DOKUZ EYLÜL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

A VALUE STREAM MAPPING FRAMEWORK WITH LEAN MANUFACTURING TECHNIQUES IN AUTOMOTIVE SECTOR

by

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September, 2020

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A VALUE STREAM MAPPING FRAMEWORK WITH LEAN MANUFACTURING TECHNIQUES IN AUTOMOTIVE SECTOR

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M.Sc THESIS EXAMINATION RESULT FORM

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A VALUE STREAM MAPPING FRAMEWORK WITH LEAN MANUFACTURING TECHNIQUES IN AUTOMOTIVE SECTOR

ABSTRACT

As in all production enterprises, reducing the costs and improving the processes are of great importance in the competitive automotive sector. For this reason, lean manufacturing principles have been adopted in order to reduce the error rates, shorten cycle times and improve the production processes. Value Stream Mapping (VSM) is one of the most critical key lean manufacturing tools that can analyze both value-added and value-added process steps and help identify hidden waste and waste sources. In addition, VSM is a visual tool for demonstrating how things work in the production line. Thanks to VSM, the current state can be determined and future state value stream can be created in line with the demand and in this direction, the company may produce a roadmap for its own objectives. In this study, the current state value stream map of an automotive electronics company was created and some improvements were made using lean manufacturing system techniques and the future state value stream map was revealed. Some of the techniques used are kaizen, root cause analysis, 5S and single minutes exchange of dies (SMED) activities.

Keywords: Value stream mapping, lean manufacturing, kaizen, root cause analysis, automotive sector

OTOMOTİV SEKTÖRÜNDE YALIN ÜRETİM TEKNİKLERİ İLE DEĞER AKIŞI HARİTALAMA ÇERÇEVESİ

ÖZ

Tüm üretim işletmelerinde olduğu gibi, maliyetlerin düşürülmesi ve süreçlerin iyileştirilmesi rekabetçi otomotiv sektöründe büyük önem taşımaktadır. Bu nedenle, hata oranlarını azaltmak, döngü sürelerini kısaltmak ve üretim süreçlerini iyileştirmek için yalın üretim ilkeleri benimsenmiştir. Değer Akışı Haritalama (VSM), hem katma değerli hem de katma değerli proses adımlarını analiz edebilen ve gizli atık ve atık kaynaklarını tanımlamaya yardımcı olabilecek en kritik anahtar yalın üretim araçlarından biridir. Ayrıca VSM, üretim hattında işlerin nasıl yürüdüğünü gözler önüne sermek adına görsel bir araçtır. VSM sayesinde mevcut durum tespit edilerek, gelecek durum değer akışları talep doğrultusunda oluşturulabilir ve bu doğrultuda işletme kendi hedefleri için yol haritası çıkarabilir. Bu çalışmada, bir otomotiv elektroniği şirketinin mevcut durum değer akış haritası oluşturulmuş ve yalın üretim sistemi teknikleri kullanılarak bazı iyileştirmeler yapılmış ve gelecek durum değer akış haritası da ortaya konmuştur. Kullanılan tekniklerden bazıları kaizen, kök neden analizi, 5S ve tekli dakikalarda kalıp değişimi (SMED) aktiviteleridir.

Anahtar kelimeler: Değer akış haritalama, yalın üretim, kaizen, kök neden analizi, otomotiv sektörü

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CHAPTER 1
INTRODUCTION

Lean manufacturing is a production and management philosophy based on cost reduction, continuous improvement and process improvement in general, which carries out efforts to eliminate all waste in a production or service system. According to Hines & Taylor (2000), it is a concept based on the Toyota Production System, which emerged as a global approach that combines different techniques to center waste generation and produce products that better meet the demands and expectations of the customer. Lean production uses many different techniques and eliminates waste to meet customer needs as and when requested. The most critical and important one of these techniques is value stream mapping (VSM) that defines all value- added and non value-added process activities in the system in terms of time, cost and labor.

Value stream mapping is a useful and common way to guide improvements and enhancements based on a detailed plan. (Liker, 2004). VSM has become an application that has started to be used more in the last half of the 20th century. Although it was one of the foundations that made the Toyota Production System lean thinking and system, VSM technique and term had not been used until then. In this context; in recent years, all companies engaged in mass production have been carrying out serious studies on the insulating processes. Especially for companies in the automotive sector, value stream mapping techniques have become more important for eliminating wastes.

In this study, in the light of the information mentioned above, VSM technique has been used in a company in the automotive electronics sector, together with many lean manufacturing philosophy methods to create an efficient production system. Although value stream and determination of waste is a common practice in the automotive industry, it was applied for the first time in the company where this study was carried out and all data were processed in real time.

Starting from the definition of the current state value stream, the company has carried out activities to minimize quality-error rates, kaizen studies, root cause analyzes and process improvement. In order to reach the sustainable target of lean manufacturing and management system, it is necessary to reveal the basic wastes within the company and define product-information value streams. For this reason, the VSM technique has been chosen as a frequently used method in the literature and automotive sector.

