 8: Line balancing for the WS1

Workstation 1				
Activity	**Start Time**	**End Time**	**Workforce**	**Roller No**
Pre-Assembly	00:00	0:27:00	A	1
Pre-Assembly	0:27:00	0:54:00	A	2
Pre-Assembly	00:54	01:21	A	3
Pre-Assembly	01:21	01:48	A	4

One workstation will be completely dedicated for the pre-assembly process. As explained above, the saving of 3 mins per pre-assembly will lead to the cycle time of 27 mins for each roller pre-assembly. Roller pre-assembly will be done continuously with a dedicated workforce. In this way, there will be four roller sub-assembly completed by 1 hour 48 minutes. The start time and end time for each roller have been shown in the table above (Table 9). Roller 1, 2, 3 and 4 will be ready at 27th, 54th, 81th, and 108th mins respectively.

Table 9: Line balancing of the WS2

Workstation 2				
Activity	**Start Time**	**End Time**	**Workforce**	**Roller No**
Transporting roller from workstation 1 to 2	0:27:00	0:29:00	B	1
Final assembly & testing	0:29:00	1:18:00	B	
Transporting roller from workstation 1 to 2	01:21	01:23	B	3
Final assembly & testing	01:23	02:12	B	

There will be two workstations for final assembly and testing with a dedicated workforce. On the first workstation for the final assembly, there will be an assembly of each alternate roller, i.e., first, third, fifth, seventh, etc. Each final assembly and testing of roller requires 51 minutes in total, which includes 2 minutes of transportation time from pre-assembly table to final assembly and testing table and 49 minutes for final assembly and testing. As soon as the first roller is ready at a pre-assembly workstation at 27th min, it will be transported to the final assembly, and testing workstation by 29th min and final assembly and testing will be completed by 78th min. There will be a buffer time of 3 mins at workstation 2 and 3 for the next operation. Time for operation start and end for roller 1 and 3 is shown in Table 10.

Table 10: Line balancing of the WS3

Workstation 3				
Activity	**Start Time**	**End Time**	**Workforce**	**Roller No**
Transporting roller from work-station 1 to 3	00:54	00:56	C	2
Final assembly & testing	00:56	01:45	C	
Transporting roller from work-station 1 to 3	01:48	01:50	C	4
Final assembly & testing	01:50	02:39	C	

Along the same line to workstation 2, final assembly and testing of pre-assembled rollers will be done. There will be final assembly and testing of following rollers at workstation 3 - second, fourth, sixth, eighth, and so on. Table 11 describes the start time and end time for roller 2 & 4 final assemblies and testing.

Table 11: Line balancing of the WS4

Workstation 4				
Activity	**Start Time**	**End Time**	**Workforce**	**Roller No**
Transporting roller from work-station 2 to 4	01:18	01:20	D	1
Inspection	01:20	01:25	E	
Packing	01:25	01:40	D	
Transportation to store	01:40	01:45	D	
Transporting roller from work-station 3 to 4	01:45	01:47	D	2
Inspection	01:47	01:52	E	
Packing	01:52	02:07	D	
Transportation to store	02:07	02:12	D	
Transporting roller from work-station 2 to 4	02:12	02:14	D	3
Inspection	02:14	02:19	E	
Packing	02:19	02:34	D	
Transportation to store	02:34	02:39	D	
Transporting roller from work-station 3 to 4	02:39	02:41	D	4
Inspection	02:41	02:46	E	
Packing	02:46	03:01	D	
Transportation to store	03:01	03:06	D	

Inspection and packing will be done at workstation 4. It will be done continuously because each roller coming from workstation two and workstation 3. There will be no wait time based on cycle time. As soon final assembly and packing are completed at workstation 2, the roller will be transported to workstation and inspection, and packing will be done, and it will be transported to the storage. The same process will be followed for subsequent rollers. All four rollers will be ready for three hours and six minutes.

