



**REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKER SCIENCE AND TECHNOLOGY
UNIVERSITY**

**INSTITUTE OF GRADUATE SCHOOL
DEPARTMENT OF INDUSTRIAL ENGINEERING**

**IMPROVING ALUMINUM CABLE MANUFACTURING PROCESS BY
IMPLEMENTING LEAN PRODUCTION TOOLS**

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MASTER OF SCIENCE**



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ABSTRACT

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Lean production system is a production system that aims to increase quality and efficiency, maximize customer satisfaction, and minimize costs by eliminating waste in the product and service creation process. Within the scope of this study, in an enterprise that produces aluminum conductors; It is aimed to adapt the lean production system in order to reduce costs, increase quality, reduce waste, and make a simpler and more efficient production. In the study, Value Stream Mapping (VSM) technique, which is one of the lean manufacturing techniques, was used primarily in order to analyze the current situation. In the VSM technique, the production flow is composed of material and information flow. Value stream mapping of the selected product group was performed with the current state map. The improvement projects that emerged after the VSM technique was applied on the product group we determined were determined in order of priority by using Multi-Criteria Decision Making (MCDM) methods. Solution suggestions are presented to the problems by using lean manufacturing techniques such as Total Productive Maintenance (TPM), Continuous Improvement (KAIZEN), JIDOKA. This study will make an important contribution to the literature in terms of the application of lean manufacturing techniques in the aluminum conductor sector that has continuous production.

Keywords: lean manufacturing, value stream mapping, multi-criteria decision making

ÖZET

YALIN ÜRETİM ARAÇLARI UYGULANARAK ALÜMİNYUM KABLO ÜRETİM SÜRECİNİN İYİLEŞTİRİLMESİ

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Yalın üretim sistemi, ürün ve hizmet yaratma sürecini israflardan arındırarak kalitenin ve verimliliğin artırılmasını, müşteri memnuniyetinin üst düzeye çıkarılmasını, maliyetlerin minimuma indirilmesini amaçlayan bir üretim sistemidir. Bu çalışma kapsamında alüminyum iletken üretimi yapan bir işletmede; maliyet azaltma, kaliteyi artırma, israfları azaltma, daha sade ve verimli bir üretim yapılması adına yalın üretim sisteminin uyarlanması amaçlanmaktadır. Çalışmada, mevcut durumun analizinin yapılabilmesi için öncelikli olarak yalın üretim tekniklerinden Değer Akış Haritalama (DAH) tekniği kullanılmıştır. DAH tekniğinde, üretim akışını malzeme ve bilgi akışı oluşturmaktadır. Mevcut durum haritası ile seçilen ürün grubunun değer akış haritalaması gerçekleştirilmiştir. Belirlediğimiz ürün grubu üzerinde DAH tekniği uygulandıktan sonra ortaya çıkan iyileştirme projeleri Çok Kriterli Karar Verme (ÇKKV) metotları kullanılarak öncelik sırası belirlenmiştir. Toplam Üretken Bakım (TÜB), Sürekli İyileştirme (KAIZEN), JIDOKA gibi yalın üretim teknikleri kullanılarak problemlere çözüm önerileri sunulmuştur. Bu çalışma, alüminyum iletken sektörü gibi sürekli üretim yapan bir işletmede yalın üretim tekniklerinin uygulanması açısından literatüre önemli bir katkı sunacaktır.

Anahtar Kelimeler: yalın üretim, değer akış haritalama, çok kriterli karar verme

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1. INTRODUCTION

1.1. Lean Manufacturing History

The history of industrial improvements from the time of mass production to lean manufacturing is expressed visually in Figure 1.1. In the 1800s, the concept of production began to be considered as a process. Eli Whitney was one of the people who were influential in the emergence of the concept of process in these years. Eli Whitney applied and continued the processes with short cycle time in the production system in the arms production facility. In the 1900s, Frederick Taylor introduced the concept of standard work. Frank Gilbreth created the work-motion study and the concept of process mapping. In the 1910s, Henry Ford implemented and developed the mass production system. He made the flow system by taking the example of the band system in the slaughterhouses. The foundation of the production and management system called lean production today has been laid in the Japanese Toyota company in the 1950s under the leadership of Eiji Toyoda and Taiichi Ohno. In the 1950s, he was sent to the United States to be trained as a Toyota production director. In addition to using some elements of the "mass production" system pioneered by Ford, Eiji Toyoda had a critical eye on this method during his trip to America to study Ford. He also blended his ingenious ideas with the birth of an appropriate and new production and management system for Japan.

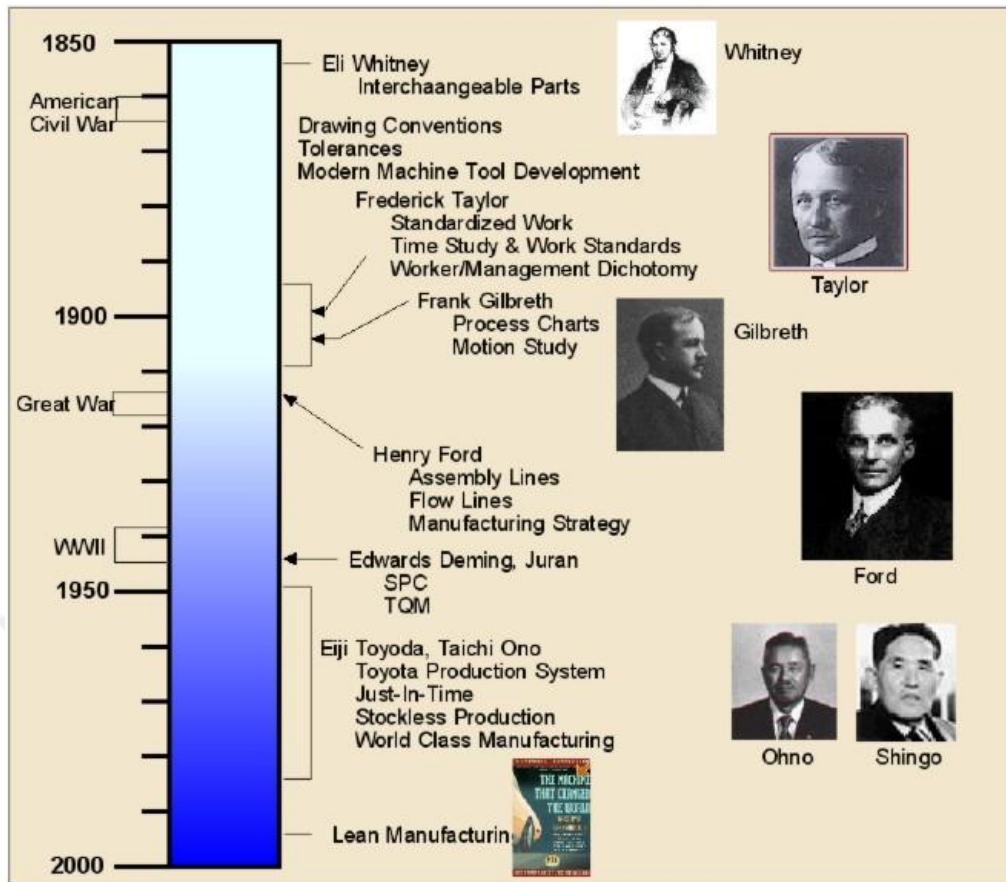


Figure 1.1 Lean manufacturing history timeline (Stratego)

It has been determined that the waste in the mass production system is quite high. It has been observed that the major reason for this is due to the inefficiently used workforce. The fact that human power is used only physically and brain power is not used in improvements causes problems in the production system. In addition, there is no flexible structure in mass production. The inefficient use of labor in production and the problems of inflexibility cause the adjustments to be made for changing from one product to another or changing the mold in production. For many reasons like these, the application of the conventional mass production approach, which has been dominant in the West since the 18th century, in Japan has not been considered appropriate for the Japanese conditions of that day.

Lean manufacturing; It is the result of a search for how to use all production factors in the most flexible way, with the least resources, in the shortest time, with the cheapest and error-free production, in a way that can respond to customer demand one-to-one, without wastage. Lean manufacturing is based on the principle of achieving all of these goals at the same time. It was

born and developed as a product of a skeptical approach or philosophy that questions all generally accepted rules and principles and does not see any established opinion as absolute.

1.2. Lean Manufacturing and Its Principles

Since the early years of industry history, companies have been in competition and are in a global race to increase their sales. Managers in companies are looking for the fastest and most economical ways of producing and distributing products and services. While the pressure in global competition is spreading from the east to the world, the survival of production companies depends on the ability to reduce production costs, the continuous development of products and the ability to keep up with the changes in socio-technological developments.

Therefore, the key to being efficient, productive and flawless is lean production. In order to understand what lean production means in a simple and detailed way, it is necessary to know the definitions of lean production and some basic lean concepts in these definitions. Lean manufacturing; It is a production system that does not contain any unnecessary elements in its structure and in which elements such as error, cost, stock labor, development process, production area, waste, customer dissatisfaction are minimized. With a very simple definition, Lean Production is based on the principle of making more production in less time, with less stock amounts, less idle employees and capital use. The lean production system is viewed as a comprehensive production system, including just-in-time production. In a broader expression, lean production is the way to respond to customer demand in the shortest time, with the least use of resources, with the cheapest and without errors. It can be defined as making use of all the potentials with the least waste and finally using all the production factors in the most flexible way. It was born and developed as a product of a skeptical approach or philosophy that questions all accepted rules and principles and does not see any established opinion as absolute (Özçelik & Cinoğlu, 2013).

There are six success factors that characterize lean manufacturing. These; project manager, teamwork, knowledge culture, integration with suppliers, concurrent engineering consumer orientation. Among these, teamwork, integration with the project manager and consumers are the factors that distinguish the concept of lean manufacturing from the less competitive alternative concept of Tayloristic structured production (Aslantaş, 2014).

The reasons that lead businesses to lean philosophy and to act lean are becoming increasingly essential. The unconscious and ruthless consumption of the raw material resources on earth, the high costs of the techniques and methods used in the production of goods and services in today's competitive environment and economic atmosphere, one of the ways to make sustainable profit possible in the long run by using quality, time and customer satisfaction system can be adopted and implemented. Lean is a philosophy, and in this philosophy, waste is anything that does not offer any benefit to the user of the product or service beyond its known meaning, and that the customer will not accept to pay extra. Reducing costs, increasing customer satisfaction, gaining flexibility to adapt to market conditions, accelerating cash flow by eliminating all kinds of waste (errors, overproduction, stocks, waiting, unnecessary works, unnecessary movements, unnecessary transportation) in all product and service creation stages from design to shipment with the aim of increasing the profitability of the company (Şeker, 2016).

Lean production is also described in many sources with terms such as "Just in Time Production" and "Toyota Production System". But it seems that lean production is actually a general system that includes all these terms. Up to now, today's lean production system has been reached with the contributions of many people other than Toyota Motor Company. Therefore, it would not be wrong to accept the "Toyota Production System" as a system that forms the basis of lean production. Just-in-time production, flow-type production; are concepts that are among the goals of lean manufacturing. There are 5 basic principles for the implementation of lean thinking (Kılıç & Ayvaz, 2016);

- Determination of values (customer value) by determining what customer values are in a product service
- Identifying value streams for a product line or a particular product during the value stream and eliminating non-value adding activities (value stream)
- Ensuring the flow of products or services by providing a continuous flow for value-adding activities (flow)
- Establishing a pull mechanism starting from the customer by determining what the customer wants, arranging stocks and when customers want it (pull system)
- Strive for excellence (excellence) to ensure continuous lean improvement

Value: The critical starting point of lean thinking is the concept of “value”. Value is created by the producer, but value can only be defined by the end customer. When viewed from the customer's side, it is the reason for the existence of manufacturers. The producers who create the value often fail to define the value correctly (Womack & Jones, 2015).

Value Stream: The second step of Lean thinking is defining the value stream. The value stream includes all the stages from one producer to another producer and the end user in the process of transforming the raw material into the final product, and it contains an incredible amount of waste.

Continuous Flow: Once value is fully defined, value stream mapped appropriately for a particular product, and wasteful steps are eliminated, value-adding activities will emerge. The continuous flow step takes place by the sequencing of these value-creating activities (Womack & Jones, 2015).

Pull: The pull principle of lean thinking envisages the customer to pull value from its source. Pulling means that no product or service is produced at any stage before the customer requests it in the later stages. The pull principle starts with the demand made by the end customer for a certain product, and it is applied as starting production by following all the stages backwards until the product reaches the customer and demanding each stage from the previous one. When this principle is applied; there is no need for stocks, scrap and waste caused by undesired production are prevented, scheduling is not required for each machine, demand fluctuations towards the beginning of the process are prevented, it is possible to produce all products in any combination and instantly adapt to changes in demand (Duman, 2019).

Excellence: In lean manufacturing, product faults, equipment failures, and waiting times are not considered normal and the root cause is constantly investigated and resolved. This step is an effort to be perfect in all processes (Kulaç, 2012). Excellence is a lean journey without an end point. The concept should be seen as “continuous improvements”. Lean thinking is based on the principle of "doing the right thing at once" instead of "doing the job right". On the other hand, since waste cannot be completely eliminated, perfection is a relative goal that is not completely attainable. In this respect, the realistic aim should be to ensure that the process is operated in line with the highest performance value that can be achieved and that this value is

constantly improved. The concept of zero defects, which is seen as the key point of excellence, is actually an approach to prevent errors from occurring rather than find and fix them.

In the second part of the thesis, the concept of lean production and the techniques used in lean production are emphasized by making use of the studies in the literature. The third section is the material and method section. In this section, the introduction of the production facility, the explanation of lean production techniques and the case study are explained. In the case study, the determination of the product family to be studied, the drawing of the value stream map, the determination of the existing problems, the determination of the bottlenecks, wastes and problems according to the calculations in the current situation map were carried out. In terms of guiding the firm in projecting the identified problems, the weights of the criteria were calculated using the AHP technique before the multi-criteria decision-making methods, and then the projects were ranked according to the degree of importance with the TOPSIS method. In the fourth chapter, what needs to be done in improvement projects are planned and lean production techniques to be used for improvements are determined. The findings as a result of the improvement study were expressed. The application of lean techniques still continues in this company, which started lean production studies. In the conclusion part, the benefits of lean manufacturing practices to the business are summarized and suggestions are presented on the applicability of other projects.

2. LITERATURE REVIEW

In order to better understand the lean production system, some case studies in the literature are examined.

Due to today's global competition, companies had to radically change their production and management practices in order to exist in the market. In this context, they have adopted several advanced technical issues to ensure just-in-time production, total quality management, lean manufacturing, flexible production systems, process improvement and efficiency. The aim of all these programs has been to reduce cost, improve quality, shorten cycle time and increase flexibility in the factory environment. However, support systems such as finance and cost management have generally not kept pace with the level of relevant operational changes implemented. Modarres et al.(2005) presented a case study on the cost of kaizen applied by Boeing Commercial Airplane Company, IRC Division, on these issues. The aim of the study is to describe a method that will provide practitioners with relevant cost data to determine kaizen costs that can be useful in implementing lean manufacturing decisions (Modarress, Ansari, & Lockwood, 2005).

Kazıcıoğlu and Yazgan (2009) proposed a new lean production roadmap that businesses can follow in transitioning to lean production. They implemented this in a tire company. In the proposed roadmap, bottlenecks and wastes are identified in the first stage. In the second stage, improvement plans are created to eliminate waste, and in the third stage, culture change and improvement plans are implemented. Value stream mapping technique is used to identify bottlenecks and waste. Again, the future situation analysis in value stream mapping technique is used in the creation of improvement plans. In the improvement projects determined in the third stage, cell system, SMED, 6 Sigma and 5S techniques were applied (Kazıcıoğlu & Yazgan, 2009).

Ar and Ashraf (2012) conducted a study on the production process of a factory that produces parts for the automotive industry based on Lean Manufacturing (LP) principles. Value stream mapping (VSM), one of the lean manufacturing techniques, was used in the study. Value stream mapping steps are explained and applied. A case study is conducted on a product. Value-added and non-value-added activities are identified (Ar & al-Ashraf, 2012).

Rahman et al. (2013) conducted a case study to determine how the Kanban system works effectively in the multinational organization and to identify the factors that prevent Malaysian small and medium enterprises (SMEs) from implementing Kanban. The study's findings show that top management commitment, vendor involvement, inventory management, and quality improvement are important for Kanban deployment and lean manufacturing. As a result, the Kanban system applied in this manufacturing company was found to be sufficient since many benefits such as operational costs, waste, scraps and losses are minimized, and excess production stocks are controlled with flexible work stations. It is stated that the company should improve its current policy and develop standard operating procedures for all processes in the production line in order to make the production process more efficient in the future (Rahman, Sharif, & Esa, 2013).

In this study, Rahman and Karim (2013) discussed tile production, which has large operational costs, excessive inventory and waste, and quality problems. They aimed to assess the possibility of reducing the operational and inventory costs of the production process through waste minimization. They developed current and future value stream mapping for such a process to analyze the current waste situation in a tile manufacturing process and to apply lean principles in production. The focus of the approach is cost reduction by eliminating non-value-added activities (Rahman & Karim, 2013).

The academic literature shows that the adoption of lean manufacturing and some of its tools such as value stream mapping (VSM) by Indian manufacturing SMEs is weak or in most cases lean initiatives fail. Aayush et al (2014) present in their study a successful application of VSM in an Indian manufacturing SME. The results of the study and the operational improvements achieved show that VSM implementation is an effective strategy for this type of organizations to improve their processes and thus overcome their current challenges. The study contributes by providing empirical evidence of the application of VSM in India and can therefore be used as a guiding reference for managers and engineers to undertake specific process improvement projects in their own organisations, similar to the one presented in this article (Saboo, Garza-Reyes, Er, & Kumar, 2014).

Inta and Muntean (2015) used lean principles to optimize production in a Romanian connector manufacturer. In the study, continuous improvement methods were examined in depth. The change in the supply system has put the company in great losses as the stocks are released and kept in production until the orders are fulfilled. To solve this problem, the KANBAN method has been applied (Inta & Muntean, 2015).

Lacerda et al. (2016) presented a case study describing the use of value stream mapping, one of the lean manufacturing techniques, in the manufacturing process of automotive parts for a large automotive company. They collected and analyzed relevant data from the process. Afterwards, the first process is mapped, the relevant wastes are identified, and subsequent processes are mapped. As a result, financial results have been estimated. Suggestions; It is presented at kaizen meetings, the action plan is discussed, and it is decided which option to choose. As a result of the application, the cycle time and labor level are reduced, the process is improved and savings are achieved (Lacerda, Xambre, & Alvelos, 2016).

Roriz et al(2017) presented an industrial case study focusing on improving the quality of manufacturing processes using lean manufacturing tools. In the first case, examination of cause-effect diagrams, Pareto analysis, setup times and performance indicators took place. In this way, main problems such as high setup times, low availability of machines, lack of organization in the work area were identified. Lean techniques such as SMED methodology, 5S technique and visual management have been applied to the problems. As a result, a 47% reduction in installation time was achieved. This corresponds to an average monthly profit of 10114 € (Roriz, Nunes, & Sousa, 2017).

Verma and Sharma (2017) conduct a case study in a small-scale industry in Ranchi, Jharkhand, presenting a lean manufacturing practice model to improve productivity and quality. The purpose of the study is to identify and fix waste related problems, the cause of equipment failure, bottleneck problems. The above issues have been analyzed in relation to reject control, inventory control, waiting time, set time and elimination of non-value added time/activities. The problems are uncovered by value stream mapping. The study shows that lean tools can be applied in small-scale industries and it is important to calculate takt time to reduce waste and increase productivity (Verma & Sharma, 2017).

Kareem et al. (2017) tried to investigate critical issues affecting the success of implementing lean production programs in iron and steel factories in the Iraqi Kurdistan Region. Survey studies were conducted to collect data within the framework of the case study. The results of the study revealed the importance of management commitment and allocating resources, training the workforce and ethical guidelines to the success of lean implementation. According to the findings; It is recommended that organizational managements provide financial and moral support to their employees in order to ensure the successful implementation of lean production (Kareem, Askari, & Muhammad, 2017).

Gören (2017) presents an industrial application example that combines VSM and simulation for the furniture industry, where waste is extremely high. Current and future state maps along with improvement suggestions for a determined product family are explained using VSM. A simulation model was created and the “before” and “after” scenarios were analyzed in detail. First of all, the current situation of the company is given and a simulation model is developed to analyze the production system in detail. Then, based on the results of the simulation and the current state map, a future state map was created with suggestions for improvement. With the suggestions made, the total flow time has been improved and the non-value-added time has been reduced (Goren, 2017).

Mohammed Faisal (2018) conducted a study aiming to analyze the future state mapping of VSM (value stream mapping) for the implementation of lean manufacturing using predictive analytics. Predictive simulation models are analyzed to understand the current state of the VSM and future state mapping. The analysis shows that VSM's predictive simulation analytics is a suitable analytical tool for implementing lean manufacturing in SMEs to increase competitiveness. The findings of this study have been empirically validated by predictive simulation analytics (Faisal, 2018).

In their study, Sousa et al. (2018) examined and collected information about the application in the cork stopper industry, taking into account the lean production philosophy. The operating conditions of the assembly machine were also analyzed to find improvement opportunities. At this stage, they used the value stream mapping (VSM) technique to identify value-adding activities and non-value-added activities. The SMED methodology was then applied to reduce downtime caused by vehicle changes, resulting in a 43% reduction in total transit time. Finally,

they applied the OEE calculation as an indicator of overall equipment efficiency to monitor and improve possible deviations during production (Sousa, et al., 2018).

Saravanana et al. (2018) discussed improving productivity in a pre-assembly line of a gearbox manufacturing company with a case study using lean concepts such as process flowchart, process Gantt chart, and time study. In the study, they presented a case study on how value stream mapping should be done on a planet carrier pre-assembly line. Value stream mapping and business standardization are key tools used in lean manufacturing and lean transformation. It makes the process smoother, helps reduce lead time and ultimately increases productivity. From the observed results, it is determined that the productivity increased from 7 parts in the first step assembly to 10 parts when the proposed VSM is applied. With the implementation of the proposed value stream system, 126 minutes of TAKT time was shortened and a processing time of 165 minutes was provided for a 10-piece request. There is an improvement of approximately 24% in the overall procedure time (Saravanana, Nallusamy, & George, 2018).

Parab and Shirodkar (2019) carried out a case study of VSM application in a special purpose lock manufacturing facility. A baseline map has been drawn to see how the production processes are progressing. With the application of process improvement techniques, a future state map was developed to design a lean process flow by eliminating wasteful activities. The current process layout, full of excessive inter-station transport, has been replaced with an efficient and cost-effective product layout. In addition, lean tools such as 3G, Kaizen and 5S have been implemented for better use of production facilities. The result was significant reductions in production lead time and WIP inventory. Production lead time and WIP inventory decreased by respectively 62.74% and 66.09% (Parab & Shirodkar, 2019).

Hartini et al. (2019) aimed to develop a manufacturing sustainability index (MSI) based on lean and sustainability concepts using sustainable value stream mapping. Delphi, Sus-VSM and AHP methods were used together to create MSI. Delphi method was used for the selection of the relevant indicators, sustainable-VSM was used for the evaluation of the indicators using the efficiency approach, and the AHP method was used for the determination of the indicator weights. This research developed a successful evaluation model for factory level furniture sustainability performance as a single score called MSI (Hartini, Ciptomulyano, & Anityasari, 2019).

Indrawati et al. (2019) conducted a study focusing on wastage in the production process in a steel processing industry. As a result, they observed that the dominant production waste is the lag time. There are seven factors that cause major production waste; operating, mechanical, tuning, electrical, computer, instrumentation and service. These factors are the cause of production waste and production activities that do not add value to the product. In this study, a maintenance improvement program was developed to reduce production waste. While the production cycle efficiency is 68.08% in the real condition, the efficiency value is 71.3% in the future condition. Production cycle efficiency increased by 3.75% with the proposed improvement plan (Indrawati, Azzam, & Ramdani, 2019).

Jimenez et al. (2019) took a case study at Shellfish company to observe the state of production process in fish marketing and value chain. In their study, they aimed to identify the wastes that affect the quality and efficiency of the products. Considering the lean production tools, improvement suggestions have been made to increase the performance in the examined value chain. As the main result, it was determined that suggestions could be made to improve the organization of the plant and the process times, and it was seen that these could be easily realized through lean tools (Jimenez, et al., 2019).

Singh et al. (2020) aim to integrate the lean manufacturing system into production processes by using value stream mapping (VSM) in a company manufacturing for the automotive industry. In this context, current situation and future situation maps were drawn. In addition, a simulation has been developed to compare the current situation and the future situation. In this way, it was observed that there was 87.59% reduction in cycle time, 76.47% reduction in in-process inventory, 95.41% reduction in production lead time, and 66.08% increase in value added. For the U-bolt section, a decrease of 95.78% in non-value-added time, 57.14% in the number of operators and 70.67% in changeover time was determined. An error of 5 s was observed between the drawn value stream map and the developed simulation (Singh & Singh, 2020).

Rehman et al.(2020) present an approach to measuring production facility performance and overall productivity in a case study they conducted at a factory in Saudi Arabia. Detailed case study analysis was done by collecting data from different production departments. Adopting the lean approach, the manufacturing industry was able to improve its performance in each

production department. After the improvement, the overall manufacturing plant performance index rose from 0.77 to 0.86, and total factor productivity increased by 11.45%. This case study focused on resource use, human and material movements, and production bottlenecks (Rehman, Usmani, Umer, & Alkahtani, 2020).

Liu and Yang (2020) proposed an advanced VSM study that combines simulation and MADM using the Grey-Taguchi method, unlike standard VSM applications. A lean implementation program is conducted at a shoe manufacturing company to validate the improved VSM. Two alternative future state VSMs, each with nine different scenarios, are proposed. With the defined optimal solution, the error rate, in-process inventory and delivery time are reduced, as well as an improvement in the order fulfillment rate. The improved VSM enables practitioners to determine the optimal future state VSM based on their preferences on multiple performance criteria (Liu & Yang, 2020).

Prasad et al. (2020) focused on the importance of lean production in their study in a textile company. The process industry, and especially the textile industry, has highly inflexible automated machines with high volume/low assortment. This complexity of the textile industry makes it essential to implement lean manufacturing strategies. He chose a mix of lean techniques to improve processes, including value stream mapping (VSM), 5S, kanban, kaizen, poka-yoke, and visual controls. Potential success levels before and after adopting lean manufacturing are illustrated using radar diagrams. The findings of the study show that a comprehensive analysis of the installation and changeover time (CO), the use of color coding, the use of kaizens are necessary for an effective lean implementation in the textile industry (Prasad, Dhiyaneswari, Jamaan, Mythreyan, & Sutharsan, 2020).

Zahraee et al. (2021) aim to make an application using takt time calculation and time frame formulation by drawing a value stream map together with computer simulation for the identification and elimination of waste in a small-scale heater industry. It has been observed that the production lead time (PLT) has decreased from 17.5 days to 11 days and the value added time has decreased from 3412 seconds to 2415 seconds with the improvement of the problems caused by VSM. Takt duration has also been reduced from 250 seconds to 192 seconds. This study will be a valuable resource for company managers and industrial engineers

in terms of providing production efficiency (Zahraee, Toloie, Abrishami, Shiwakoti, & Stasinopoulos, 2020).

Sadiq et al.(2021) argue that the integration of lean manufacturing and blue ocean production approaches helps achieve holistic manufacturing excellence, and approaches that integrate the two paradigms are scarce. To this end, they developed an integrated framework combining the concepts of lean manufacturing and blue ocean manufacturing (BOM) through a survey. Using the value stream mapping tool of lean manufacturing and the four action frameworks of BOM, they performed an exercise on a case study. As a result of the application, 26% and 39% improvements were recorded in lead time and value added time, respectively. In addition, more than 50% reduction in greenhouse gas emissions harmful to the environment has been recorded with the implementation of the integrated framework (Sadiq, et al., 2021).

Verma and Sharma (2021) present a sustainable VSM (Sus-VSM) methodology that includes several criteria to evaluate not only the economic performance of a production line, but also its environmental and social sustainability performance. Metrics are chosen to assess process water consumption, raw material use, energy consumption, potential hazards to the work environment, and physical work done by workers. Next, necessary visual symbols are created for each proposed metric in Sus-VSM to easily visualize potential areas for continuous improvement. Many deficiencies emerged in the pilot case study of the satellite antenna manufacturing enterprise. Therefore, it is concluded that future case studies are needed to further refine and validate the data collection procedure and additional changes to the initial Sus-VSM methodology (Verma & Sharma, 2021).

Inga et al (2021) conducted a case study in an enterprise that produces at a lower level than they can do with their capacity and resources. Due to the high losses, they suggested improving the production process through a model that applied Lean Manufacturing techniques on the production lock line in the metalworking company. The study was carried out using engineering tools that diagnose the current situation and the causes of the problem. As a result, the techniques to be applied are 5S, TPM, Six Sigma and Poka Yoke which aim to reduce defective products, unproductive times and machine downtime to increase productivity level. In this way, productivity increased by 8-12% (Carranza-Inga, Villayzan-Palomino, Altamirano, & Carpio, 2021).

Akcacı and Ozyurt(2021) aimed to determine the transition process of a synthetic yarn manufacturer operating in Gaziantep Organized Industrial Zone to the lean production system and what advantages emerged as a result of the process. According to the pilot region and product selected in the enterprise, the current system was analyzed and the operation was determined. VSM application was made to detect the disruptions and activities that do not add value in the process. Accordingly, the problems in the processes were tried to be eliminated by using lean tools such as Kaizen, TPM, OEE, 5S according to the jobs in the departments. In the department where the lean production system was implemented, a decrease in energy consumption and a decrease in the number of personnel and an increase in the amount of production were achieved (Akçacı & Özyurt, 2021).

Table 2.1 Literature review

No	Author And Year Of Study	Sector	Methods
1	Modarres et al. , 2005	Airplane	Kaizen
2	Kazıcioğlu and Yazgan, 2009	Tire	VSM, Creating the Cell system, 6 Sigma, SMED, 5S
3	Ar and Ashraf, 2012	Automotive	VSM
4	Rahman et al. , 2013	Automotive	KANBAN
5	Rahman and Karim, 2013	Tile	VSM
6	Aayush et al. ,2014		VSM
7	Inta and Muntean, 2015	Connectors	Kanban, Kaizen
8	Lacerda et al. , 2016	Automotive	VSM
9	Roriz et al. , 2017	Carton	SMED, 5S and visual management
10	Verma and Sharma, 2017		VSM
11	Kareem et al. ,2017	Iron and Steel	
12	Goren, 2017	Furniture	VSM
13	Faisal, 2018	Textile	VSM
14	Sousa et al. , 2018	Cork stopper	VSM and SMED
15	Saravanana et al. , 2018	Gearbox	VSM, 5S, OEE, continuous flow, JIT
16	Parab and Shirodkar, 2019	Lock	VSM

17	Hartini et al. , 2019	Furniture	VSM, Delphi, AHP
18	Indrawati et al. , 2019	Steel	VSM
19	Jimenez et al. , 2019	Shellfish	VSM
20	Singh et al. ,2020	Automotive	VSM
21	Rehman et al. 2020	Water heater	Measurement of performance and total productivity.
22	Liu and Yang,2020	Shoe	VSM
23	Prasad et al. ,2020	Textile	VSM, 5S, kaizen, poka-yoke and visual controls
24	Zahraee et al. ,2021	Heater Industry	VSM and computer simulation
25	Sadiq et al. ,2021	Automotive part	VSM and approaches of blue ocean manufacturing
26	Verma and Sharma,2021	satellite television	Sus-VSM technique
27	Inga et al. ,2021	Metal	5S,TPM, Six Sigma, Poka-Yoke
28	Akcaci and Ozyurt,2021	Textile	VSM, TPM, OEE, 5S

In Table 2.1 the previous studies that I discussed in my thesis are presented in summary form. When we examine the studies applied in the literature, we see that lean production practices are generally carried out in the automotive, furniture sector and enterprises with assembly lines. Again, in the studies in the literature, value stream mapping, which is an important tool for observing the basis of the lean production system and the current status of the companies, has been carried out in a standard way. The lack of such lean production studies has been noticed in the aluminum conductor and cable manufacturing (continuous production) sector, where I implemented my thesis. As a result of each process of the products discussed in the application part of my thesis, different production units are obtained. The production parameters (capacity utilization rate, etc.) and calculation methods calculated to convert them into the product unit demanded by the customer are quite unique and serve as an example for enhanced value stream mapping. Considering all these, this thesis will make an important contribution to the literature in the context of using lean production practices and numerical methods (multi-criteria decision making methods) together.

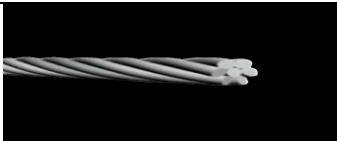
3. MATERIALS AND METHODS

3.1.Factory Introduction

This study was realized in a company that produces aluminum conductors and cable. General information about the company is as follows.

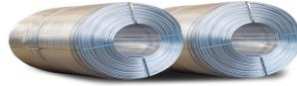
All Aluminum conductors and cables produced by the company we are working on are min. It is produced from aluminum ingots of 99.7% purity and above. Known as a strong and reliable manufacturer, especially in the European, African and Middle Eastern markets, the company offers Aluminum Rod / Wire Rod (9.50mm - 12mm - 15mm), Aluminum Wires (1.70mm - 5.40mm) and AAC used in transmission lines and distribution networks, It manufactures ACSR, AAAC, ACAR conductors and ABC cables. In Table 3.1, the products are indicated with their visuals. Besides all these traditional conductors, the company also manufactures ACCC (Composite Core Aluminum Conductors) conductors, which are the most advanced and efficient High Current Carrying Capacity, Low Deflection conductors. The company, which has a monthly production capacity of 6,000 tons, exports its products to more than 50 countries in 5 continents. Its operating factory is built on a total area of 150.000m2 and meets the majority of its own energy needs with 2MW capacity Solar Power Plants.

Table 3.1 Products of factory

PRODUCTS		
		
AAC All Aluminum Conductors	ACSR Aluminum Conductors Steel Reinforced	AACSR Aluminum Alloy Conductor Steel Reinforced
		
ACAR Aluminum Conductor Alloy Reinforced	AAAC All Aluminum Alloy Conductors	ACCC Aluminum Conductor Composite Core



ABC Aerial
Bundled/Twisted Cables



Aluminum Rod Wire



Aluminum Drawn Wire

3.1.1. Continuous Casting Wire Rod Activity

Aluminum ingots with a minimum purity of 99.7% are charged into the melting furnace to be melted. Each charge is given a number. The metal, which is melted at approximately 750 °C, is transferred to the quenching furnace continuously through a channel. Necessary alloys are added here. Slag dust is thrown into the quenching furnace and it is cleaned of metal slag. The liquid metal taken from the quenching furnace at 710-730°C is given to the casting machine with a float providing the flow rate, without turbulence and at a constant flow rate. Aluminum bar with 2090 mm² cross-sectional area is obtained at a temperature of about 500°C by giving cooling water through the copper outer enveloped casting wheel working together with the steel strip in the casting machine and the channel located outside. This busbar is converted into aluminum wire rod with 9.5, 12 or 15 mm diameter in the rolling machine working synchronized with the casting machine. (In hot rolling, 2-5% oil is added to the water used.). Wire rod exit temperature is 180 - 220°C. The wire rod is subsequently and continuously stacked in wire rod baskets with a transfer section called a gooseneck. It is made to be used in stacking hauling machines and about 2 tons and above. Each basket is numbered and written on the manufacturing label. The label hangs on the basket.

3.1.2. Aluminum Wire Drawing Activity

Length and diameter values of 9.5, 12 or 15 mm diameter aluminum wire rods coming from the continuous aluminum wire rod production line and the conductors to be used in their braids are important. Accordingly, it is drawn in the diameter range of 1.96 to 4.5 mm in 5 wire drawing machines in the enterprise. Drawing oils used in aluminum wire drawing machines become unusable and renewed according to the total amount of wire drawn. Each coil is numbered and written on the manufacturing label and the label is hung on the coil.

3.1.3. Aluminum Conductor Stranding Activity

Drawn aluminum wires in suitable diameter and length values are stranded in the stranding machines available in the enterprise and made into a braided aluminum conductor. For this production, aluminum wires drawn in aluminum wire drawing machines are used. While the aluminum conductors are being braided, they are wound on wooden reels. Each reel is numbered and written on the manufacturing label. The label is placed on the core of the reel and made ready for packaging.

3.1.4. Sheathing Activity

In the machine to be used in sheathing, a motor rotates the screw in a sleeve covered with an electrical heater, allowing plastic granules such as PE and PVC to melt under temperature. The molten plastic material is coated on the aluminum conductor by forming a longitudinal shape, and the closed loop in the form of a long channel enters the water to cool. After cooling, it is wound on a reel as solidified. The reeled and insulated insulated cables are twisted according to their composition in the Drum Twister Machine and wound onto steel reels. These cables coming out of the Drum Twister are transferred to the wooden reels with the cable transfer machine in the quantities requested by the customer.

All processes and production flow in the company are shown in Figure 3.1.

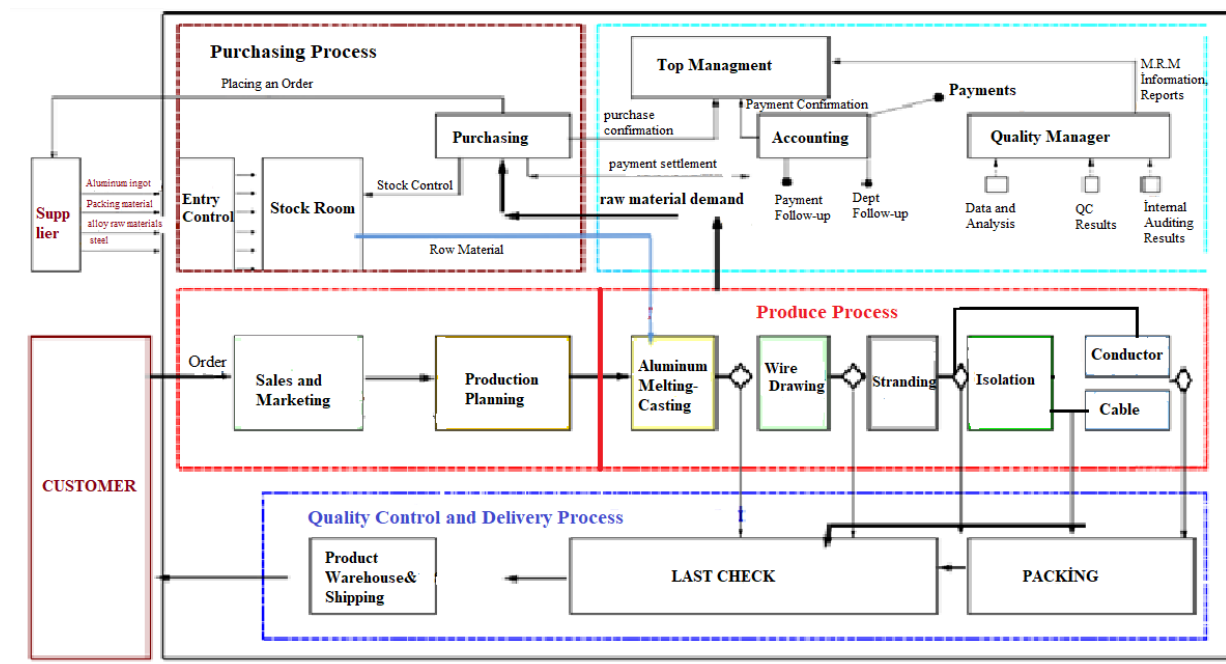


Figure 3.1 Production flow

The equipment used by the company while producing and the manufacturing process are shown in Figure 3.2.