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Subject of the investigation: ASSEMBLY LINE MATERIAL FLOW

Current procedure | Suggestions

Lfd. Nr.	Process	Bearbeit.: Form change +	Bearbeit.: Condition change +	Bewegen: Handle O	Bewegen: Transport >	Control □	Waiting D	Storage Δ	Output: Nr.	Output: Unit	Distance in m: X	Distance in m: Y	EQUIPMENT	Work force	Progress time	Individual times in: move: Handle	Individual times in: move: Transport	Individual times in: Control	Individual times in: Waiting	Individual times in: Storage	Remark: Current procedure	Remark: Suggestions
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
1	INPUT & STORAGE OF MATERIAL				>	□	D	Δ		2956	900	15	Forklift	2	95	27	8	60				
3	TRASPORT TO FINAL ASSEMBLY STATION				>					1871	315	256	Crane	2	2	2						
4	SUBASSEMBLY			O						1137	88	176	Heating machine	2	27	27					same person as at step 3	
5	FINAL ASSEMBLY			O						1871	176	176	Tools		40	40					same person as at step 4	
6	BB FILLING WITH GREASE			O			D						Equipment with grease	1	9	9					same person as at step 3&4	
7	TRANSPORT				>					1871	132	132	Crane		5		5				same person as at step 6	
8	FINAL INSPECTION					□	D				66	164	Inspection tools	1	5			5				
9	PACKAGING			O									Crane		10	10					same person as at step 7	
10	TRANSPORT				>						176	132	Crane		5		5					
11	STORAGE							Δ							281					281	same person as at step 14	
12	SHIPPING			O	>					1871	121	132	Crane, Truck	2	10	5	5					
	Sum			7	8	2	1	2		1085	1974	1183		10	489	120	23	65	0	281	Nr.	

Figure 5-10: Process Map of the assembly process for HQ Bender Roller

Based on the future state of the roller assembly, 327 mins has been reduced compared to the cycle time of the current state.
A total of 186 mins will be required from pre-assembly to storage for four rollers, i.e., 46.5 mins for each roller which was 176 mins earlier. It saves 129.5 mins for each roller as it reduces wait time and work is balanced as per each workstation (Figure 5-10).

Table 12: Savings in the future state for HQ12 Bender Roller

Time	Current State	Future State
	Mins	Mins
CT (VA)	96	91
CT (NVA)	185	0
Transportation	25	17
Waiting at storage	436	376
Total Time	**742**	**484**

Total time reduction for one roller is 258 mins - from 742 mins to 484 mins. It means there is a saving of 34,8 % per roller. The same workstations can be used for another roller assembly if the assembly of roller diameter 150 is completed.

- SS1 Ø300 I-Star Roller

The current state of roller assembly is analyzed, and reduction in cycle time is being done to make the MF smoother and faster. This leads to future state timesheet along with future state VSM.
Reduction of the time has been done at the following steps:

1. If the material can be delivered in the sets, total cycle time would be decreased for one whole step, material grouping, that is around 25 minutes per roller. Roller jackets that are inspected and qualified in advance are usually sent back to storage, and then from storage are sent to the workstation. In case they are prepared according to schedule, there won't be a need for transportation back to storage. Instead, they will be delivered directly to the workstation. This improvement is implemented during the observation, and because of that process, flow is shown with included improvement.

2. Unnecessary motions are identified at pre-assembly (A1) and final assembly station (A2). NVA activities at A1 are mostly related to unnecessary movements, like when the employee goes to the storage area for parts even though he already spent five minutes on material gathering before he starts with assembly. With a complete collection of material and tool preparation, it is possible to save at least four minutes per series. During the first observation of the pre-assemble station, employees used old, manual tools for the screw tightening. Meanwhile, they start to use

pneumatic drills, that improved process for a few minutes, so process map is made according to that time. During the process, the bearing must connect with the bearing block. Since connecting doesn't go smoothly, employees are using a hammer to push bearing more easily. They need around two minutes per piece. One possible solution is to preheat bearing block before connecting and bearing would get in more easily, where only a few seconds will be enough. There are preheating machine at the workshop, at the final assembly station, where it is measured that bearing block needs around fifteen minutes for heating. Even though the preheating machine seems like a good solution, with the installation of one heating machine, there will be a long waiting time between bearing block preparation and bearing block heating – four blocks can be prepared while one bearing is heated.

3. At A2 station, bearing blocks and sleeves need to be preheated before assembling. Currently, each sleeve and bearing block is heated separately. The sleeves can be heated together, and in that way, it is possible to save two times per five minutes (3 minutes for heating and 2 minutes of movement) that is ten minutes in total per roller. In the case of installation of the second heating machine, two bearing blocks can be preheated at the same time, with savings of 20 minutes per roller.