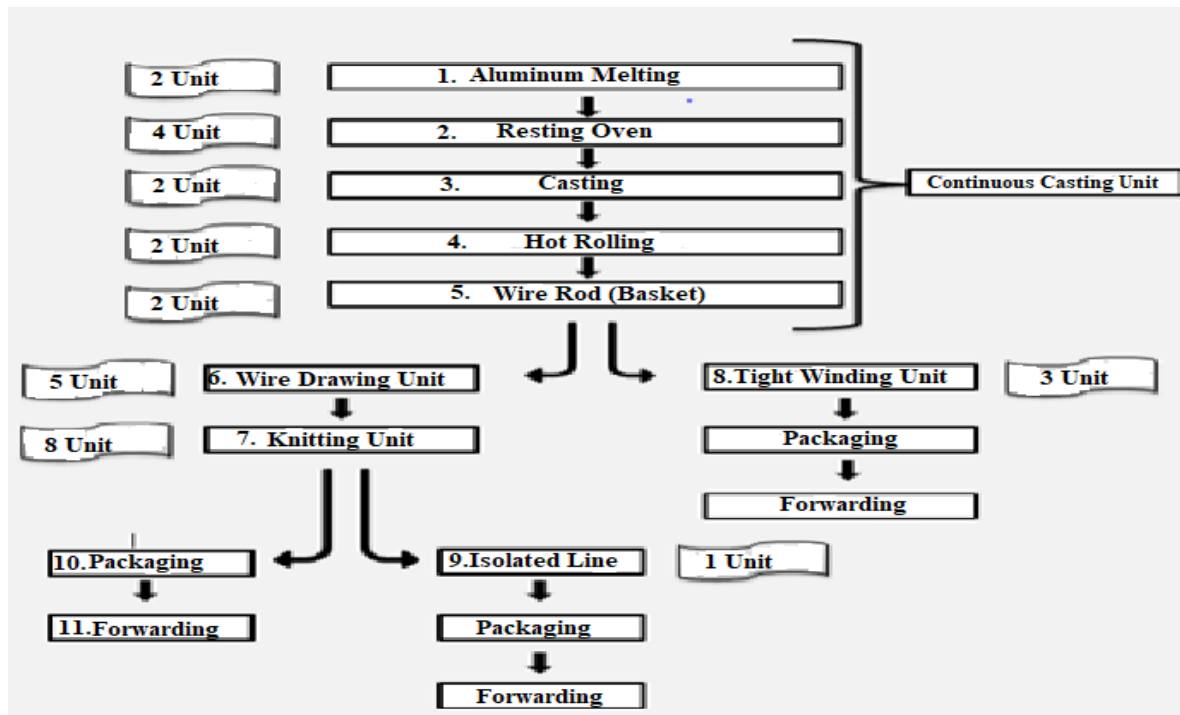


Figure 3.2 Production equipment and processes

The manufacturing processes and their explanations are given in detail at Table 3.2.

Table 3.2 Production process explanation

No	Process Name	Explanation
1	Aluminum Melting	The loaded aluminum ingots are melted with Natural Gas
2	Resting Oven	Liquid aluminum is kept hot in these ovens
3	Casting	Liquid aluminum is poured into the circle to solidify.
4	Hot Rolling	Rolled into a solid aluminum bar exiting the casting machine, it is turned into wire rod.
5	Wire Rod (Basket)	It is the part where the wire rod coming out of rolling is rolled up.
6	Wire Drawing Unit	Wire rods are drawn into diameters of the desired size and made into wire.
7	Stranding	Wires are twisted coaxially and made into conductors.
8	Tight Winding Unit	Wire rods are more tightly wound on reels.

9	Isolated Line	The bare conductors are covered with plastic material such as PE, PVC.
10	Packaging	It is to make the material produced in line with the demands of the companies ready for shipment.
11	Forwarding	The products loaded on the vehicles are sent to the customer.

3.2.Methods

Lean manufacturing enables it to be noticed by identifying the waste in the processes. It is a systematic approach that reduces company costs, accelerates production and increases quality by reducing or eliminating waste. Lean manufacturing system structure is usually represented by a structure called “Lean House”. As can be seen in Figure 3.3, some lean manufacturing techniques are used to ensure high quality, fast production and low cost.

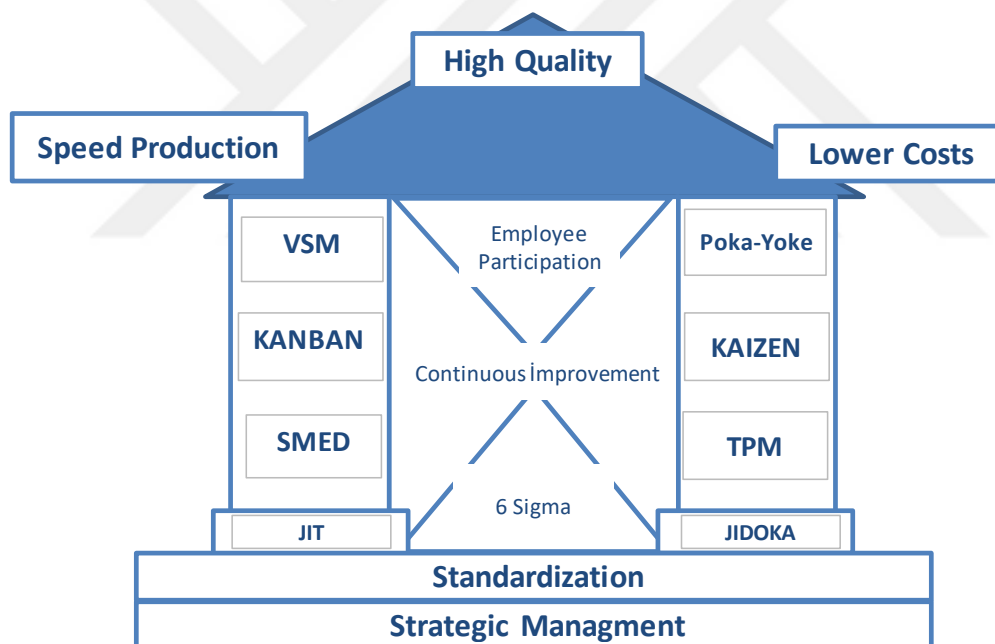


Figure 3.3 Lean house

3.2.1. Lean manufacturing techniques

3.2.1.1. 5S (*Seiri, Seiton, Seiso, Seiketsu, Shitsuke*)

5S is a technique that forms the basis of improvement of production processes and lean manufacturing practice. 5S is a system for organizing spaces; so that work can be carried out

efficiently, effectively and safely. This system focuses on placing everything it belongs to and keeping the workplace clean, making it easier for people to get their work done without wasting time or risking injury. The method name is derived from the first letters of Japanese words: Seiri (extraction), Seiton (editing), Seiso (cleaning), Seiketsu (Standardization), Shitsuke (Education-Discipline). This sequence also shows the application steps.

Seiri – Extraction: Necessary and unnecessary materials (unwanted machinery, apparatus, equipment, spare parts, raw materials, documents, furniture, etc. items in the work area) are separated from each other, unnecessary materials are removed from the work area.

Extraction application steps shown figure 3.4;

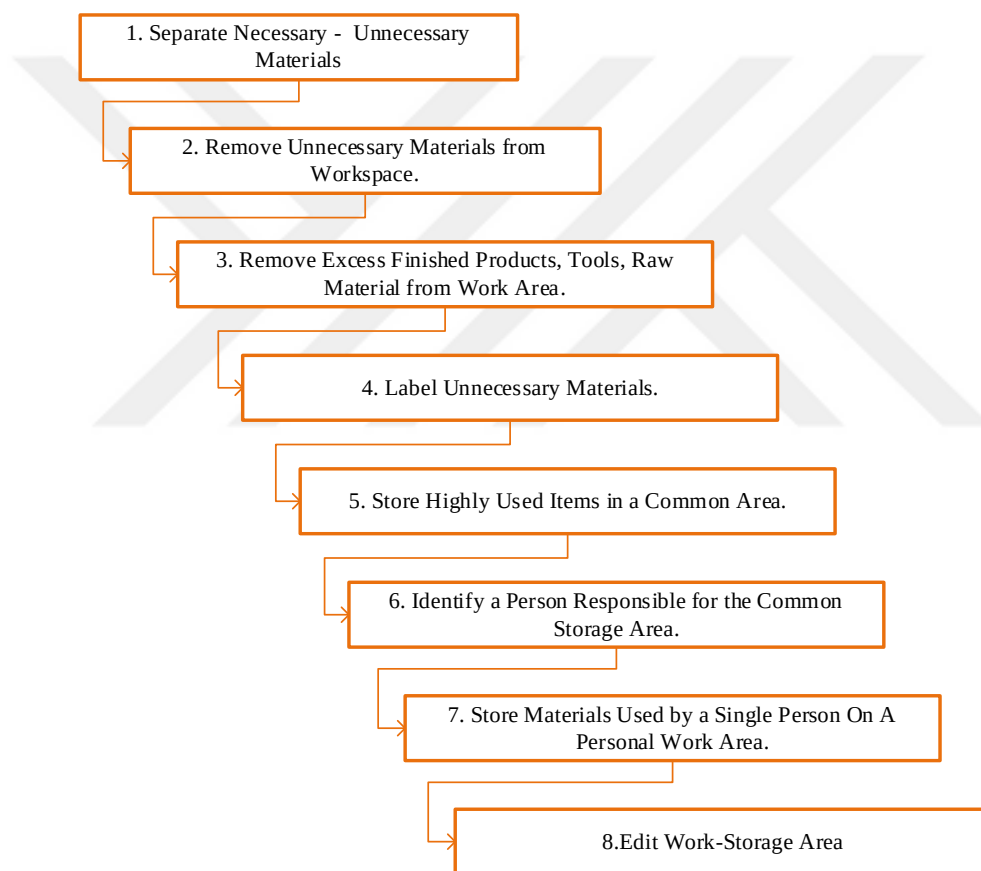


Figure 3.4 Extraction application steps

1. Separate necessary and unnecessary materials.
2. Remove unnecessary materials from the work area. (Throw away materials that will never be used, store materials that will not be used now.)
3. Remove the finished products, tools, raw materials that you consider as surplus from the work area.

4. Label the materials that are unnecessary and that you want to get rid of with the color red.
5. Store materials that will be used by the majority of workers in a common area.
6. Assign a person to organize and manage the common warehouse area.
7. Store materials that only one person needs at their personal work site
8. Organize the work-storage area.

Seiton – Editing: Materials are arranged appropriately and securely so that they are ready for use when needed. The aim is to reach the desired materials within 30 seconds to be used when necessary.

Editing implementation steps shown figure 3.5 ;

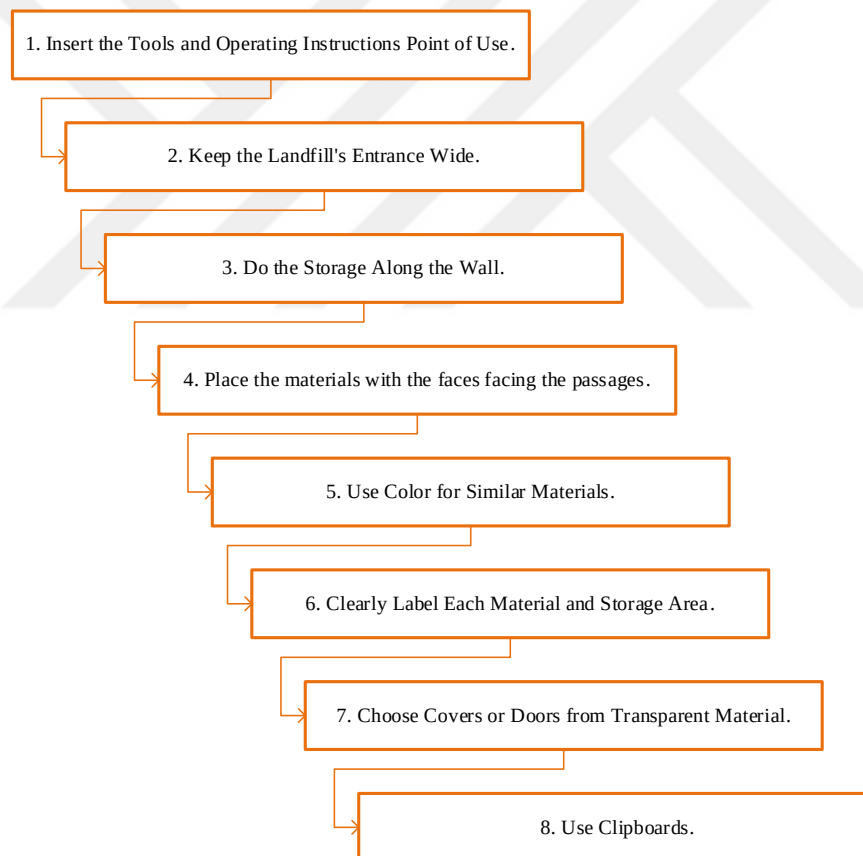


Figure 3.5 Editing implementation steps

1. Place tools and instructions for use at points of use.
2. Keep the entrance to the landfill wide.
3. Make storage along the wall to save space.

4. Place the front of the materials facing the passages for easy access.
5. Use color to easily identify similar materials.
6. Clearly label each material and its storage site.
7. Choose covers or doors from transparent materials for visibility.
8. Use boards to organize the tools, measuring tools needed for each specific machine.

Seiso – Cleaning: Sets the standard for workplace care and proper cleaning. The working area should be free from all kinds of dust, oil and dirt and should be kept clean. Pollution must be destroyed at source. The aim is to keep targets in good condition, identify and eliminate the causes of contamination and maintenance of machinery.

Cleaning application steps shown Figure 3.6;

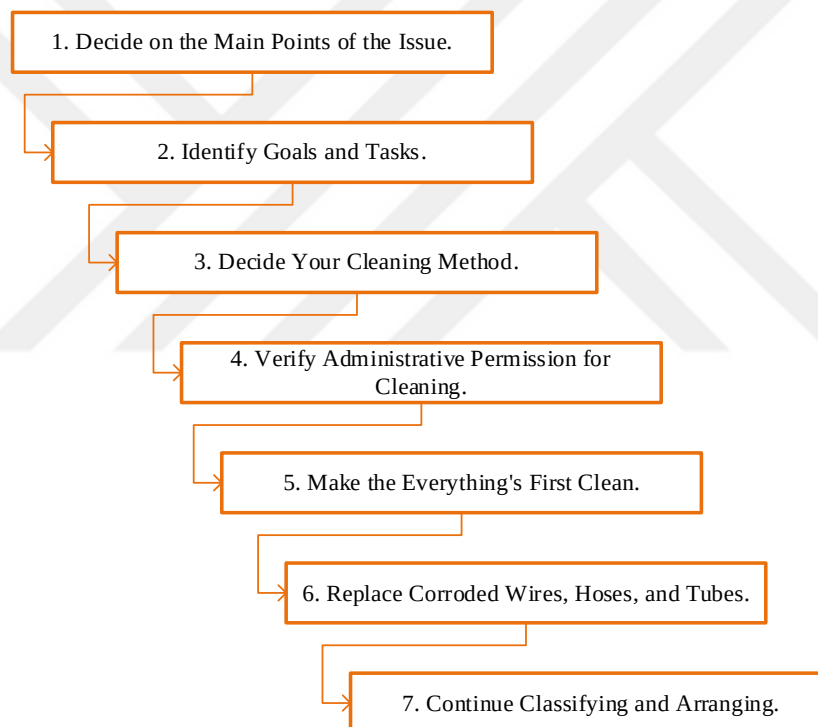


Figure 3.6 Cleaning application steps

1. To decide on the main points of the issue.
2. Identifying goals and tasks.
3. Deciding on the cleaning method
4. Verification of administrative permission for cleaning
5. To do the first cleaning of everything.
6. Replacing worn wires, hoses and tubes with new ones.
7. Continuing to classify and organize.

Seiketsu – Standardization: Sets the rules for the first three stages of 5S. At this stage, essentially the responsibilities of the employees are defined and the procedures and instructions that support the implementation of the previous steps and aim for continuity are created. Being clean and tidy is a habit. A control mechanism is established to ensure that everyone complies with the procedure.

Standardization implementation steps shown Figure 3.7;



Figure 3.7 Standardization implementation steps

1. Determination of sorting, arranging and cleaning conditions
2. Establishing standards, guidelines and procedures for the above conditions using the 5S standard development form
3. Fulfill and enforce standards and procedures
4. Desired visualization of standards and procedures
5. Monitoring and maintaining desired conditions.

Shitsuke – Education-Discipline: In this step, employees' habits of complying with previous changes and acting in accordance with standards are increased. Compliance with the procedure and the results obtained are measured. It is a difficult and long phase because it forces you to change the habits of both production workers and management.

Education-Discipline application steps shown Figure 3.8;



Figure 3.8 Education-discipline implementation steps

1. Education – Planning for discipline
2. Ensure management support for the plan and make necessary corrections
3. Educating everyone in the field about 5S standards and objectives
4. Creating and maintaining a 5S Communication board
5. Creation of other means of communication
6. Making 5 minutes 5S and weekly 5S activities and 5S activities part of daily work.
7. Continued development of standards and visual methods to make all standards clear
8. Continue to increase the participation of all employees

The 5S method does not require large financial investments, allows for the creation and maintenance of jobs in governance functions and ways of cleaning, and the proper regulation of the work environment. By creating more organized and cleaner workspaces, it helps to reduce costs, work accidents, waste and breakdowns, as well as increase productivity, quality and work safety. It is also the first step to strengthen employees' sense of ownership of the workplace.

3.2.1.2. Kaizen - continuous improvement

The transition of the world market from the segmented markets to the global market has brought about the tough competition that requires offering high quality to customers at low cost, as well as the necessity to develop customer-oriented products and services quickly. Today's successful companies have managed to survive with continuous improvement activities by foreseeing these changes instead of being content with the current situation. In this process, all successful companies, especially Japanese companies, have adopted and implemented the Kaizen philosophy.

In Japanese, Kai means "change" and zen means "better". The word Kaizen, which is formed by the combination of these two words, is used in the sense of continuous improvement. Kaizen is based on the logic that nothing is perfect, everything can be improved. It is a change-oriented life philosophy based on the principle of constantly improving every aspect of home, work, private and social life with small steps.