4. At A2 workstation, before assembly, employees are checking roller jacket surfaces and polish inside the surface. Here, they are losing two minutes per roller jacket, which is six minutes per roller set. Roller jacket preparation step is the NNVA step since the workshop cannot influence the surface quality of the delivered roller jacket (another workshop supplies them), but double polishing in one process flow is NVA. Additional polishing can be easily removed by radical quality inspection at the roller jacket preparation step. Furthermore, there is a waste of time on the preparation of nuts for installation. It takes six minutes per each nut to be prepared, and even if it is earlier, satisfy quality inspection. Removing this step can reduce cycle time for twelve minutes per roller. Again, at A2 station, there is a waste of motion for material reaching, ten minutes in total for one roller set.

5. At A3 workstation, employees are using a hydraulic machine that helps to settle different parts in the right positions. During the assembly process, roller sets are moved three times from the table to the machine. Here employees are spending almost fifty minutes: 15 for preparation, 14 on transportation, and 20 waiting for the machine to finish. For now, there is no other way to fix parts together, so this can be classified as NNVA. However, two employees are not needed during the whole process, so one worker can transport, prepare, and observe while another can take sleeves and bearing blocks to preheating machines. The same thing is happening during the preheating of bearing blocks. One worker transports the bearing block to the machine and waits until it is finished. As already said above, each bearing block needs approximately 15 minutes to be heated, and every

roller set contains four bearing blocks. That results in one hour where the worker is waiting instead of preparing or assembling another roller (half of an hour in case of installation additional heating machine). Future state time and VSM are shown below in Figure 5-11 and Figure 5-12.

Table 13: List of savings

Activity	Savings per roller	Rollers per month (avg)	Rollers assembled per year	Time saving per month	Time saving per year	Invest-ment required
Transport	30 mins	24	24*12=288	30*24=720 mins i.e. 12 hrs	12*12=144 hrs i.e. 6 days	No
Pre-heating of sleeves	20 mins	24	24*12=288	20*24=480 min i.e. 8 hrs	8*12=96 hrs i.e. 4 days	Yes
Polishing of nuts	10 mins	24	24*12=288	10*24=240 mins i.e. 4 hrs	4*12=48 hrs i.e. 2 days	No
Pre-heating of bearing blocks	30 mins	24	24*12=288	30*24=720 mins i.e. 12 hrs	12*12=144 hrs i.e. 6 days	Yes
Total	90 Mins	24	24*12=288	90*24=2160 mins i.e. 36 hrs	36*12=432 hrs i.e. 18 days	Partial

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			made by:
Reviser	Datum	Subject of the investigation: ASSEMBLY LINE MATERIAL FLOW Ø300I	Current procedure / Suggestions

Lfd. Nr.	Process	Bearbeit. + Form change	+ Condition cha	Bewegen O Handle	> Transport	□ Control	D Waiting	Δ Storage	Distance in m X	Y	Work force Nr.	Lohn bzw	Art	Progress time	Individual times in.......... Bearbeiten	move Handle	move Transport	Control	Waiting	Storage	Remark	
1	2	3	4	5	6	7	8	9	12	13	15	16	17	18	19	20	21	22	23	24	25	
1	INPUT OF MATERIAL					□	D		60		2			30				15	15			
2	STORAGE OF MATERIAL				>			Δ	2	10				1170		15	15			1140	same persons as at step 1	
3	ROLLER JACKETS PREPARATION			O	>	□			36	48				37		17	12	8			same persons as at step 3	
4	TRANSPORT TO FINAL ASSEMBLY				>				50	48				2			2				same persons as at step 3&4	
5	SUB - ASSEMBLY			O			D		20	2	1			4		4						
6	TRANSPORT BB TO FINAL ASSEMBLY				>				15	2				4		2	2				same person as at step 6	
7	FINAL ASSEMBLY			O	>		D		70	70	2			288		118	15	5	150			
8	FINAL INSPECTION					□					1			5				5				
9	PACKAGING			O					0	12				10		10					same person as at step 8	
10	TRANSPORT				>				40	12				6			6				same person as at step 10	
11	STORAGE							Δ														
12	SHIPPING			O	>				5	6	2			7		3	4					
	Sum			6	11	3	3	2	298	210	8			1563.0	0	169	56	33	165	1140	Nr.	