Kaizen summarizes the mobilization of the workforce by providing the main channel for employees to contribute to the development of their company. Various authors highlight different key features, but most focus on three key concepts (Brunet & New, 2003):

1. Kaizen is continuous- used to indicate both the established nature of the practice and its place in a never-ending journey towards quality and efficiency;
2. It is incremental in nature, as opposed to restructurings or technological innovations (for example, the installation of new technology or machinery) initiated by major management;
3. It is participatory, requires the participation and intelligence of the workforce, produces internal psychological and work-life quality benefits for employees

As shown in Figure 3.9, one of the most important elements of continuous improvement is the plan-do-check-act action cycle. The PDCA cycle is one of the most important building blocks of lean production, which describes the process of making improvements and the logic based on eliminating waste.

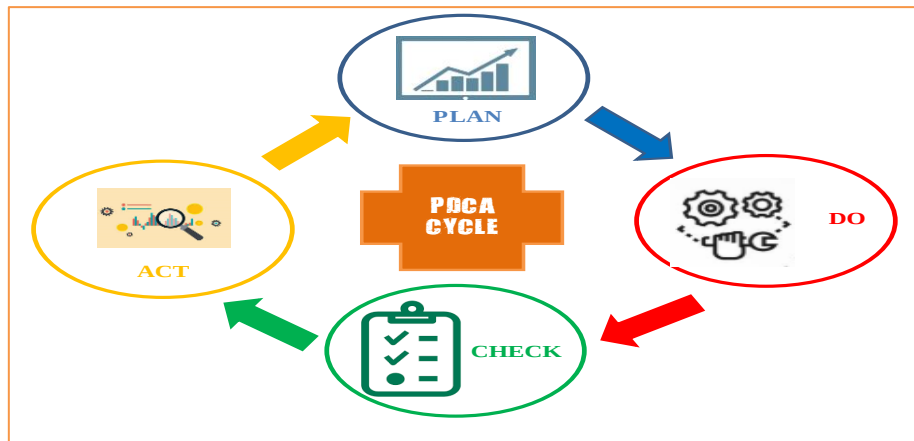


Figure 3.9 PDCA cycle

Kaizen connects the tools used to solve emerging problems. The main problem solving tools are as follows;

- Pareto Diagrams
- Cause-Effect Diagrams
- Scattering Diagrams
- Graphics
- 5N1K Method
- Cause-Cause Analysis
- Histograms
- Control Tables
- Control Charts

Kaizen is based on the need to improve 16 losses in order to reduce costs, increase quality, and deliver on time. These losses may vary on a business basis and may increase in number. The sixteen most important losses are shown in Table 3.3.

Table 3.3 Sixteen big losses

NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
GROUP	Machine							Labor				Materials and Energy				
LOSS TYPE	Loss of Fault	Loss of Setup	Loss of Start	Small Postures	Speed Losses	Scrap (Waste) Losses	Top-up / Supply Loss	Loss of Shutdown	Management Loss	Loss of manipulation	Line Organization Loss	Transport Loss	Measurement Loss	Energy Loss	Material Loss	Loss of Consumables

3.2.1.3. Just in time (JIT)

Just-In-Time (JIT) manufacturing is a Japanese management philosophy applied in manufacturing. Essentially, it involves having the right products in the right place, at the right time, in the right quality and quantity. The idea of producing the necessary units in the required quantities at the required time is defined by Just-in-time in the short term. Just in time, for example, in the process of putting parts together to make a car, means that the necessary kinds of subassemblies from previous processes must arrive on the product line in the required quantities at the time they are needed. If Just-in-time is performed throughout the company, unnecessary stocks in the factory will be completely eliminated and there will be no need for warehouses or warehouses. Inventory carrying costs will decrease and capital turnover ratio will be increased. However, relying solely on a central planning approach that directs production schedules to all processes simultaneously is very difficult to achieve just-in-time in all processes of a product such as an automobile with thousands of parts. For this reason, it is necessary to look at the production flow in the Toyota system in reverse; in other words, people of a particular process go to the previous process to withdraw the required quantities of required units at the required time. So what the previous process has to do is only produce enough units to replace those that have been withdrawn. JIT Manufacturing accelerates the speed of the production process by trying to smooth the flow of materials from suppliers to customers (Htun, Maw, & Khaing, 2019).

3.2.1.4. Total productive maintenance (TPM)

The origin of TPM can be traced back to 1951, when preventive maintenance was introduced in Japan. Nippondenso was the first company to implement preventive maintenance between factories in 1960. Preventive maintenance is a concept where operators produce goods through machines and a team works to maintain these machines. However, considering the automation work in the company, more maintenance personnel were required and this became a problem. Therefore, the management decided that the routine maintenance of the equipment should be carried out by the operators. (This is autonomous maintenance, which is one of the features of TPM). The maintenance group only took over the basic maintenance work. Thus, Nippondenso, which has already implemented preventive maintenance, has added autonomous maintenance by production operators to its processes. The maintenance team went to equipment modification to improve reliability. This leads to neglect of maintenance. Thus, preventive maintenance gave

birth to productive care, along with maintenance prevention and sustainability improvement. The types of maintenance are as follows;

- Failure Maintenance
- Preventive Maintenance
 - Periodic maintenance
 - Predictive Maintenance
- Corrective Maintenance
- Maintenance prevention

TPM can also be thought of as the medical science of machines. Total Productive Maintenance (TPM) is a maintenance program that includes a newly defined concept for the maintenance of facilities and equipment. The aim of the TPM program is to significantly increase production, while at the same time increasing employee motivation and job satisfaction. TPM indicates that maintenance is a necessary and vital part of the business. Downtime for maintenance is scheduled as part of the production day, and in some cases as an integral part of the production process. The goal is to keep emergency and unscheduled maintenance to a minimum (J, 2015).

OEE (Overall Equipment Effectiveness), one of the building blocks of TPM, developed by Seichi Nakajima, the founder of the TPM (Total Productive Maintenance) method in the 1960s, is one of the most important performance indicators of Japanese management systems. With OEE, it is possible to measure and monitor machine stops, performance and quality losses with a single parameter. Account management is one of the most important indicators that are clearly evident, calculated in the same way all over the world and used for the same purpose. It shows the amount of machine capacities that we actually use. OEE aims to reduce by focusing on losses. It prioritizes losses and ensures that KAIZEN is done on the right issues.

OEE value calculation is shown in Figure 3.10.

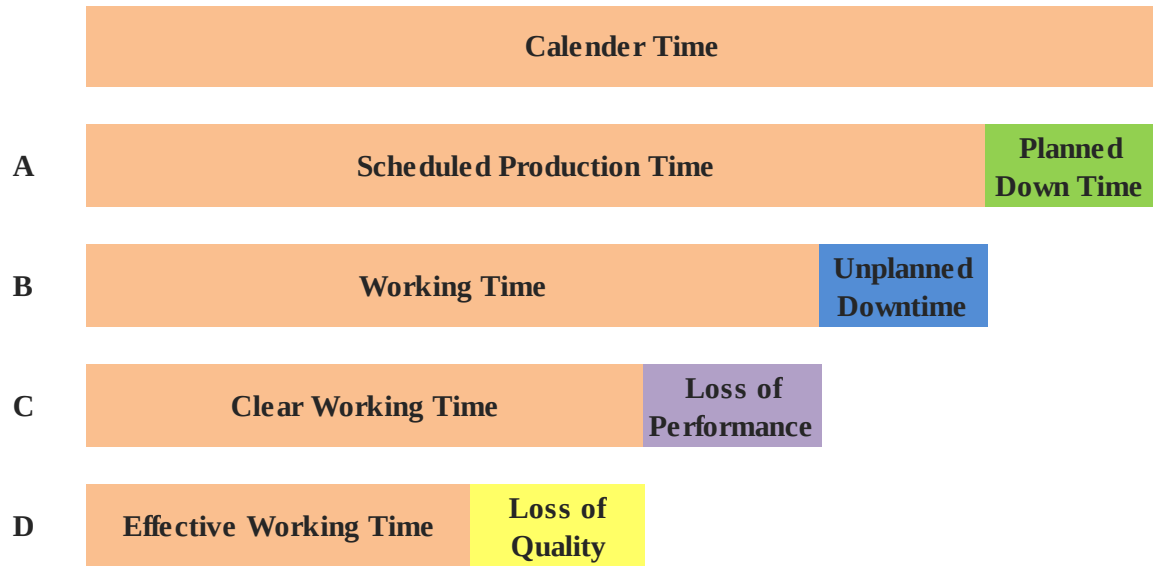


Figure 3.10 Account of OEE

The times shown in Figure 3.10 are calculated as in Eqs.(3.1-3.4)

$$\text{Scheduled Production Time} = \text{Calendar Time} - \text{Planned Downtime} \quad (3.1)$$

$$\text{Working Time} = \text{Scheduled Production Time} - \text{Unplanned Downtime} \quad (3.2)$$

$$\text{Clear Working Time} = \text{Working Time} - (\text{Loss of Speed} + \text{Small Downtime}) \quad (3.3)$$

$$\text{Effective Working Time} = \text{Clear Working Time} - \text{Loss of Quality} \quad (3.4)$$

The parameters used in calculating OEE value are given Eqs.(3.5-3.8).

$$\frac{B}{A} = \text{Availability Rate} \quad (3.5)$$

$$\frac{C}{B} = \text{Performance Rate} \quad (3.6)$$

$$\frac{D}{C} = \text{Quality Rate} \quad (3.7)$$

$$OEE = \left(\frac{B}{A}\right) * \left(\frac{C}{B}\right) * \left(\frac{D}{C}\right) * 100 \quad (3.8)$$

3.2.1.5.Poka-Yoke

Poka-Yoke, first defined as Baka-Yoke, is basically defined as a mechanical and electronic mechanism that prevents and eliminates human error. It is aimed to establish systems that aim to prevent the repetition of errors and the formation of faulty products in the system of Poka-Yoke and that continuously improve the process. The word poka; It means carelessness, inattention, unwanted error. The word yoke is; Derived from the word Yokeru, it means to eliminate, to eliminate. Poka-Yoke: Used together in Japanese to mean error isolation or error avoidance. The aim of Poka-Yoke is to develop preventive and auxiliary tools or strategies against various errors and defects caused by human factors such as forgetfulness and carelessness, and to achieve zero defect production without the need for more control elements (Çanakçıoğlu, 2019).

Shiego Shingo, one of the Japanese management thinkers, brought the concepts of zero error and poka-yoke to the new management philosophy with his work called Zero Control System, published in 1986. According to Shingo, the use of statistical quality control tools in the organization may not completely eliminate errors. Shingo recommends using a technique called Poka-Yoke in this regard. Poka-Yoke, forgetfulness, carelessness, misunderstanding, lack of concentration, lack of standards, etc. It aims to achieve zero-defect production by using anti-error and auxiliary tools and strategies against situations caused by human factors.

The Poka Yoke system uses three tools during execution (Dudek-Burlikowska & Szewieczek, 2009).

- 1- Control at the Source: It is the determination and reset of quality control at the source, before reaching the customer, in case of any error.
- 2- 100% Inspection: All products are passed through devices that can control various elements (weight, height, width, etc.) that may cause errors.
- 3- Preventive Actions: When an error is detected, it is to take the necessary measures immediately.

3.2.1.6.Jidoka

The concept of jidoka was born in the early 1900s when Sakichi Toyoda invented a textile loom that automatically stops when any yarn breaks. Jidoka focuses on the causes of problems. So the first time a problem occurs, work stops immediately. This guides making improvements

that create quality in the process by eliminating the root causes of errors. Jidoka is sometimes called automation, meaning automation with human intelligence (Yalın Enstitü, 2016).

The Jidoka principle, developed by the company's founder, Sakichi Toyoda, contributed to Toyota's development of three concepts. These; When faulty products are produced, the machine automatically shuts down to prevent operation, reducing labor and instead increasing the efficiency of machines, or allowing an operator to manage multiple machines, and Toyota's assembly lines allow operators to stop the assembly line when an obvious problem arises. It is the development of triggers that provide the opportunity and ensure that everyone's sensitivity to error remains alive (Aksoy, 2019).

When a faulty part is produced, the Jidoka system stops the line and waits for human intervention. Any defective product cannot proceed to the next step in any way. Underneath this lies not producing any products, rather than producing defective products. Jidoka system, which attaches importance to the quality control system, has the feature of stopping the line (Ersöz, Sarız, & Ersöz, 2020).

3.2.1.7.SMED (Single Minute Exchange of Dies)

Single minute exchange of dies guarantees a fast and efficient transition from one working product to the next. Transition time is the time spent from the last intact piece of one product to the first intact piece of the next product. This time is spent cleaning and replacing machine parts and setting up the next product. Proper implementation of the SMED improvement system provides greater flexibility and improved product flow in the production area. It is very important for the goal of reducing batch size. Single minute exchange of dies indicates that the change should occur within a single-digit time (under 10 minutes). Today, by applying different tools and techniques, techniques to achieve single-digit transition time have been obtained and applied in production areas in order to shorten and standardize the downtime between two batches (Al- Akel Karam, 2018).

SMED Steps;

1. Observation of Current Methodology (Preparation, Video recording, Analysis)
2. Separation of Internal and External Activities (Separation of Internal Setup and External Setup)

3. Conversion of Internal Activities to External Activities
4. Improvement of Internal and External Setups
5. Deployment of Solutions
6. Standardization

3.2.1.8.Kanban

In the Japanese Dictionary, "blood" means "signal" while "forbidden" means "card" or "board". The Kanban card is a signal to take action and suggests the production of parts in the "pull" production system, which was invented and developed as part of Toyota's production system. Accordingly, Kanban refers to "signal cards" that signal the need for a particular product. Taiichi Ohno thought of Kanban when he visited an American supermarket. Here the racks have been changed when the quantity was reduced to a certain extent. (pulling mechanism). Kanban focuses more on the work to be finished on time rather than who does what. People work together but do not work at the same pace, do not have the same knowledge and skills and must be synchronized. In Kanban, work is organized into tasks or processes, allowing team members to self-perceive the workflow in the most efficient way. Five basic features in successful applications of the Kanban method (Maneva, Koceska, & Koceski, 2016):

- Visualize the workflow
- Work in Progress Limit (Work in progress)
- Manage the stream
- Make Process Policies Clearly
- Develop Collaboratively

In order to understand the Kanban system, we first need to know the production systems. Production control systems; There are two types as pulling systems and pushing systems. While pushing systems are classical systems, pulling systems are just-in-time production systems. Production and inventory control in push systems is based on demand forecasts and intermediate stocks are available. Kanban is a communication tool developed by Taiichi Ohno at Toyota and used in just-in-time production and inventory control systems. A kanban or card is placed on the parts that are produced, indicating the quantity delivered. When all the pieces are used, the same card returns to the point where it was processed and creates the next request (Şeker, 2016).

3.2.1.9.Value Stream Mapping (VSM)

The value stream is the set of value-added and non-value-added activities needed to produce a product along the main streams essential to each product. In the value stream, not a single operation of a single product, but the entire information and production flow of the product under consideration is seen. In this way it helps us to see the whole. In addition, it only helps us to identify wastes in the value stream and to see the sources of these wastes. Value stream mapping allows us to see the differences between the current state of the production system and the future state and to visualize it in a simple way. In value stream mapping, the first material stream always comes to mind. But information flow is as important as material flow. The mapping of both must be carried out with the same care. We can understand what each process needs to do next with the information flow. The process starts when a product is ordered from the customer and ends when it is shipped back to the customer. Mapping is realized by following the material and information flow passing through each process.

VSM is a powerful tool for visualizing and understanding the flow of material and information along the value stream. It is very effective in revealing the wastes in the production process. The targeted outputs when adapting VSM to a manufacturing process are lower production costs, faster response time to the customer, and higher quality products. In order to obtain the necessary information about the production processes, the participation of the staff from the key departments is required. After mapping the 'current state' using VSM symbols and identifying the waste of the process, the desired 'future state' can be mapped out along with the definition of an action plan to achieve it (Lacerda, Xambre, & Alvelos, 2016).

The steps to be followed in value stream mapping are given in Figure 3.11. The first step to be implemented is the product family selection. After the product family is selected, the material and information flow between the processes is followed and the current situation map is drawn. All details in the current situation are recorded. Value adding and non-value adding activities are determined. Improvement studies are carried out by making use of lean production techniques in order to eliminate non-value-added activities, that is, waste sources. As a result of the improvement studies, the future situation map is drawn.

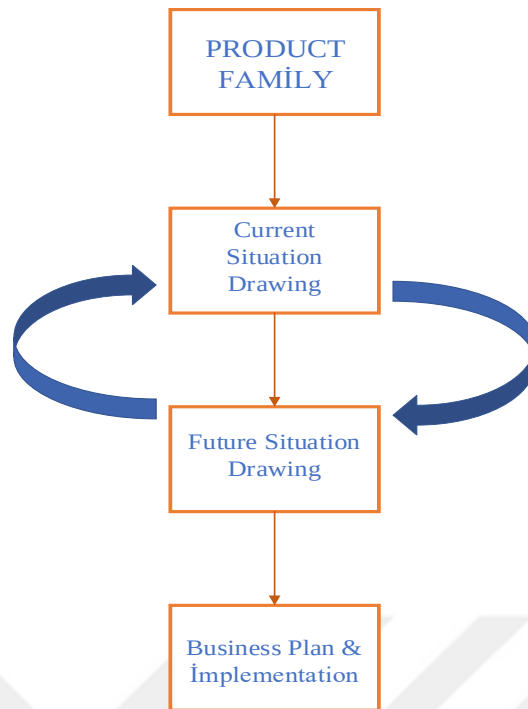


Figure 3.11 Steps to implement value stream mapping

Product family selection

When performing value stream mapping, it is necessary to focus on a single product family. Customers are interested in the products they order, not all the products produced in the factory. There is no need to do it for all products in the production area. It is necessary to define the value stream of product families from the perspective of the customer. A product family is a group of products that go through similar processes and use common equipment during the production phase. An example of this is shown in Figure 3.12. When grouping the product family, how much and how often the customer requests is also an important consideration.

		PRODUCTION STEPS AND EQUIPMENT					
		1	2	3	4	5	6
PRODUCTS	A	X	X	X	X	X	
	B	X		X	X	X	
	C	X	X	X	X		
	D		X	X		X	X
	E		X	X		X	X

A Product Family

Figure 3.12 Product family selection

Current situation map

Developing the future situation is possible with a good analysis of the current situation. Mapping starts at the “door-to-door” flow level in the firm. Various shapes are used to show the processes and flows taking place on the map. A rough drawing can be made in the field using paper and pencil. The first thing to do is to calculate the takt time. Takt time is used to synchronize production speed with sales speed. “Takt time” refers to how often you need to produce a part or product, depending on the sales level, to meet customer requests.

$$\text{Takt Time} = \frac{\text{Work Time Available per Shift}}{\text{Customer Demand Amount Per Shift}} \quad (3.9)$$

The terminology used in the current state and future state map is as follows;

Cycle Time: Indicates the frequency of part or product completion by a process. It is the time between two consecutive products produced.

Lead Time: It is the time a part or product spends in the process until it is completed. It is the time from the beginning to the end of the value stream.

Value Added Time: It is the time spent by employees transforming the part or product as requested by the customer.

Every Part Every: For example, if you change models from one product or part to another product or part every four days, the production batch size is referred to as "four-day part".

Change Over: It is the time it takes to switch from one model to another. Uptime; It shows the machine usage rate.

There are some symbols that are used when drawing a current state map. These are shown in Figure 3.13.