Figure 5-11:Future process map of the SS Roller for assembly process

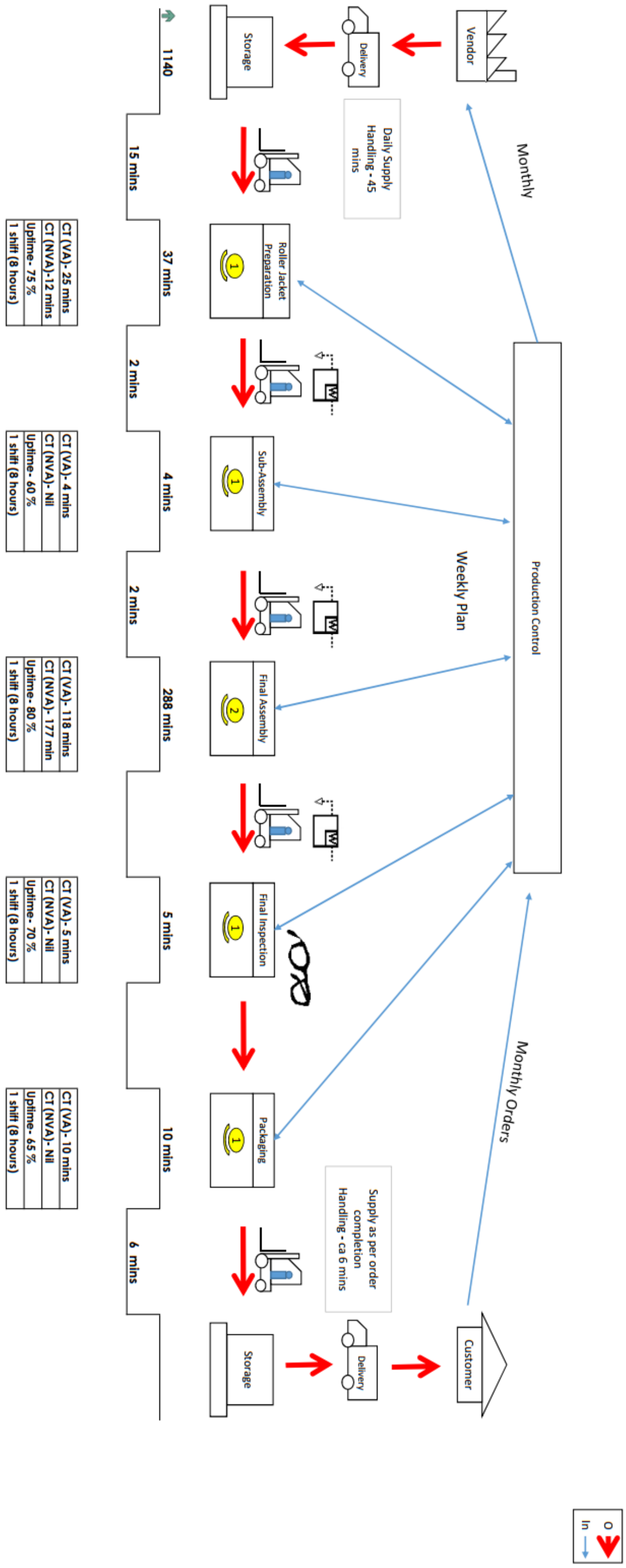

Figure 5-12: Future state of the VSM of SS Roller in the assembly process

As compared to the current state, there is a total reduction of 2083 mins in future state total time. Savings are a consequence of the reduction of material grouping and transportation step, reduction in time at final assembly due to polishing and pre-heating of material.