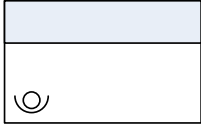
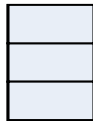
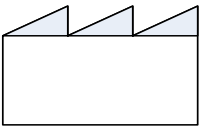
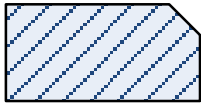
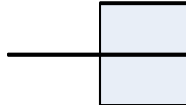
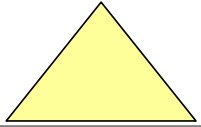
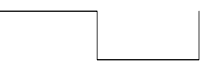
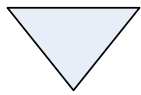
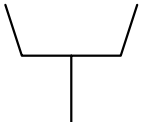
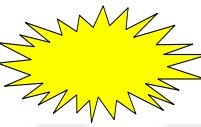
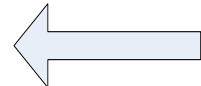
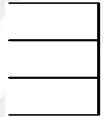
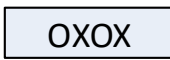
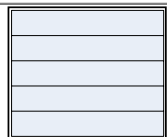
	Process		Production Kanban		Safety stock
	Customer / Supplier		Pull Kanban		Timeline Total
	Inventory		Timeline		Signal Kanban
	Shipping Truck		Batch of production		Kanban Post
	Push Arrow		Kaizen explosion		Pull Arrow
	Shipment Arrow		Supermarket		Load Balancing
	Data Table		Electronic information		FIFO Output

Figure 3.13 Symbol of value stream mapping

As indicated in Figure 3.14 in the current state map drawing, the following steps are;

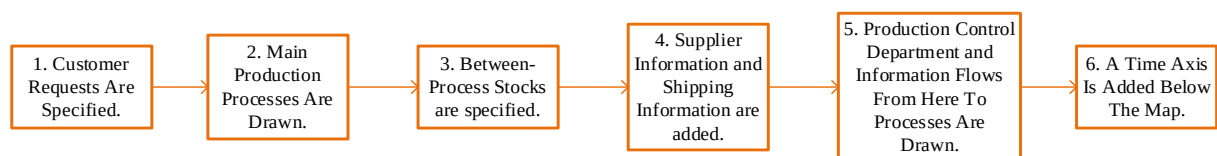


Figure 3.14 Drawing steps of current situation map

1. Customer requests are indicated with the factory symbol in the upper right corner of the map and an information box is added below.
2. The main production processes are drawn by adding an information box below using the process box.
3. Interprocess stock is indicated by a warning triangle.

4. The supplier information is added to the upper left corner of the map. Shipment information from the supplier to the customer is added.
5. The production control department and the information flows going from there to the processes are drawn in the center of the map, a push symbol is added between the processes.
6. A time axis is added to the bottom of the map to show added value times and flow time. And their total values are calculated on the right side. Then some questions are answered regarding the demand, material flow, information flow and supporting developments for the design of the future state.

Future state map

The purpose of value stream mapping is to uncover and eliminate wasteful sources with the implementation of the future state value stream, which will be realized in a short time. The aim is to create a production chain where each process connects to its customer(s) by a continuous flow or pull system, and each process tries to produce only what the customer needs when it needs it. Suppose you are working with an existing product and process in an existing business; Some waste in the value stream will arise as a result of product design, previously purchased machinery, and distance between locations of some activities. These features of the current situation may not be changed immediately. The step of drawing the future state is the second step of Value Stream Mapping. The feature of this step is to make analyzes based on the current situation. As a result of these analyzes, it is the step where joint decisions are taken for acceptable improvements and implemented. The future state map drawn as a result of the improvements is now the current state. Thus, there is a continuous loop between the current state and the future state. There are some key questions that should be asked and answered, which are thought to facilitate the drawing of the future state map. These are as follows;

1. What is takt time based on customer demand and net working time?
2. Is continuous flow used wherever possible?
3. Is the supermarket used to maintain production control? Will the finished product from which the customer draws be produced to the supermarket, or will it be produced directly for shipment?
4. Where can the continuous flow system be installed?

5. Where will supermarket pull systems be installed to control the production of pre-continuous processes?
6. At what point in the production chain (pacemaker process) is production scheduling done?
7. How is the production mix leveled in the pacemaker process?
8. What improvements are needed to get the value stream to flow as outlined into the future state map?

Business plan and implementation

It is the step where the improvement activities regarding the future status of the Value Stream Mapping are planned and the starting point of the implementation studies to be implemented. Team members follow the measurements of the activities to be carried out and the results are seen in a planned manner. All stages come to life through the implementation process. This stage is the most concrete step followed to see the impact of the entire working system on the production processes.

3.2.2. Multi-criteria decision making techniques

In the thesis study; Multi-criteria decision making techniques were used to determine the degree of importance for the project design of the problems that emerged as a result of the current situation analysis and to determine the order of implementation accordingly.

3.2.2.1 Analytical hierarchy process (AHP)

AHP was created by Saaty (1980) to deal with decision making problems in complex and multi-criteria situations regardless of the sector. AHP assists in making decisions characterized by several interrelated and often competing criteria and sets priorities among the decision criteria when set in the context of the decision objective. One of the key features is that the decision criteria are evaluated according to their relative importance to allow trade-off between them (Darko, et al., 2018). The AHP framework uses hierarchical structures to illustrate a problem and judgment options for users, providing a systematic methodology to calibrate the numerical scale to measure qualitative performances. It simplifies analysis by breaking down the complex assessment into smaller manageable sub-assesses. The approach has as input the subjective judgments of each decision maker and the measured weight of each alternative as output. Its strength lies in its ability to rank choices in order of meeting complex and competing needs and interests (Baffoe, 2019).

AHP application steps are as follows (Al-Harbi, 2001);

Step 1: The Problem is Defined.

Step 2: Hierarchical Structure is created.

The highest level of the hierarchy is the main target; the lowest level is the decision alternatives.

Step 3: The pairwise comparisons matrix is created.

By using a severity scale that takes values between 1 and 9, first the basic criteria, sub-criteria if any, and finally all the criteria are taken into account, matrices are created in which the decision options are compared according to the criteria. Comparison matrices are a square matrix with 1 diagonal elements.

$$a_{ij} = 1 \text{ for } i = j, i, j = 1, 2, 3, \dots, n \quad (3.10)$$

$$a_{ij} = \frac{1}{a_{ji}} \text{ for } i \neq j \quad (3.11)$$

a_{ij} , i . by criterion j . is the binary comparison value of the criterion, and the a_{ji} value is obtained from $1/a_{ij}$. This property is called the reciprocity property. a_{ij} value is, “To what extent should the criterion i be preferred over another criterion j ?” This is the answer to the question. The scale taken into account while creating the pairwise comparison matrix is shown in Table 3.4.

Table 3.4 The comparison scale of pairwise Saaty

Importance	Definition	Explanation
1	Equally Important	Both options are equally important.
2	Weak	
3	A Little Bit Important	One criterion was considered a little more important than the other.
4	Reasonable Plus	
5	Too Important	One criterion was deemed more important than the other.
6	Strong Plus	
7	Too Much Important	The criterion was definitely considered much more important than the other criterion.
8	Very Very Strong	

9	Highly Important	It is based on a variety of information that one criterion is extremely important to another.
---	------------------	---

Step 4: The pairwise comparison matrices are normalized.

The normalized matrix is obtained by dividing each element in the matrix by the sum of its column. The sum of each column of the normalized matrix is 1.

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}}, i, j = 1, 2, \dots, n \quad (3.12)$$

Step 5: The priority vector is calculated.

The sum of each row of the normalized matrix is averaged by dividing by the size of the matrix. These values are the weights of importance calculated for each criterion. These weights form the priority vector.

$$w_i = \left(\frac{1}{n}\right) \sum_{j=1}^n a'_{ij}, i, j = 1, 2, \dots, n \quad (3.13)$$

Step 6: The consistency ratio is calculated.

After the priority vector is determined, the step of calculating the consistency of the comparison matrices is started. In order to determine whether an A matrix formed as a result of pairwise comparison is consistent or not, the coefficient called "Consistency Index-CI" must be calculated. The CI coefficient is found as shown in Equation 3.14.

$$CI = \frac{\Delta_{max} - n}{n - 1} \quad (3.14)$$

$$\Delta_{max} = \frac{1}{n} \sum_{i=1}^n \left(\frac{\sum_{j=1}^n a_{ij} \cdot w_j}{w_i} \right) \quad (3.15)$$

$$d_i = \frac{x_i}{w_i} \quad (3.16)$$

$$\Delta_{max} = \frac{\sum_{i=1}^n d_i}{n} \quad (3.17)$$

In order to evaluate the consistency, the Rassal Index (Random Index-RI) value must be known. An RI value is chosen based on the size of the matrix. The RI values defined for the n-dimensional comparison matrices are shown in Table 3.5.

Table 3.5 Rassal index (Random index-RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

After CI and RI values are determined, “Consistency Ratio-CR” is calculated as shown in equation 3.18.

$$CR = \frac{CI}{RI} \quad (3.18)$$

A value of CR less than 0.10 means that the comparison matrix is consistent.

Step 7: After the creation of the pairwise comparison matrices, the priority of each compared element is calculated. There are priority vectors for each criterion. Then, with the help of matrix operations, an average score is obtained for each alternative.

Step 8: Decision options are listed.

By combining the priority vectors obtained for the criteria, the entire priority matrix is obtained. The result vector is obtained by multiplying all the priorities matrix with the priority vector of the decision options and adding them. The decision option with the highest weight in this vector is determined as the decision option that should be preferred for solving the problem.

3.2.2.2.TOPSIS

The basic logic of the TOPSIS method, which is one of the multiple decision making techniques, is to create a positive ideal solution and a negative ideal solution. That is, the basic principle of the method is based on ranking the alternatives according to the ideal solution. By making a ranking starting from the alternative that is relatively close to the ideal solution; The

relative closeness of the other alternatives, respectively, is determined. Topsis method application steps (Soba & Eren, 2011);

Step 1: Decision Matrix is created.

The decision matrix is a $n \times m$ matrix created by the decision maker after the decision options and evaluation criteria are determined. Here, n and m are the number of decision options and evaluation criteria, respectively. The rows of the D decision matrix represent the decision options and the columns the criteria. d_{ij} , shows the current performance $i = 1, 2, \dots, n$, $j = 1, 2, \dots, m$ according to the j criterion of option i .

Step 2: Normalization of the decision matrix

The standard decision matrix is obtained by dividing the values belonging to each criterion by the square root of the sum of the squares of those criteria. It is given in Equations (3.19-3.20).

$$r_{ij} = \left\{ \frac{d_{ij}}{\sqrt{\sum_{k=1}^n d_{kj}^2}}, i = 1, 2, \dots, n \right\} \quad (3.19)$$

$$r_{ij} = \begin{cases} \frac{d_{ij} - \min d_{ij}}{\max d_{ij} - \min d_{ij}} & \text{if } A_i \text{ is a benefit criterion} \\ \frac{\max d_{ij} - d_{ij}}{\max d_{ij} - \min d_{ij}} & \text{if } A_i \text{ is a cost criterion} \end{cases} \quad (3.20)$$

Step 3: A weighted standard decision matrix is created.

Weight of each criterion (w_i , $i=1, 2, \dots, m$) is calculated according to the importance of the criteria, where $\sum_{i=1}^m w_i = 1$. By multiplying the elements of the R matrix with their respective weight values, the weighted standard decision matrix, V, in Equation 3.21 is formed.

$$V = r_{ij} * w_i, \quad \forall i, \forall j, \quad i = 1 \dots, m, \quad j = 1 \dots, n \quad (3.21)$$

Step 4: Positive ideal and negative ideal solution values are obtained.

By using the V matrix, positive ideal and negative ideal solution sets are obtained for each criterion according to the purpose of the evaluation criterion of interest. If the evaluation criteria are in terms of utility, the positive ideal solution is the largest values of the columns of the matrix V, and the negative ideal solution is the smallest values of the columns of the matrix V. If the evaluation criteria are in terms of cost, the positive ideal solution is the smallest values of the columns of the matrix V, and the negative ideal solution is the largest values of the columns of the matrix V. Here, the positive ideal solution set $V^+ = \{V_1^+, V_2^+, \dots, V_m^+\}$ and the negative ideal solution set $V^- = \{V_1^-, V_2^-, \dots, V_m^-\}$

Step 5: The distance values to the positive ideal and negative ideal solution values are obtained.

The Euclidean approach is used to find the deviations of the evaluation criteria for each decision option from the positive ideal and negative ideal solution values. Distance values;

$$S_i^+ = \sqrt{\sum_{j=1}^m (V_{ij} - V_j^+)^2}, i=1,2,\dots,n \quad (3.22)$$

$$S_i^- = \sqrt{\sum_{j=1}^m (V_{ij} - V_j^-)^2}, i=1,2,\dots,n \quad (3.23)$$

It is calculated as. Accordingly, the distance value is calculated as much as the number of decision alternatives.

Step 6: The relative closeness coefficients to the ideal solution are calculated.

The distances from the positive ideal and negative ideal solution values are used to calculate the relative closeness coefficients of each decision alternative to the ideal solution.

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-}, i=1,2,\dots,n \quad (3.24)$$

With this equation, relative closeness values are calculated for each decision alternative. Here, $0 \leq C_i^+ \leq 1, i=1,2,\dots,n$. It is the share of the distance from the negative ideal solution in the total distance. Accordingly, decision alternative close to 1, $C_i^+, i=1,2,\dots,n$ are preferred primarily.

3.3. Application of Lean Production Tools in the Company

A study has been started for the application of lean production techniques in a company that produces aluminum conductors and cables. VSM, which is a lean manufacturing technique, was primarily used to reveal the problems and wastes in the value chain of the company. The product family was selected from the products produced in 2019. Every process that the selected products visited were considered starting from customer order to the delivery of the order.

3.3.1. Lean Production Team

A team was first determined in the VSM application in the company. The people in the team are experts in their fields. The team consists of 15 people. These are shift supervisors, two operators from each production process, plant manager, production engineer, maintenance and repair engineer, R&D Engineer.

3.3.2. Product family selection

Based on the production information in 2019, the high quantity products that exposed to the most in number and the similar processes are determined. Pareto analysis is used for selecting the desired products. According to the Pareto analysis 20-80 rule, 80% of all products and annual production amounts are given in Table 3.6. The list of all manufactured products is given in Appendix Table A.1. The graph of the Pareto analysis is given in Figure 3.15.

Table 3.6 Products constituting 80% of annual production amount

Product Name	Total(k)	Cumulative	Cumulative Rate	Increase Rate
ACSR PH	1572870	1572870	16.16%	16.16%
X 12 mm Alüminyum Rod	778634	2351504	24.16%	8.00%
ACSR PG	692017	3043521	31.27%	7.11%
Y 12 mm Alüminyum Rod	606204	3649725	37.50%	6.23%
ACSR RV	592388	4242113	43.59%	6.09%
Y 9.5 mm Alüminyum Rod	573996	4816109	49.49%	5.90%
ACSR 210/35	558509	5374618	55.22%	5.74%
X 12 mm Alüminyum Rod	506085	5880703	60.42%	5.20%
ACSR CD	467485	6348188	65.23%	4.80%
ACSR HW	413261	6761449	69.47%	4.25%
X 12 mm Alüminyum Rod (DK1)	366852	7511407	77.18%	3.77%
ACSR TL	258344	7769751	79.83%	2.65%

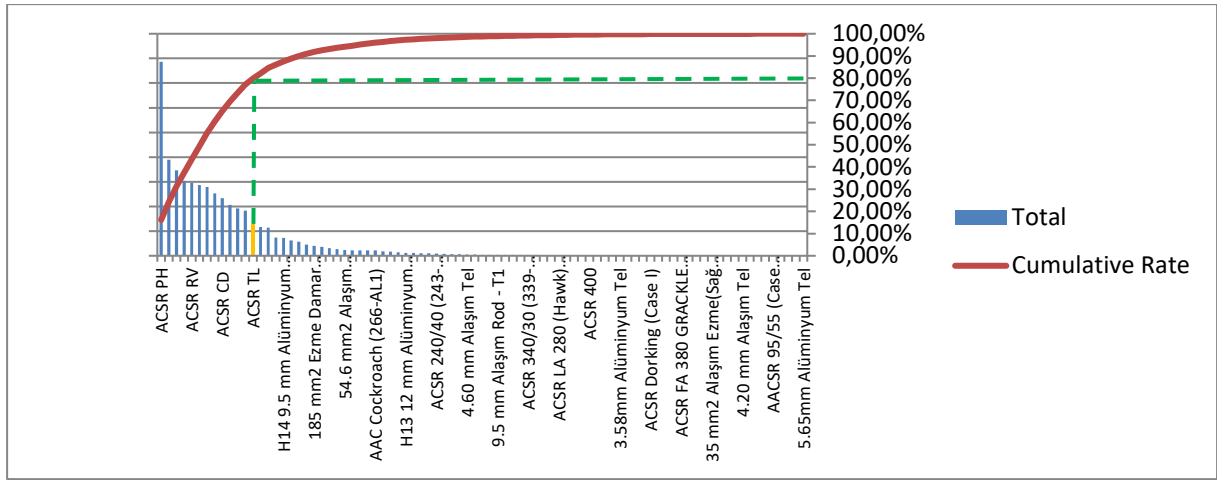


Figure 3.15 Pareto analysis

Among the products shown in Table 3.6, the most processed products are discussed. As a result of the analysis, seven products are selected as ACSR PH, ACSR PG, ACSR RV, ACSR 210/35, ACSR CD, ACSR HW, ACSR TL. In the continuation of the study, it will be proceeded without the phrase ACSR at the beginning of the determined products.

3.3.3. Current situation map

3.3.3.1. Properties of Product

The first step in the production of aluminum conductor is the casting process to turn aluminum ingot into wire rod. Then, the wire rod is drawn in the wire drawing process and finally, the aluminum conductor is formed as a result of wire stranding process. The wire diameters and wire numbers of the seven products are different from each other given in Table 3.7.

Table 3.7 Wire diameters and wire numbers of the product family

Product	Wire Diameter(mm)	Wire Numbers
PH	3.9	54
PG	4.25	6
RV	3.37	6
210/35	3.2	26
CD	3.38	54
HW	3.44	26

TL	3.61	30
----	------	----

Due to the different properties of the seven product features, the required parameter values in the current situation map are calculated separately. As mentioned before, there are two casting machines, five wire drawing machines and seven stranding machines in the factory. The incoming raw material takes the form of wire rod after passing through the casting process. The wire rod properties of these seven products in the product family are the same. However, the wire diameter of each product in the wire drawing process is different, and the number of wires in stranding machines is also different. Products are classified according to the characteristics of stranding machines. For example, a 54 wire product cannot be processed in small size stranding machine. The X markers shown in Table 3.8 the products that have processes in the corresponding stranding machines.

Table 3.8 Distribution of products in stranding machines

Products	Stranding-1	Stranding-2	Stranding-3	Stranding-4	Stranding-5	Stranding-6	Stranding-7
PH					X	X	
PG	X	X	X	X	X	X	X
RV	X	X	X	X	X	X	X
210/35					X	X	X
CD					X	X	
HW					X	X	X
TL					X	X	X

3.3.3.2. Customer request

Customer order data for 2019 were collected through the ERP (Enterprise Resource Planning) system. It is recorded in kilograms in the ERP Program. Before entering the aluminum ingot (raw material) casting process, the data is in kilograms. Afterwards, the wire rod coming out of the casting process is also expressed in kilogram units. However, semi-finished and finished products from wire drawing and stranding processes are expressed in meters. Figure 3.16 shows the information of finished and semi-finished products.