Table 14: Comparison of the current and future state

Time	Current State	Future State
	Minutes	**Minutes**
CT (VA)	294	153
CT (NVA)	2119	65
Transportation	93	35
Waiting at storage- 1440 mins	1140	1140
Total Time	**3646**	**1563**

5.2.2 DISASSEMBLY PROCESS

Future state for disassembly is being made in a similar way to the assembly process. After analyzing the cycle times of the current state, the focus was shifted to the bottleneck process and NVA times. Significant improvements have been made in terms of reduction of overall lead time for the disassembly process, which is due to a major reduction in NVA times along with time reduction due to utilization of machines and efficiency at optimal capacity. The same is being reflected in the timesheet as well as a VSM of a future state.
Improvement points are explained in the list below:

1. The disassembly process is not as continuous as now. For roller disassembly, there is NVA time that is caused by waiting time for the welder. Welding for roller disassembly is being done by outside welder but in the current workshop only. The welder comes when there is enough number of rollers that need unwelding. Suggestions for the reduction of NVA time in roller disassembly are:

   a. Future rollers won't require welding operation for disassembly.
   b. The welder can be engaged regularly for one roller disassembly or whenever there are two roller disassembly is planned. The welder can be intimated prior to the same, and there will be no delay in roller disassembly.
   c. Workshop workers can be trained for the welding operation.

2. Currently, the full capacity of the ultrasonic machine is not being utilized. One-time ultrasonic cleaning requires 2 hours, and it is being carried out in one batch for one roller disassembly, which results in the engagement of the machine for 2 hours x 1 = 120 mins. But the batch which is being used for cleaning is filled with parts till level one, i.e. one layer. Additional layers

can be put, but it will cause ineffective cleaning. To tackle this issue and to utilize the maximum capacity of the cleaning machine, perforated stackable mesh pallets can be used to stack the disassembled parts till level two. It will allow for better and effective cleaning. Therefore, ultrasonic cleaning can be performed in half time as that of the current state, i.e. it will be completed in 60 mins.

3. Similar to ultrasonic cleaning full capacity of the neutralization machine is not being utilized in the current state. By utilization of optimal capacity for roller diameter 300, time taken for neutralization in the future state of roller disassembly of diameter 300 will be 60 mins.
4. Roller disassembly requires 262 mins for one roller while the next step requires 35 mins for bearing block disassembly. It means there can be a maximum of 2 roller disassembly in a day. If bearing block disassembly will be done simultaneously, then there will be the utilization of the workforce for a very low period in a day, i.e., 70 minutes. It is advisable to do the operation once there is a minimum of three days of inventory after roller disassembly step, i.e., six rollers. These six disassembled rollers will be moved to the next step for bearing block disassembly, and it will be completed in a single day with complete utilization of the workforce.

All the above explained points are being reflected in timesheet below (Figure 5-4).

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Reviser / Datum	**Subject of the investigation** Disassembly Line Material Flow	Current procedure / Suggestions

Lfd. Nr.	Process	Form char +	Condition +	Handle o	Transport >	Control □	Waiting D	Storage Δ	Distance in m X	Distance in m Y	Funding	Work force Nr.	Work force Lohnbzw. Lo	Work force Art	Progress time	Bearbeiten	Handle	Transport	Control	Waiting	Storage	Remark
1	2	3	4	5	6	7	8	9	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	TRANSPORT				>				325	5	Truck	1			12			12				
2	ROLLER DISASSEMBLY			o			D				Crane, maschine	3			300		292	8				
3	TRANSPORT				>				7	2												
4	BEARING BLOCK DISASSEMBLY			o		□					Tools	5			35		35					
5	TRANSPORT TO SEGMENT WORKSHOP				>				75	5	Forklift	1			10		5	5				
6	HIGH PREASSURE CLEANING			o											20		20					Performed at Segment workshop
7	TRANSPORT TO RS-A				>				75	5	Forklift, trolley				15		5	10				
8	ULTRASONIC CLEANING			o			D		5	5	Machines, crane				63		60	3				
9	TRANSPORT				>				3	3	Crane				2			2				
10	NEUTRALIZATION			o						5	Machines, crane				60		60					
11	TRANSPORT				>				3	3	Crane				2			2				
12	RUST REMOVING			o						5	Machines, crane				15		15					
13	TRANSPORT				>				16	6	Truck, forklift,crane				5		2	3				
14	BEARING BLOCK WATER TEST			o		□					Machine	1			34		4		30			
15	FINAL INSPECTION					□			2		Testing tools	1			60				60			
16	TRANSPORT				>				2	2	Trolley	1			5			5				
17	PAINTING			o					2		Brush	1			7		7					
18	STORAGE			o				Δ	20			1			10		10					
															0							
	Summe/ Übertrag			9	8	3	2	1	535	41		14			655	0	515	50	90	0	0	**Nr.**

Figure 5-13: Future state of the process flow in the disassembly line

As discussed above, in the current state full capacity of the machine for ultrasonic cleaning and neutralization is not being utilized. If the perforated batch used in the machine is being stacked with more two batches then cleaning for the whole roller will be reduced to half, 60 mins instead of 120 mins. This kind of batch and stacking arrangement for roller parts will allow the cleaning media to flow through all the surfaces with minimal hindrance. This will result in better cleaning with reduced time and energy. Cleaning will be completed in one batch instead of two batches for ultrasonic cleaning so energy saving will be there along with time and effort saving.