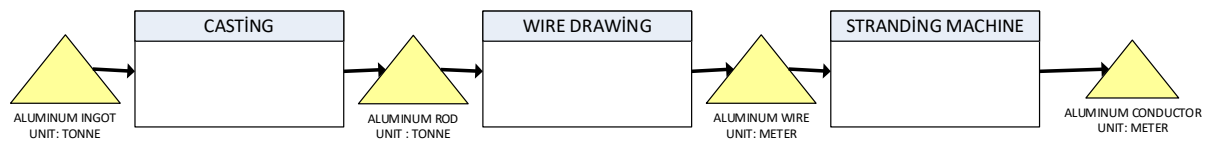


Figure 3.16 Product quantity metrics throughout the production process

The parameters (cycle time, changeover, etc.) to be calculated in the value stream map must be expressed with a single unit of measurement. For this reason, annual customer demands have been converted to meters of measurement units. In the value stream map, customer information and related production data are expressed as in Figure 3.17.

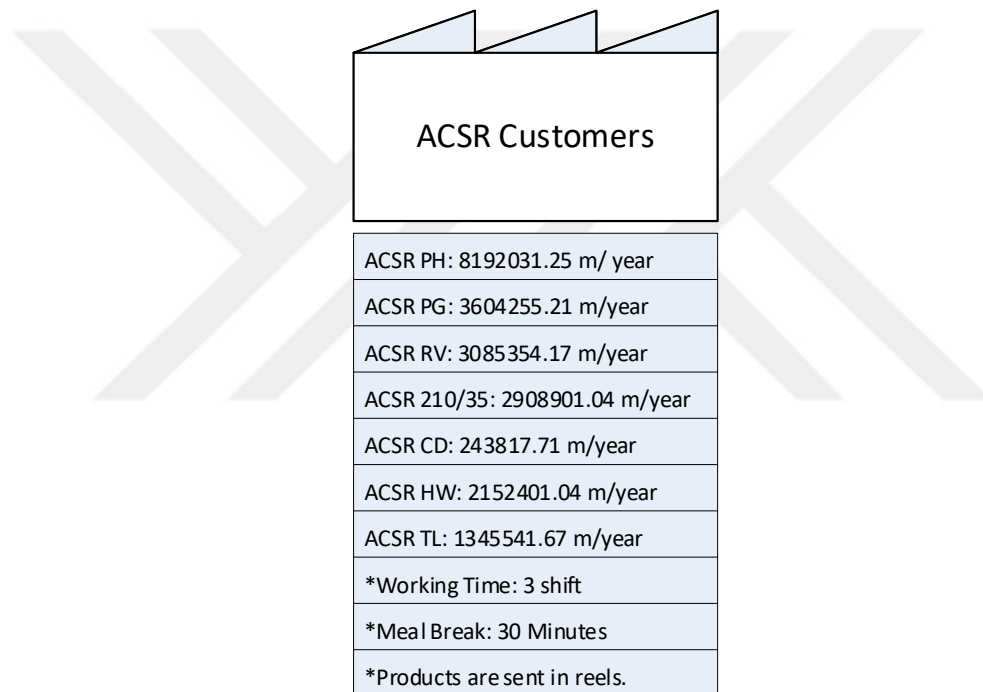


Figure 3.17 Customer symbol and data on the VSM

3.3.3.3. Information flow

All over the information flow in the VSM is from the customer order to raw material purchase. This information flow is examined in three parts. In the first part, the sales unit is informed via e-mail for the customer order and the sales unit enters these orders into the ERP program. It is shown in Figure 3.18.

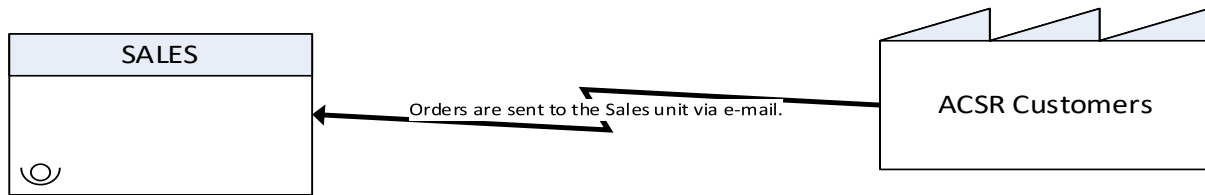


Figure 3.18 Information flow from customer to sales unit

In the second part, the information flow from sales department to the production planning and purchasing department are considered. The production planning is carried out in central planning and factory planning. The central planning unit is in the head office in Istanbul, where the administrative management part of the company is located. Central planning follows the customer orders coming to the sales unit through the ERP program. It makes the planning of the deadlines of the orders and sends them to the factory planning unit. The factory transmits the material requirement list that will come from the planning to the purchasing unit. The factory planning unit performs machinery, equipment and operator planning according to the product and deadline information from the central planning. The aforementioned information flow is shown in Figure 3.19.

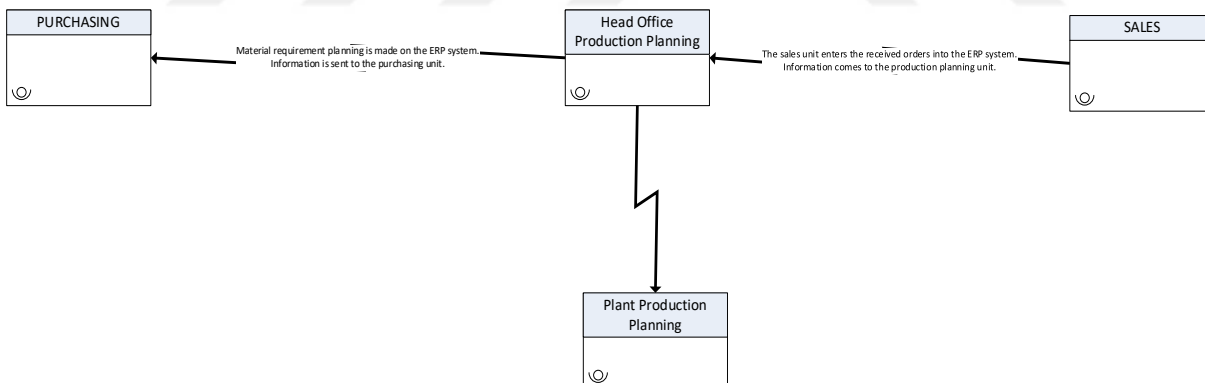


Figure 3.19 Information flow between sales, production planning and purchasing

In the last part, the information flow between purchasing department and the suppliers in the context of the material requirement list is illustrated in Figure 3.20. The purchasing department provides procurement list of the material (raw materials, auxiliary materials, etc.).



Figure 3.20 Information flow from purchasing unit to supplier

3.3.3.4. Material flow in production process

After the flow of information is completed, the next step is the shipment of the raw materials and supplementary materials from the relevant suppliers. First, the delivered raw materials enters the input control unit at the factory. The raw material that passes the input control is transported to the site for the casting process. This flow is visually expressed in Figure 3.21.

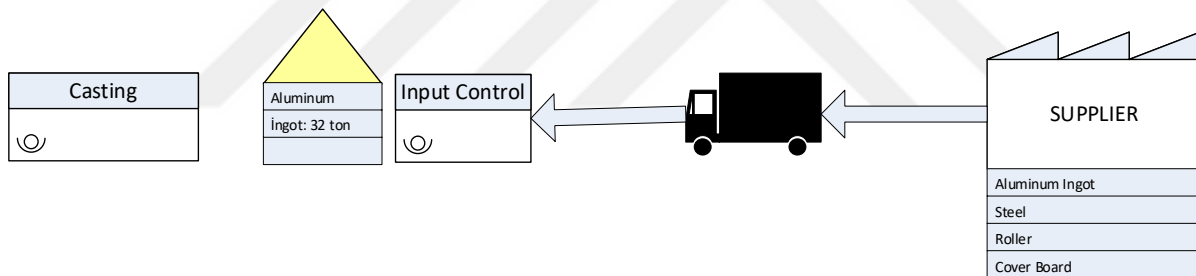


Figure 3.21 Flow of materials from supplier to factory

The factory works in three shifts and there is a 30-minute lunch break in each shift. The usage time of an 8-hour shift is 7.5 hours. Except for the total downtime and maintenance periods, 220 days of work are carried out during the year.

After the supply of raw materials, the machines are put into to use for the production processes. While analyzing the current situation of VSM, some performance values of the machines used need to be calculated. The formulations to be used in these calculations and their explanations are shown in Table 3.9. The times are followed from a production receipt (Master production scheduling (MPS) Number) determined for each product. Due to the different properties of

products in the same product family, the calculations are adjusted for each product and each process (casting, wire drawing, stranding, packaging) separately.

Table 3.9 Calculated values and formulations in information boxes on the current situation map of VSM

Parameters	Formulation	Explanation
Quantity (M)		Unit- Annual production amount
(Cycle time) C/T(sec)	1/a	How many seconds is produced in 1 meter?
Production Speed m/sec	a	How many meters are produced in 1 second?
Staff Cycle Time C/T(St)(sec)	b	Bobbin change time spent per meter - (Time to change a bobbin / Amount of wire in a bobbin (mt))
Total Cycle Time C/T(tot)(sec)	(1/a)+b	total cycle time = t
Changeover Time C/O (sec)		Time in transition from work to work (Quick return)
Weekly Production	c	(Annual production amount / Annual working days x Week days)
Weekly Production Capacity	(d x e) / t	Working Time x Working Rate / Total cycle time
The Capacity Utilization Rate	c/ k	Weekly Production / Weekly Production Capacity
Working Time	d	Weekly working time = Daily Working Hours x Weekly working Days x number of machines x 60 x 60
Working Rate	e	Average working hours per day / 24 hours

The raw material that is transported to the field and ready to be processed is in the form of aluminum ingots. These ingots are first to be thrown into the melting furnaces and turned into liquid metal. Before being thrown into the melting furnace, the furnaces have a preparation process. This takes about 24 hours. The information on the time taken until the wire rod is produced as a result of the casting process after being thrown into the melting furnace is shown in Figure 3.22.

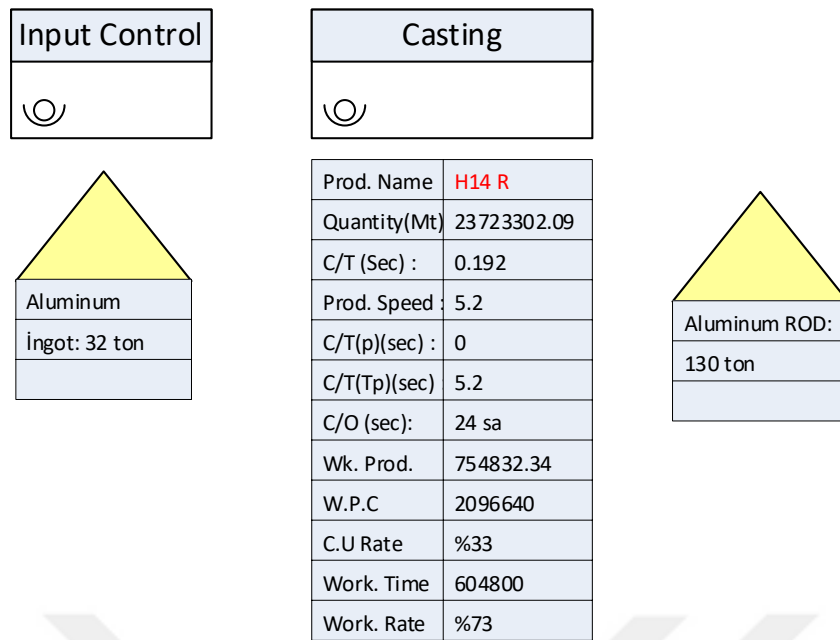


Figure 3.22 Casting process

The wire rod properties after the casting process of the products are the same. Therefore, calculations are made for wire rod called H14. The wire rod is reduced to the desired diameters by entering the wire drawing process.

Wire Drawing							
☺							
Prod. Name	PH 3.9	PG 4.25	RV 3.37	210/35 3.2	CD 3.38	HW 3.44	TL 3.61
Quantity(Mt)	8192031.25	3604255.21	3085354.17	2908901.04	2434817.71	2152401.04	1345541.67
C/T (Sec) :	0.101	0.213	0.109	0.103	0.104	0.104	0.116
Prod. Speed :	9.91	4.7	9.15	9.72	9.6	9.6	8.6
C/T(p)(sec) :	0.054	0.06	0.048	0.033	0.021	0.003	0.032
C/T(Tp)(sec) :	0.155	0.273	0.157	0.136	0.125	0.134	0.149
C/O (sec):	2579	1320	1366.9	3579	2120	2517	4284
Wk. Prod.	260655.54	114680.848	98170.36	92555.9	77471.47	68485.48	42812.68
W.P.C	8143936.15	4619344.77	11529000	9271708.58	10103303.86	9391304.35	10836000,
C.U Rate	%3.20	%2.48	%0.85	%1	%0.77	%0.73	%0.4
Work. Time	3024000	3024000	3024000	3024000	3024000	3024000	3024000
Work. Rate	%41.7	%41.7	%41.7	%41.7	%41.7	%41.7	%41.7

Figure 3.23 Wire drawing process

All calculations considering the production quantities of the products in 2019 is given in Figure 3.23. The production rate information in the calculations shows how many seconds 1 meter of each product is produced. The cycle time of the bobbin change work done by the personnel in the wire drawing process has been calculated. While calculating the transition time from job to job, serial rotation process is considered. Data are collected according to the tracked production receipt number.

Wires of different diameters coming out of the wire drawing process enter the stranding process according to the customer's request. The stranding process of the products is made with different diameters and different numbers of wires. According to the number of wires, the stranding machines they process also change. It is shown in detail in Figure 3.24 that the products will be processed with which machines, how many pieces and what diameter of wire.

Stranding Machine							
							
Mach. Name	5-6	1-2-3-4-5-6-7	1-2-3-4-5-6-7	5-6-7	5-6	5-6-7	5-6-7
Prod. Name	PH 54* 3.9	PG 6* 4.25	RV 6* 3.37	210/35 26*3.2	CD 54* 3.38	HW 26*3.44	TL 30*3.61
Quantity(Mt)	8192031.25	3604255.21	3085354.17	2908901.04	2434817.71	2152401.04	1345541.67
C/T (Sec) :	1.724	1.538	1.250	2.174	1.887	2.564	1.923
Prod. Speed :	0.58	0.65	0.80	0.46	0.53	0.39	0.52
C/T(p)(sec) :	0.75	0.69	0.45	0.38	0.442	0.39	0.45
C/T(Tp)(sec) :	2.474	2.232	1.704	2.553	2.329	2.956	2.375
C/O (sec):	2854	3718	2326	2464	2265	2750	2641
Wk. Prod.	260655.54	114680.85	98170.36	92555.9	77471.47	68485.48	42812.68
W.P.C	407452.17	451542.44	806400	532978.86	534240	460397.17	707616
C.U Rate	%64	%25.40	%12	%17	%15	%15	%6
Work. Time	1209600	2419200	2419200	1814400	1209600	1814400	1814400
Work. Rate	%83	%42	%42	%75	%83	%75	%75

Figure 3.24 Stranding process

Due to the difference in wire numbers and diameters, there are also differences in cycle times and other calculated times. The products discussed in our case study were tracked from the work order numbers. Instant data were obtained with on-site observation and our calculations were made by considering instant cycle times and transition times from work to work. The

number of machines where the products are processed is taken into account in calculating the capacity utilization rates.

The packaging processes of the final products formed at the end of the stranding process are carried out according to customer requests. The packaging process times of the products we deal with are kept instantaneously and on-site. Since the machine is not used in the packaging process, there is no machine cycle time. The processing times of the operators are calculated. Detailed data is shown in Figure 3.25. After the packaging process is completed, the shipment of the products takes place.

Packaging							
							
Prod. Name	PH	PG	RV	210/35	CD	HW	TL
Quantity(Mt)	8192031.25	3604255.21	3085354.17	2908901.04	2434817.71	2152401.04	1345541.67
C/T (Sec) :	0	0	0	0	0	0	0
C/T(p)(sec) :	0.34	0.27	0.17	0.15	0.25	0.17	0.24
C/T(Tp)(sec) :	0.34	0.27	0.17	0.15	0.25	0.17	0.24
C/O (sec):	0	0	0	0	0	0	0
Wk. Prod.	223419.03	98297.87	84146.02	79333.66	66404.12	58701.85	36696.6
W.P.C	1421550	1795365	2855655	3167100	1892430	2740635	2025000
C.U Rate	%16	%5	%3	%3	%4	%2	%2
Work. Time	486000	486000	486000	486000	486000	486000	486000
Work. Rate	%100	%100	%100	%100	%100	%100	%100

Figure 3.25 Packaging process

We can summarize the current state of this value stream with data from observing current operations plotted on the map. The time axis is plotted under the process boxes and stock triangles to calculate the production flow time. Production flow time is the time that elapses during the movement of a part from its transportation to the enterprise as raw material to shipment to the customer. The shorter the production flow time, the shorter the time between raw material payment and payment for the product. A shorter production flow time will lead to an increase in the number of stock turns. The flow time (in days) for each stock triangle is calculated as follows; stock quantity divided by daily customer demand. By summing the flow times of each process and each stock triangle in the material flow, an estimate of the total

production flow time is obtained. In the company where the application is made, this period is 11.6 days. In the next step, for each process in the value stream, only value-added times or process processing times are summed. While the total processing time of one meter of the product group handled in the company is only 19.53 seconds, it takes 11.6 days for the same product group to complete its way in the factory. The current state map, which all processes and calculations are made, is shown in Appendix Figure B.1 as a whole.

Measurements and calculations in the current state map are primarily made in Microsoft Excel. Later, drawings are made in Microsoft Visio application.

Analysis and evaluations are made with the team on the current situation map. Areas open to improvement in the production process are identified. Areas of improvement are shown in Appendix Figure B.2 with kaizen bursts on the current situation map.

The identified kaizen bursts are as follows;

1. Failure to reach the speeds specified in the product recipes
2. Low machine working rates
3. Product loading times too long and non-standard
4. Shutdown of machines due to lack of operator
5. The high number of wire breaks in the wire drawing process
6. Long downtime due to failure
7. Failure to record operation standard steps in serial rotation
8. Non-standard series turnaround times
9. Failure to schedule the delivery vehicles on time

It is not possible to implement all of the identified kaizen bursts in terms of time and cost. Therefore, the priority order of kaizen bursts had to be determined. Multi-criteria decision making techniques (AHP and TOPSIS) are used while determining the order of priority. The criteria we will use for ranking are determined according to the three basic objectives of lean production (quality, delivery, cost). This was decided together with the lean production team. The weight calculations of the criteria according to the company dynamics are not the same. For the weight calculation, firstly, pairwise comparison matrices were created and scored according to the relative importance scale (Saaty Scale) by the experts in the company. Comparison matrices are created for each person in line with the data obtained from six

personnel who are experts in their fields. The final pairwise comparison matrix was created geometric mean of the scores from the experts. The pairwise comparison matrix of each expert and the aggregated matrix are given in Table 3.10.

Table 3.10 The pairwise comparison matrix of each expert and the aggregated matrix

<i>Expert 1</i>	Quality	Delivery	Cost
Quality	1	5	1
Delivery	0.2	1	1
Cost	1	1	1
<i>Expert 2</i>	Quality	Delivery	Cost
Quality	1	5	7
Delivery	0.2	1	0.33
Cost	0.14	3	1
<i>Expert 3</i>	Quality	Delivery	Cost
Quality	1	0.2	1
Delivery	5	1	7
Cost	1	0.14	1
<i>Expert 4</i>	Quality	Delivery	Cost
Quality	1	7	6
Delivery	0.14	1	5
Cost	0.17	0.2	1
<i>Expert 5</i>	Quality	Delivery	Cost
Quality	1	5	5
Delivery	0.20	1	0.33
Cost	0.20	3	1
<i>Expert 6</i>	Quality	Delivery	Cost
Quality	1	3	3
Delivery	0.33	1	0.2
Cost	0.33	5	1
Aggregated matrix (geometric mean of all experts opinions)			
	Quality	Delivery	Cost
Quality	1	2.84	2.93
Delivery	0.35	1	0.96
Cost	0.34	1.04	1

Each element in the matrix is normalized by dividing by its column sum. The sum of each column of the normalized matrix is 1. The normalized matrix is shown in Table 3.11.