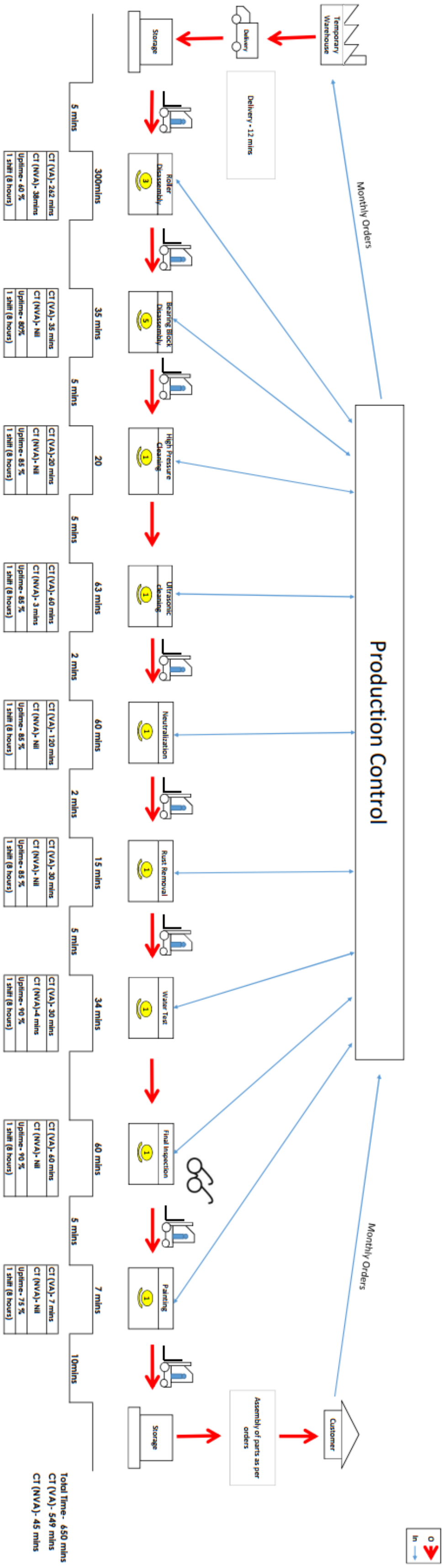

Figure 5-14: Future VSM of the disassembly process

The above figure explains the material and information flow for the disassembly process of roller diameter 300 with the help of the VSM.

Table 15: Current vs. Future state in the disassembly line

Time	Current State	Future State
	Mins	Mins
CT (VA)	714	549
CT (NVA)	1089	45
Transportation	51	51
Total Time	**1868**	**655**

Table 15 summarises the improvements made in terms of time for the roller disassembly process in a future state as compared to the current state for the same. There is a saving of 1213 mins in a future state, which means there should be a 65% improvement in time in a future state. The MF will be smoother and faster.

5.3 Kanban

- **Assembly process**

1. Production planning

Once an order is received, it is being written on the board, and planning for production can be done once when it is a green card for the raw material availability given. This system can work in an excel spreadsheet and also with physical cards.

Table 16: Kanban Table 1

Colour Signal	Description
(red)	Items are missing-parts are not delivered
(yellow)	Specific items are missing
(green)	All items are available - assembly can start

There will be three cards that will be used to send physical signals. Different component or part is required for assembly of one particular roller. In the current state, the material is received one day before for the assembly. One supervisor will check the material received, and he will assign the material received to the rollers that are yet to assemble. In a table, all orders for the month will be listed, and a card will be placed for component availability check. If the item is available in the workshop, then the green color card will be placed else, a red color card will be placed.

If all the components required for one particular roller assembly are available in the workshop, then the overall status will have a green card, and that roller can be assembled on the next day. In case, few components are available, (one or more component is unavailable), then the yellow card will be placed in overall status. This will help the manager to focus on missing components for the next delivery of parts from the vendor or temporary warehouse. In case there is no available component for roller assembly, a red card will be placed in the overall status of material availability. The demonstration of the same is given in Table 17.

Table 17: Kanban Table 2

Customer	Roller	Raw Material Availability				
		Roller Jacket	Oil Seals	Bearing 1	Bearing 2	Overall status
HQ3	Sleeve 120					
SS1	I-Star 230					
HQ12	Split 200					

Things become easy by using Kanban cards, and it helps the manager or supervisor to take quick and correct actions. This particular type of card system will help the workshop to secure items' availability, and no extra item will be assembled if there is no item available for that specific order. The job will be released for assembly only if the overall status has a green card.

2. Kanban in the assembly process

Any work in progress inventory and waiting time is wastage. Future statue of VSM is made using a line balancing concept, which means there will be no waiting time for the material assembly. As the scheduling for assembly will be done based on the overall status of raw material availability and the line is balanced, so there will be only one item assembled at each workstation.
If workload or cycle times are different for each workstation, then work in progress inventory for each workstation can be planned based on the cycle time of workstation. The maximum WIP number will always be fixed. As in the case of roller diameter 150, there will be no WIP due to line balancing.

Demonstration of the Kanban card system to control assembly process and accumulation of WIP inventory is as follows-

Table 18: Kanban Table 3

Colour Signal	Description
	Specific items are missing
	Work in progress
	Activity is completed
	Workstation is not functional

Table 19: Kanban Table 4

Kanban Board				
Item	Workstation 1	Workstation 2	Workstation 3	Workstation 4
Roller dia 150				
Remark - Work is going on smoothly at all workstations as there is only one roller assembly is going on, and no WIP is held in between				

Table 20: Kanban Table 5

Kanban Board				
Item	Workstation 1	Workstation 2	Workstation 3	Workstation 4
Roller dia 150				
Remark - Final assembly and testing at workstation two are complete, but assembly is still going on workstation 4. WIP held up at work-station 2				

It indicates that there is a problem in final inspection and packaging at workstation four. To resolve the issue and smoothen the process flow, the supervisor or manager needs to focus on workstation four so that work in progress inventory can be eliminated from workstations.
In this case, the operator at workstation two will inform the manager as it will cause WIP at workstation one too after some time. Based on the situation, the manager can ask the operator at workstation 2 to help operation at workstation four or can assign some tasks until the process is in the same flow again.

Table 21: Kanban Table 6

Kanban Board				
Item	Workstation 1	Workstation 2	Workstation 3	Workstation 4
Roller dia 150				
Remark - There is no assembly going on at workstation 3				

It indicates that there is no assembly going on at workstation. It means there is a shortage at workstation three, which is caused due to the workflow at workstation one. The workstation one, in this case, requires more focus and attention.

Table 22: Kanban Table 7

Kanban Board				
Item	Workstation 1	Workstation 2	Workstation 3	Workstation 4
Roller dia 150				
Remark - Workstation 2 is not functional				

It indicates that workstation two is not functional. So workforce deployment and other activities can be planned accordingly such that cycle time at each work station is nearly balanced.

- **Kanban for Disassembly Process**

Kanban can be used in the disassembly process to make rollers more visible. It can be used in production planning and also to control work in progress inventory.

Furthermore, it helps to set up just in time inventory in the supply chain. Also, it can be used whether in procurement or inventory management of work in progress between workstations or at dispatch warehouse.

1. Production planning

After receiving an order for roller disassembly, planning for disassembly operation needs to be done. It will depend on the availability of resources to carry out the specific operation. In this case, machine, workforce, and chemicals are required. Moreover, with switching manual processes to an automatic one, the availability of high pressure cleaning machines needs to be checked.

Table 23: Kanban Table 8

Colour Signal	Description
	No resource is available for disassembly
	All the required resources for disassembly are available

Table 24: Kanban Table 9

Resource Availability				
Welder	In house Machines	Manpower	High pressure Machine	Overall Status

Things become easy by using Kanban cards, and it helps the manager or supervisor to take quick and correct actions. This particular type of card system will help the workshop to have roller disassembly based on the availability of all the resources required for the same. The job will be released for disassembly only if the overall status has a green card.