Table 3.11 Normalized matrix

Normalized Matrix			
	Quality	Delivery	Cost
Quality	0.59	0.58	0.60

Delivery	0.21	0.20	0.20
Cost	0.20	0.21	0.20

The sum of each row of the normalized matrix is averaged by dividing by the size of the matrix. These values in Table 3.12 are the weights of importance calculated for each criterion.

Table 3.12 Importance weights

	Quality	Delivery	Cost	Criterion Weights
Quality	0.59	0.58	0.60	0.59
Delivery	0.21	0.20	0.20	0.20
Cost	0.20	0.21	0.20	0.21

After making pairwise comparisons and determining their priorities, the consistency of the comparison matrices is calculated. The calculated consistency value is shown in Table 3.13.

Table 3.13 Consistency calculation

Total	Criterion Weights	Total/Criterion Weights	Δ_{max}	Consistency Index	RI	Consistency Ratio (CR)
1.77	0.59	3.0010	3.0006	0.0003	0.5250	0.0006
0.61	0.20	3.0004				
0.62	0.21	3.0004				

The comparison matrix is consistent since the value of CR is less than 0.10.

After determining the importance weights of the criteria, the TOPSIS method was applied to determine the priority order of the kaizen bursts according to the determined criteria. First, the decision matrix was created. As a result of the brainstorming with the experts in the company, points were given using the Saaty scale. The decision matrix created is given in Table 3.14.

Table 3.14 Scoring of improvement projects - decision matrix

		Criteria		
WEIGHT		0.59	0.2	0.21
Project Number	Improvement Project (Alternative)	Quality	Delivery	Cost
P1	Failure to Reach the Speeds Specified in the Product Recipes	1	7	5
P2	Low Machine Working Rates	1	7	7
P3	Product Loading Times Too Long and Non-Standard	1	5	4
P4	Shutdown of Machines Due to Lack of Operator	1	6	3

P5	The High Number of Wire Breaks in the Wire Drawing Process	1	3	3
P6	Long Downtime Due to Failure	1	7	9
P7	Failure to Record Operation Standard Steps in Serial Rotation	1	4	4
P8	Non-Standard Series Turnaround Times	1	5	5
P9	Failure to Schedule the Delivery Vehicles on Time	1	5	3

Problems that emerged after the current situation analysis were evaluated according to quality, delivery and cost criteria. In this evaluation, the effects of alternatives on increasing the quality, reducing the cost and shortening the delivery time are examined. For instance, the effect of the problem of not being able to reach the speeds specified in the product recipes on cost reduction is 5. Accordingly, the normalization calculation is carried out by taking into account the Equation 3.19. The results obtained by normalizing the decision matrix are shown in Table 3.15.

Table 3.15 Normalized matrix

Project Number	Normalization			Normalized Matrix		
P1	1	49	25	0.33	2.91	1.62
P2	1	49	49	0.33	2.91	3.17
P3	1	25	16	0.33	1.49	1.03
P4	1	36	9	0.33	2.14	0.58
P5	1	9	9	0.33	0.53	0.58
P6	1	49	81	0.33	2.91	5.24
P7	1	16	16	0.33	0.95	1.03
P8	1	25	25	0.33	1.48	1.62
P9	1	25	9	0.33	1.48	0.58
	3.00	16.82	15.45			

A weighted standard decision matrix is created according to the importance of the criteria. It is shown in Table 3.16. Then, according to the purpose of the evaluation criterion of interest, positive ideal and negative ideal solution sets are obtained for each criterion.

Table 3.16 Weighted matrix

Project Number	Weighted Matrix
----------------	-----------------

P1	0.196	0.582	0.339
P2	0.196	0.582	0.665
P3	0.196	0.297	0.217
P4	0.196	0.428	0.122
P5	0.196	0.107	0.122
P6	0.196	0.582	1.100
P7	0.196	0.190	0.217
P8	0.196	0.297	0.339
P9	0.196	0.297	0.122
Max	0.196	0.582	1.100
Min	0.196	0.107	0.122

The relative closeness coefficients to the ideal solution are calculated. The distances from the positive ideal and negative ideal solution values are used to calculate the relative closeness coefficients of each decision option to the ideal solution. These values are shown in Table 3.17.

Table 3.17 Positive ideal and negative ideal solution values distances

Project Number	S+	S-	C
P1	0.76	0.52	0.41
P2	0.43	0.72	0.62
P3	0.93	0.21	0.19
P4	0.99	0.32	0.24
P5	1.09	0.00	0.00
P6	0.00	1.09	1.00
P7	0.97	0.13	0.11
P8	0.81	0.29	0.26
P9	1.02	0.19	0.16

According to the calculated relative closeness values, decision options close to 1 are preferred primarily. The three most important kaizen bursts were determined by ordering the kaizen bursts from the largest to the smallest according to these values. The ranking of the kaizen bursts according to their importance is given in Table 3.18.

Table 3.18 Order of improvement projects by significance

Project Number	Improvement Project (Alternative)	C
P6	Long Downtime Due to Failure	1.00
P2	Low Machine Working Rates	0.62
P1	Failure to Reach the Speeds Specified in the Product Recipes	0.41
P8	Shutdown of Machines Due to Lack of Operator	0.26
P4	Non-Standard Series Turnaround Times	0.24
P3	Product Loading Times Too Long and Non-Standard	0.19
P9	Failure to Schedule the Delivery Vehicles on Time	0.16
P7	Failure to Record Operation Standard Steps in Serial Rotation	0.11
P5	The High Number of Wire Breaks in the Wire Drawing Process	0.00

Kaizen bursts designated to do remedial work; long downtimes due to failure, low machine working rates and inability to reach the speeds specified in the product recipes. The improvement works carried out for the determined kaizen bursts are explained in detail in the results and discussion section.

4. RESULTS AND DISCUSSION

The improvement projects that emerged as a result of the analysis of the current situation map were ranked according to their importance. As a result of this ranking, it was decided to deal with the first three projects due to cost and time constraints with company officials. These projects are; long downtimes due to malfunctions, low machine operating rates, inability to reach the speeds specified in the product recipes.

It is determined that the low machine operating rates are a very important factor in the calculation of periods such as cycle time. The working rate was calculated with the traditional method by asking the company's production and production planning officers. It has become important to determine the problems such as the ineffective calculation of the machine operating rate and the inability to follow it continuously and to present improvement suggestions on this subject. It is observed that the traditional value, which is working rate calculation, corresponds to the OEE (Overall Equipment Efficiency) in lean production. In this context, infrastructure works have been started in order to be able to calculate the OEE values in the company. The parameters used in the OEE value calculation were calculated over the data received from the ERP system. These parameters are; performance, availability and quality ratios. The fact that these rates are followed separately has been a guide for the company in terms of identifying and categorizing the problems. When looking at the current situation map, the three kaizen explosions determined are the problems that occur in wire drawing machines. For this reason, OEE values of wire drawing machines are discussed in this study. The results in the period when OEE calculations for the first time are shown in Table 4.1.

Table 4.1 OEE values calculated for wire drawing machines

	Availability Rate	Performance Rate	Quality Rate	OEE Value
Wire Drawing 1	27%	48%	100%	12.96%
Wire Drawing 2	32%	54%	100%	17.28%
Wire Drawing 3	38%	49%	100%	18.62%
Wire Drawing 4	42%	45%	100%	18.90%
Wire Drawing 5	44%	53%	100%	23.32%

The machine-based values of the ratios used in the OEE calculation are shown graphically in Figure 4.1.

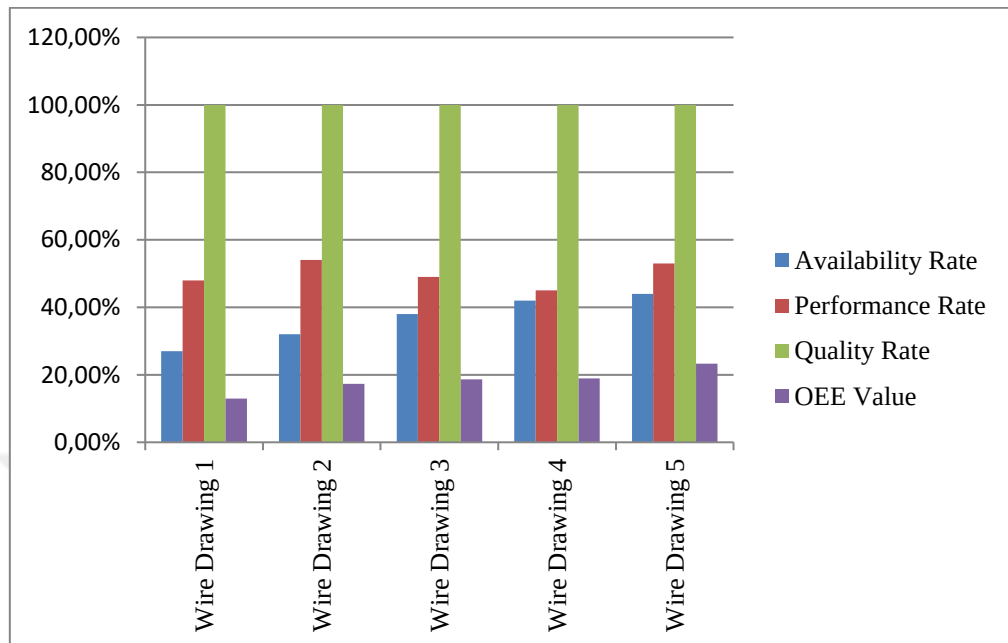


Figure 4.1 Graphical display of OEE values and multipliers

When the low OEE values were analyzed and investigated, various improvement projects emerged. Among these, the first one is the problem of excessive downtime due to machine failures. The long downtimes due to machine failures caused the availability rate of OEE parameters to be low. Within the scope of the project, downtimes caused by machine failures were analyzed together with the maintenance and repair team. In the wire drawing process, the downtime data of February 2021 due to the failure were examined. As shown in Figure 4.2, it was observed that the most downtime due to failure was in the wire drawing 5 machine with 12.92 hours. These downtimes were followed by wire drawing 3, wire drawing 2, wire drawing 4 and wire drawing 1, respectively.

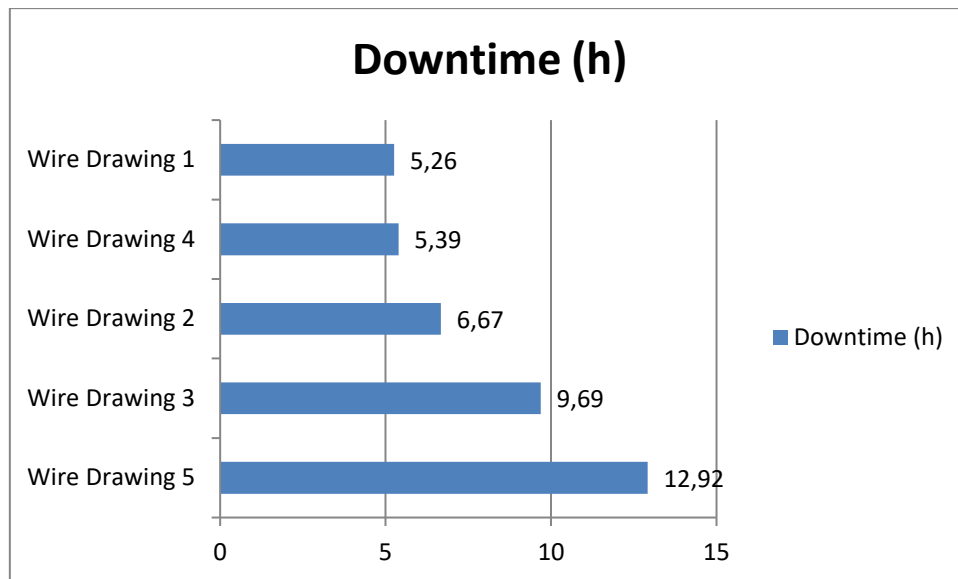


Figure 4.2 Downtimes due to machine failure in wire drawing machines

In order to make this analysis easier, studies have been started to create fault records in the enterprise resource planning (ERP) system. By this means, the number and duration of malfunctions can be viewed online. A scenario was created in such a way that the machine operator opens a fault record to the ERP system and a fault notification is sent to the maintenance operator screen. In this way, the problem of late intervention of the maintenance operator to the malfunction has been eliminated and downtime has been reduced. In order to reduce the number and duration of the failures, it has been suggested that the planned maintenance should be reviewed and revised in accordance with the TPM technique. As a result of the implementation of the planned maintenance and the online recording of the malfunctions, the downtimes due to malfunctions were improved. Data for March 2021 are shown in Figure 4.3. According to these data, times due to breakdowns are decreased as follows; 4.32 hours for wire drawing 5, 3.15 hours for wire drawing 3, 2.47 hours for wire drawing 2, 1.46 hours for wire drawing 1, 2.49 hours for wire drawing 4.

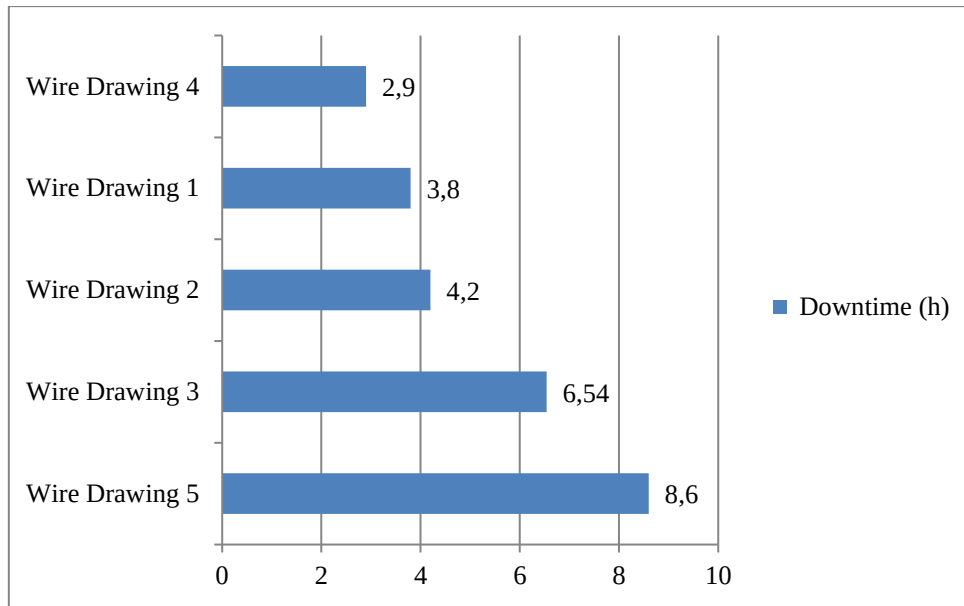


Figure 4.3 Downtimes due to machine failure in wire drawing machines as a result of improvement studies

As a result of the study, with the preventive maintenance work included in the total productive maintenance technique of lean production, a total of 34.7% improvement is achieved in the downtimes caused by mechanical failure in the wire drawing process. Changes in machine-based availability rates as a result of improvements in downtime are shown in Figure 4.4. Availability rates have increased for all wire drawing machines.

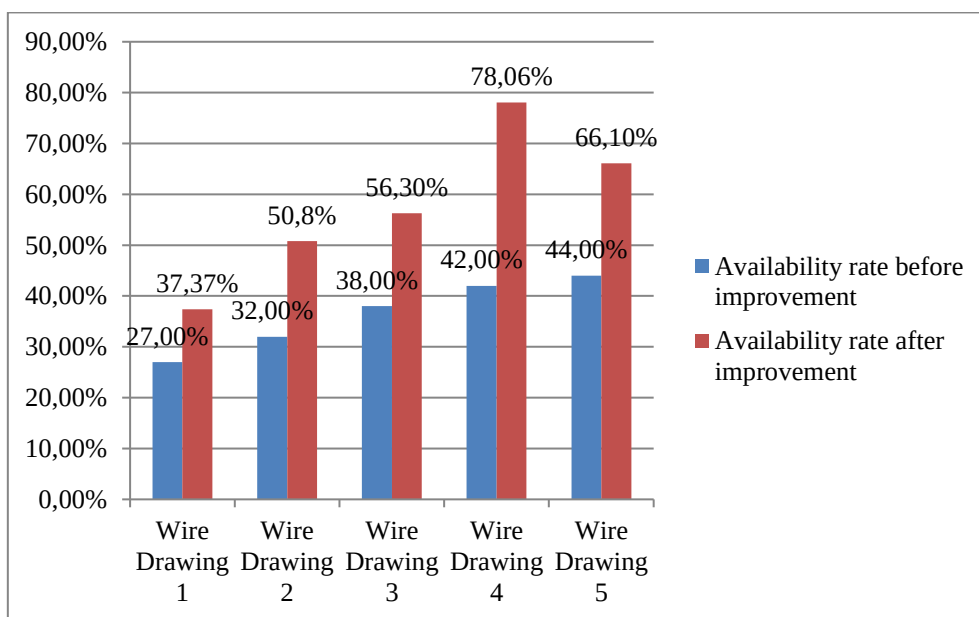


Figure 4.4 Availability rates before and after improvement

Another issue that has come to the fore with the beginning of the calculation of OEE values in the company is that the performance ratio is quite lower than it should be. The performance ratio is calculated by dividing the amount produced in the machine by the amount that needs to be produced. The amount to be produced is calculated by multiplying the time the machine runs and the speed in the product recipe. Therefore, one of the situations that has the most impact on the low performance ratio as a result of the analysis made in wire drawing machines is that the operating speeds are not operated at the speeds specified in the product recipe. As a solution to this situation, first of all, the production planning department and the product recipe rates were updated again. In order to control them, an online tracking system has been established. As an example, in Figure 4.5 and Figure 4.6, instant line speeds of the products produced on wire drawing 1 and wire drawing 3 machines are shown.

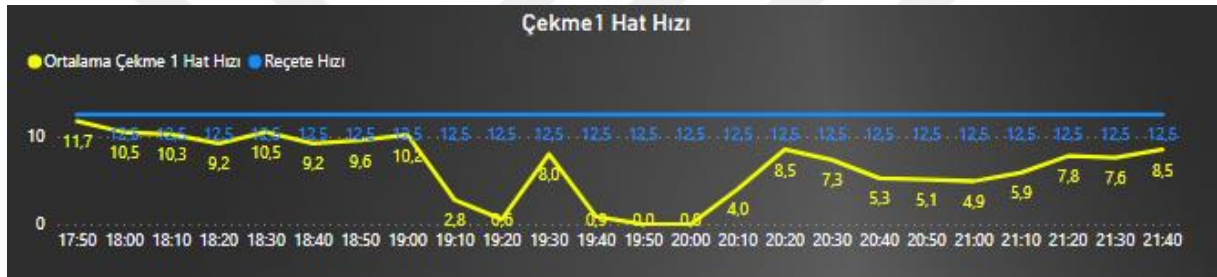


Figure 4.5 Machine line speed online tracking graph

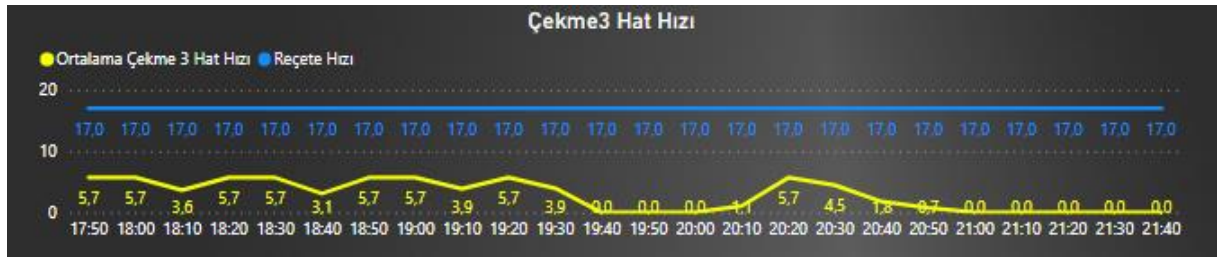


Figure 4.6 Machine line speed online tracking graph 2

In the next stage, the products that could not reach the recipe speed during production were determined. Their ratio in production has been calculated. Then, if these products work for more than 10 minutes under the determined speeds, a system that gives a warning was installed. In this way, the relevant persons who received the warning started to intervene immediately. JIDOKA technique, one of the lean manufacturing techniques, was used to improve the subject. As a result of this study, it was observed that there were improvements in the low performance ratio due to not being able to reach the prescription speed. As shown in Figure 4.7, the increases

in performance ratios are respectively; 10% in wire drawing 1, 8% in wire drawing 2, 16% in wire drawing 3, 12% in wire drawing 4, 6% in wire drawing 5.

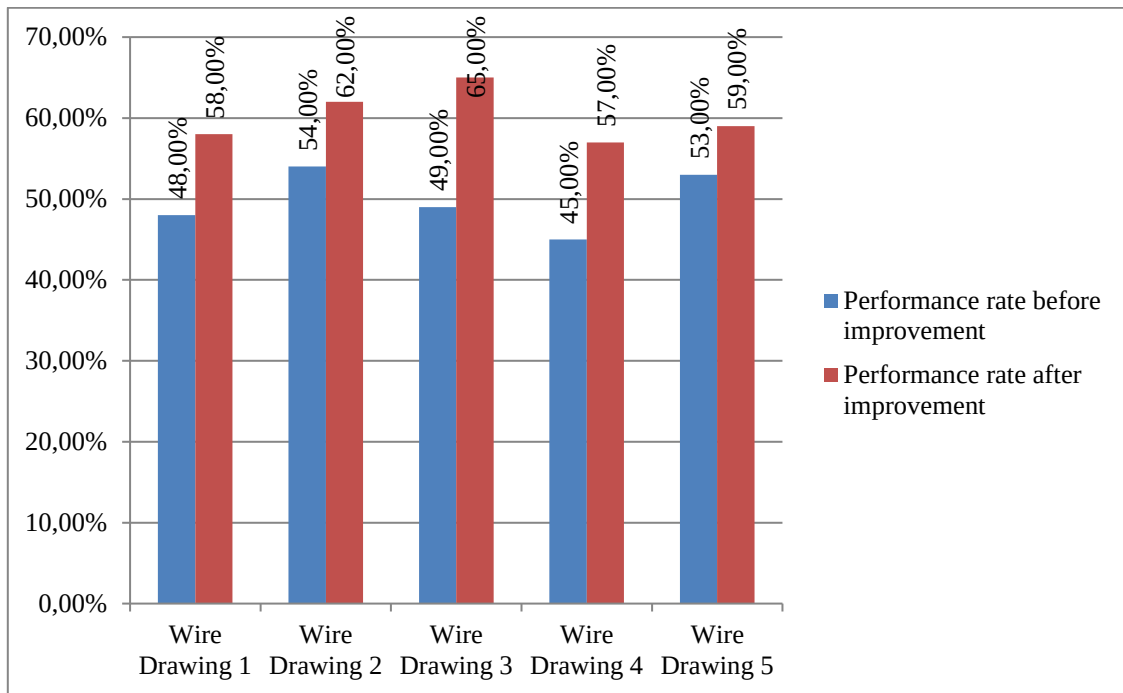


Figure 4.7 Performance rates before and after improvement

After calculating the first OEE value, improvements were made in performance and availability rates. The values obtained as a result of these studies are shown in Table 4.2 and Figure 4.8.

Table 4.2 OEE and multiplier values at the end of improvement studies

	Availability Rate	Performance Rate	Quality Rate	OEE Value
Wire Drawing 1	37.37%	58%	100%	21.68%
Wire Drawing 2	50.82%	62%	100%	31.51%
Wire Drawing 3	56.30%	65%	100%	36.60%
Wire Drawing 4	78.06%	57%	100%	44.50%
Wire Drawing 5	66.10%	59%	100%	39.00%

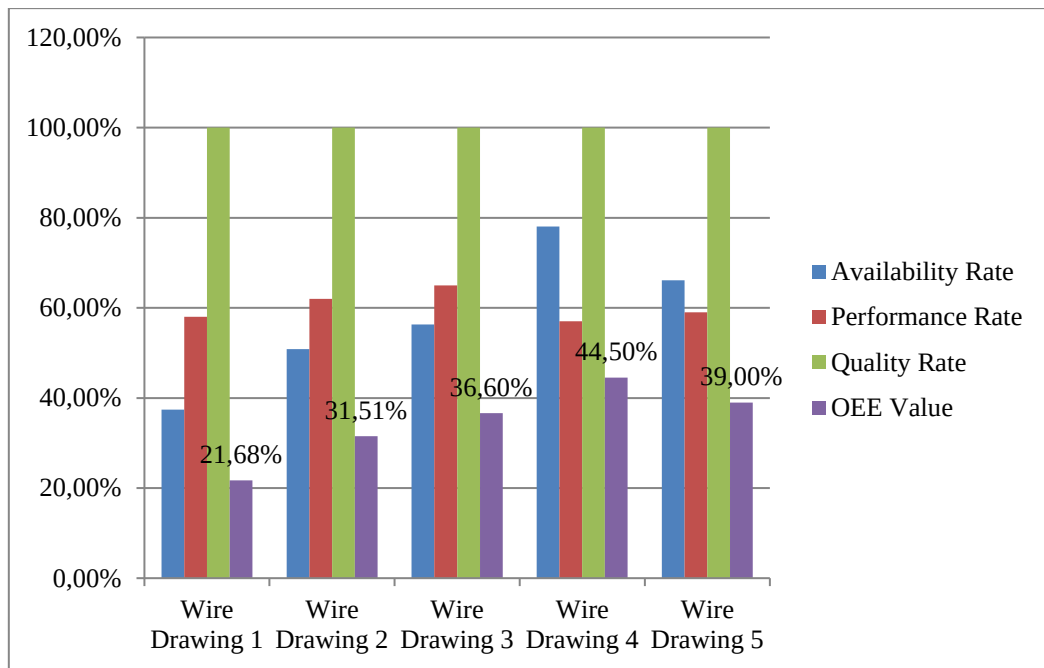


Figure 4.8 OEE and multiplier values

Changes in OEE values on a bench basis are shown in Figure 4.9. There has been an extremely high increase in the new OEE values obtained. The highest increase in OEE was observed in wire drawing 4.

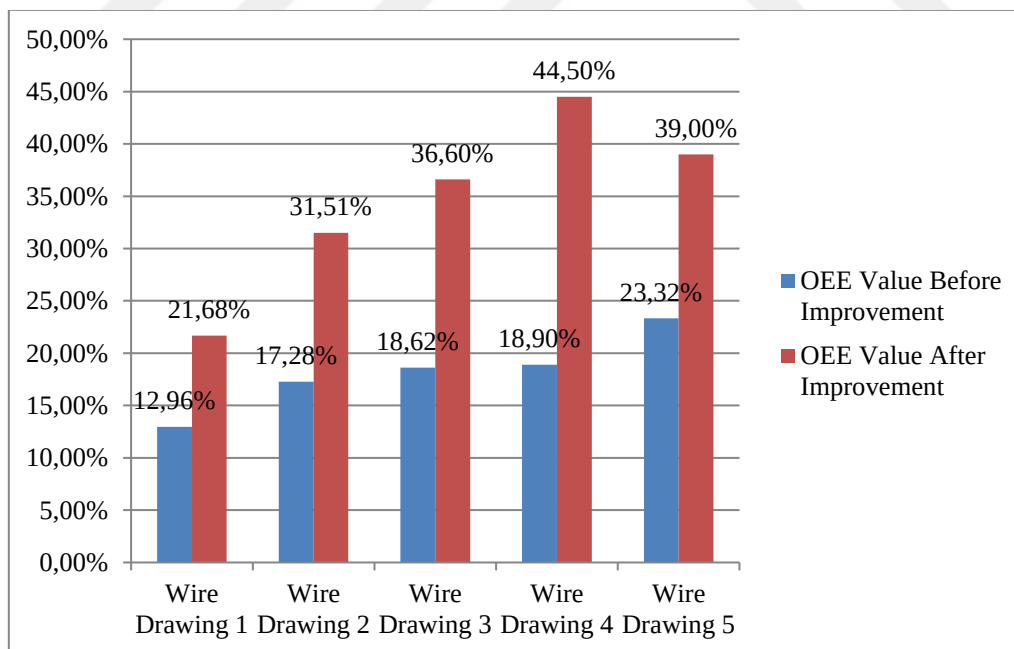


Figure 4.9 Change in OEE values

5. CONCLUSIONS

In this thesis, value stream mapping technique, which is one of the cornerstones of lean production, is used to determine the current situation in a factory producing aluminum conductors. Total productive maintenance (TPM), OEE, KAIZEN (continuous improvement) and JIDOKA techniques from lean manufacturing techniques are used for waste elimination and improvement studies. Wastes and bottlenecks are observed with value stream mapping. The current situation is mapped and the problems in the production flow were determined. While drawing the current situation map, unlike other studies in the literature, seven products are considered together instead of a single product. Pareto analysis was used to determine these products. The products that make up 80% of the company's annual production amounts have been studied. This product family is illustrated in a single current state map. Before starting the improvement works of the problems that emerged after the analysis of the current situation, an order of importance was established by considering some criteria. For this, AHP and TOPSIS, which are multi-criteria decision making techniques, were used. Due to cost and time constraints, improvement studies were started for the first three of the problems whose priority order was determined. These improvement efforts are focused on reducing losses due to low machine operating rates, machines not operating at BOM speeds, and excessive downtime due to machine failures. Wire drawing machines were handled in the improvement studies. When the studies started, it was revealed that these three problems were interrelated. In order to improve the low machine operating rates, it was decided that the OEE values should be calculated first in the company. For this, various infrastructure works were carried out. In order to more accurately assess machine availability, OEE was calculated first. The calculations of the ratios to be used in the OEE parameters were performed separately. At the end of this calculation, drawing 1, drawing 2 drawing 3, drawing 4, drawing 5 OEE values were found to be 12.96%, 17.28%, 18.62%, 18.90%, 23.32%, respectively. As a result of the low values, it was decided to make some improvements in performance and availability rates. One of the biggest reasons for the low performance ratio is that the machine operating speeds cannot reach the specified level. Within the scope of this project, the speeds of the machines in the bill of materials were revised and updated. An online display system was established to compare the working speeds with the speeds in the bill of materials. If the working speed is less than the prescription speed for a certain period of time, a setup has been created to give a warning to the

relevant people. Thus, the relevant people were able to find the root cause of this problem and take action more quickly. At the end of the improvement work, performance ratios increased by 10% in drawing 1, 8% in drawing 2, 16% in drawing 3, 12% in drawing 4, and 6% in drawing 5. When the reasons why the availability rate did not reach the desired level were examined, the excessive downtime due to machine malfunctions stood out. It was decided to carry out improvement studies in this regard. Planned maintenance has been updated with the maintenance - repair team. The malfunctions were recorded in the ERP system and arranged so that the relevant maintenance operator would be notified. In this way, both the response time to the malfunction and the repair time were reduced. As a result of regular maintenance of the machine, there was a decrease in malfunctions. This has led to an increase in the availability rate. 10.37%, 20.8%, 18.30%, 36.06% and 22.10% improvements were achieved in drawing 1, drawing 2, drawing 3, drawing 4 and drawing 5 machines, respectively.

As a result of the improvement efforts, the improvements in availability and performance rates were also reflected in the OEE rate. Our new OEE values were 21.68% in wire drawing 1, 31.51% in wire drawing 2, 36.60% in wire drawing 3, 44.50% in wire drawing 4, and 39% in wire drawing 5. The value we calculated with traditional methods as the machine operating rate has now been revised as OEE. And it began to be calculated more systematically. Easier analyzes on equipment efficiency started by looking at the OEE value and the parameters used in its calculation. Problems were identified and the opportunity to get down to their root causes was seized.

In our thesis study, three of the improvement projects could be done due to time and cost constraints. It was stated that these three projects should be disseminated for other machines as well. Lean manufacturing techniques that should be used in relation to other improvement projects were explained to the company. Suggestions for improvement were made. As can be seen from the study, Lean manufacturing provides companies with the opportunity to make big profits when small improvements in businesses are standardized. Lean manufacturing is a production systematic and requires continuity. All its steps are a whole and follow each other. There is no limit to improvement activities. In order for lean production to be successful, it must be adopted from the lower level to the executive level and a company culture must be created.

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APPENDICES

Appendix A.

Appendix Table A.1 Production quantities of all products in 2019.

Product Name	Total	Cumulative	Cumulative Rate
ACSR PH	1572870	1572870	16.16%
X 12 mm Alüminum Rod	778634	2351504	24.16%
ACSR PG	692017	3043521	31.27%
Y 12 mm Alüminum Rod	606204	3649725	37.50%
ACSR RV	592388	4242113	43.59%
Y 9.5 mm Alüminum Rod	573996	4816109	49.49%
ACSR 210/35	558509	5374618	55.22%
X 12 mm Alüminum Rod	506085	5880703	60.42%
ACSR CD	467485	6348188	65.23%
ACSR HW	413261	6761449	69.47%
240 mm2 Ezme Damar (37x3.00)(Left)	383106	7144555	73.41%
X 12 mm Alüminum Rod (DK1)	366852	7511407	77.18%
ACSR TL	258344	7769751	79.83%
AAAC 63 (GES 1640059)(Right)	232608	8002359	82.23%
ACSR Sw	228696	8231055	84.57%
ACSR 120/20 (122-AL1/20-ST1A) (Case I)	147796	8378851	86.09%
H14 9.5 mm Alüminum Rod	144002	8522853	87.57%
ACSR Lk (Case II)	123249	8646102	88.84%
ACSR Chick	114371	8760473	90.01%
AAC Pn	90196	8850669	90.94%
185 mm2 Ezme Damar (37W)(Left)	80535	8931204	91.77%
AAC 95 (93-AL1)	72579	9003783	92.51%
150 mm2 Ezme Damar (19x3,25) (Left)	62135	9065918	93.15%
H12 12 mm Alüminum Rod (DK2)	54076	9119994	93.71%
54.6 mm2 Alaşım Ezme(Left)	46280	9166274	94.18%
500 mm2 Ezme Damar (58 Telli)	44106	9210380	94.64%
70 mm2 Ezme Damar (19W)(Right)	43951	9254331	95.09%
ACSR 95/15 (94-AL1/15-ST1A) (Case I)	43644	9297975	95.54%
AAC Cockr (266-AL1)	43233	9341208	95.98%
70 mm2 Alaşım Ezme (Left)	36093	9377301	96.35%
AAC Ast	32924	9410225	96.69%
AAC Ro	29350	9439575	96.99%
H13 12 mm Alüminum Rod (DK1)	24059	9463634	97.24%
AAC Horn (158-AL1)	24012	9487646	97.49%
AAC 625 (626-AL1)	21475	9509121	97.71%
12 mm Alloy Rod - T1	19499	9528620	97.91%

ACSR 240/40 (243-AL1/39-ST1A) (Case I)	17363	9545983	98.09%
ACSR LA180 (147-AL1/34-ST1A)	14782	9560765	98.24%
ACSR Blu	13543	9574308	98.38%
ACAR 630 (54/7)(Right)	12126	9586434	98.50%
4.60 mm Alloy Wire	10126	9596560	98.61%
ACCC Lis	9142	9605702	98.70%
ACSR AC 500/26 (502-AL1/27-ST1A)	7994	9613696	98.78%
ACSR Dra	7693	9621389	98.86%
9.5 mm Alloy Rod - T1	7282	9628671	98.94%
AACSR 15.3(Right)	7257	9635928	99.01%
AAC 150 (147-AL1)	6887	9642815	99.08%
ACSR 435/55 (434-AL1/56-ST1A) (Case I)	6730	9649545	99.15%
ACSR 340/30 (339-AL1/30-ST1A) (Case I)	6527	9656072	99.22%
2.38 mm Alloy wire	6240	9662312	99.28%
ACSR 400/93 (406-AL1/93-ST1A)	5985	9668297	99.34%
16 mm2 Ezme Damar (7x1,69)(Sol Örüm)	5722	9674019	99.40%
ACSR LA 280 (Hawk) (242-AL1/39-ST1A)	5663	9679682	99.46%
ACSR 630	5655	9685337	99.52%
ACSR LA 455 Condor (402-AL1/52-ST1A) (Case II)	4462	9689799	99.56%
ACSR 700/86 (688-AL1/86-ST1A)	3904	9693703	99.60%
ACSR 400	3772	9697475	99.64%
AAAC Aster 570 (570-AL4) (Case II)(Left)	3490	9700965	99.68%
ACSR Lynx (183-AL1/43-ST1A)	3423	9704388	99.71%
ACSR Partridge (135-AL1/7-ST1A)	2887	9707275	99.74%
3.58mm Alüminum wire	2553	9709828	99.77%
4.25mm Alüminum wire	2080	9711908	99.79%
4.30 mm Alloy Wire	2035	9713943	99.81%
ACSR Peacock	1865	9715808	99.83%
ACSR Dorking (Case I)	1823	9717631	99.85%
ACSR 185/30 (184-AL1/30-ST1A) (Case I)	1806	9719437	99.87%
AAC Phlox	1252	9720689	99.88%
GSW 70 (19x2,21)(Sağ)	1180	9721869	99.89%
ACSR FA 380 GRACKLE (606-AL1/77-ST1A) (Case I)	1158	9723027	99.91%
ACSR 150/25 (149-AL1/24-ST1A) (Case I)	987	9724014	99.92%
AAC 638 (638-AL1)	909	9724923	99.92%
AAAC 300 (300-AL3)(Right)	847	9725770	99.93%
35 mm2 Alloy Ezme(right)	827	9726597	99.94%
AAC Cosmos	684	9727281	99.95%
AAC 604-AL1(AL 380 HAWTHORN)	669	9727950	99.96%
AAAC Greeley(Right)	653	9728603	99.96%
4.20 mm Alloy wire	606	9729209	99.97%
AAC 35 (34-AL1)	571	9729780	99.97%
AAC 70 (66-AL1) (19x2.10)	550	9730330	99.98%

2.50 mm annealed aluminum wire	505	9730835	99.99%
AACSR 95/55 (Case 1)(Right)	395	9731230	99.99%
AAAC Aster 95 (93-AL4)(Left)	383	9731613	99.99%
ACSR 152/25 Ostrich (152-AL1/25-ST1A)	350	9731963	100.00%
AACSR 50/30 (Case 1)(Right)	248	9732211	100.00%
5.65mm aluminum wire	52	9732263	100.00%



Appendix B.