2. Kanban in the disassembly process

Any kind of work in progress inventory and waiting time is wastage. As there are ten steps in the complete process of roller disassembly which are being carried at different machines. Few measures have a higher cycle time & others have very low. Therefore, to utilize the machine and workforce with complete efficiency and effectiveness, the Kanban card system can be used. No doubt that waiting time will be increased, but it will not matter if orders are discontinuous. In the case of a continuous order system, line balancing can be planned, and machines and workforce deployment can be done accordingly.

If workload or cycle times are different for each workstation, then work in progress inventory for each workstation can be planned based on the cycle time of workstation. The maximum WIP number will always be fixed. As in case of roller diameter 300, there will be WIP of 6 rollers at roller disassembly. There will be a card of each roller disassembly, which will be placed on board in sequence. When there will a minimum of six cards placed at Kanban board, then bearing block disassembly will start. One day WIP will be created after bearing block disassembly, and it will be sent for high pressure cleaning. Similarly, rust removal will start when six rollers after neutralization are available, as neutralization requires 180 mins for each roller, and rust removal requires only 30 mins. Demonstration of the Kanban card system to control the assembly process and accumulation of WIP inventory is as follows:

Table 25: Kanban Table 10

Colour Signal	Description
	Material shortage at the workstation
	Work in progress
	Activity is completed
	Workstation is not functional

Table 26: Kanban Table 11

Kanban Board					
Item	Job No	Roller Disassembly	Bearing Block Disassembly	Neutralization	Rust Removal
Roller dia 300	1				
Roller dia 300	2				
Roller dia 300	3				
Roller dia 300	4				
Roller dia 300	5				
Roller dia 300	6				
Remark - Once six rollers are being disassembled at step 1 (roller disassembly), then bearing block disassembly will start. Similar at rust removal step.					

Table 27: Kanban Table 12

Kanban Board					
Item	Job No	Roller Disassembly	Bearing Block Disassembly	Neutralization	Rust Removal
Roller dia 300	1				
Roller dia 300	2				
Roller dia 300	3				
Roller dia 300	4				
Roller dia 300	5				
Roller dia 300	6				
Roller dia 300	7				
Remark – Once six rollers are being disassembled at step 1 (roller disassembly), then bearing block disassembly will start. Similar at rust removal step.					

In this way, it will be easier for the workshop manager to have an overview of the process, and he will be able to utilize the workforce more efficiently.

6 Conclusion/Summary/Outlook

This research is dealing with the investigation of possible improvements of material and process flow of roller maintenance workshop using Lean. Several tools were used: Value Stream Mapping, Line Balancing, Kanban. The main goal of improvement development is to ensure the harmony of all process elements.

The process flow analysis at PTTS is made based on the current layout organization and current cycle time of observed products. The analysis helped to identify several issues related to processing procedures. In the assembly line, most of the issues are related to material purchase and delivery. Because of the missing delivery, the workshop is forced to produce parts that are not ordered, and meanwhile, required orders are not delivered. Additionally, several types of wastes are identified along the assembly line: transportation, unnecessary movement, waiting, and waste of human creativity.
The disassembly line is also having a problem with waiting time, especially with rollers that used to be maintenanced in another workshop, where other working procedures were being used. An additional issue that is identified at the disassembly line is the cleaning process. Machine cleaning is shut down, and the complete cleaning process is done manually. Three alternative options for the cleaning procedure are analyzed. Layout investigation helped to identify transportation distance and effects of each variant on cycle time.

Improvement suggestions are developed with the guidance of Lean and visualized and analyzed with usage of Value Stream Mapping and Process Flow Map. Furthermore, layout variants are evaluated with different criteria like effect on the process, transportation distance, flow, and cycle time. Line Balancing and Kanban are made to ensure almost the same process time at different stages of the process, and to reduce waste time. A combination of the suggestions results in an overall improvement of the process and the material flow.

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7.4 List of Abbreviations

MF	Material Flow
NVA	Non – Value Added
RS-A	Observed maintenance workshop
TW	Temporary workshop
VA	Value Added
VSM	Value Stream Mapping