The most important contribution of this study to the literature and to the company is that all processes can be examined in a single file thanks to the VSM technique and it establishes a bridge that creates a common language between employees and management. Thus, it has been shown once again that value stream chains can be seen on a single map of the entire production process. Additionally, it is understood that it facilitates the detection of problematic blind spots in the electronics industry.

This study is organized as follows. Chapter 2 gives an overview of relevant literature on VSM. Chapter 3 explains lean concept, lean manufacturing philosophy and value stream mapping. Chapter 4 describes the case study in automotive sector and some lean manufacturing techniques such as root cause/ 5-why analysis and SMED activities. Also, the current state value stream map was prepared and improvement and kaizen suggestions were submitted to the factory management for the points considered as losses. Chapter 5 provides future state value stream mapping. Finally, in Chapter 6 the results and the conclusions are presented.

CHAPTER 2
LITERATURE REVIEW

Lean production is a system that continues its validity in the enterprises that are active in all production and service sectors starting from 1950s to today. According to Rothstein (2004), lean manufacturing is regarded as a large production system paradigm that includes a variety of methods, including full-time inventory systems, teamwork, multidisciplinary, engagement of all employees, and policies to ensure and improve product and process quality. Cox & Blackstone (1998) make the following definition for lean manufacturing: Lean production is a set of methodologies that demonstrate the importance of minimizing the level of use of all resources (including labor, time, cost) in the enterprise. Its aim is to define and eliminate non-value-added activities in all processes such as purchasing processes, research and development activities, production planning and production, and project management.

The main purpose of the lean production system is to eliminate all wastes in the enterprise in order to enhance the value of the activities that the customer is willing to pay and consequently the competitiveness level (Liker, 1998). Worley & Doolen (2006) define waste as any activity that does not add value for the customer and creates costs for the enterprise, even if it must be realized. Hicks (2007) also argues that the basis for the successful implementation of lean manufacturing philosophy is to determine what constitutes value, to understand process flows and waste analysis. Enterprises have found that they can continuously increase their efficiency and reduce their costs by identifying and eliminating or minimizing waste and using basic lean manufacturing methods (Imai, 1997). Sawhney, Kannan & Li (2009) refer to value stream mapping as one of the primary and most widely used primary lean production philosophy techniques in the literature to determine activities and wastes without added value. Ramesh, Prasad and Srinivas (2008) state that the feature of value stream mapping, which makes it different from other process and stream analysis, can examine both material and information flow while analyzing material flows of processes.

Implementing the value stream methodology means not thinking about all processes one by one, but seeing the big picture, and value stream map (VSM) provides a common ground for all phases and processes, thus making decisions and activities to be implemented to eliminate wastes in value streams and improve processes (McDonald et al., 2002). Monden (1994) states that value stream maps are generally used to reveal process activities in businesses that add value, do not add value and must be made, but do not add value. There are many studies in literature connected to lean manufacturing techniques and especially VSM. Among these studies, researches involving the applications of VSM in the production sector in the form of case study and a few studies on cost accounting and customer satisfaction are listed in the table below.

Table 2.1 Lean production and value stream mapping case studies

Paper	**Objective**	**Tools Used**	**Type of Industry**
Braglia et al. (2006)	Presenting the necessary value flows to construct a production system characterized by a tense and level flow that meets all needs and expectations of customers and contributes to zero value for customers.	Critical path mapping, VSM and temporized bill of material	Refrigirator
Wee & Wu (2009)	Using a case-based approach and a multi-stage problem-solving methodology to demonstrate how product and process quality and costs are affected by weak supply chain processes	The 5- why analysis, VSM and future state map	Automotive and motor industry
Chen, Li & Shady (2010)	The case study presented in this paper intends to give lean practitioners a reference for implementing lean systems in small manufacturing operations	5 whys, design of experiments, standard operation routine sheets and kaizen	Industrial switchgears and switchboards
Rahani & al-Ashraf (2012)	Using a case-based approach to determine how lean manufacturing tools are utilized to help the process industry eliminate waste, maintain better inventory control, improve product quality, and capable of better operational control	The mapping process, kaizen activities, performance analysis and work measurement	Japan Automotive Industries

Table 2.1 continues

Bertolini et al. (2013)	Defining a flexible and hybrid product planning control system	Synchro-material resource planning, VSM and fixed- order quantity approach	Electro-injectors
Ruiz-de-Arbulo-Lopez et al. (2013)	Determination of the deficiencies of conventional cost accounting techniques	ABC analysis, box score, activity based costing and capacity study	Empirical
Faulkner & Badurdeenb (2014)	Presenting a comprehensive methodology to develop Sustainable VSM by identifying suitable metrics and methods to visually present them	VSM and sustainability metrics	Satellite television
Librelato et al. (2014)	By analyzing the productive processes of a business, to establish an integration between VSM and the thinking process of theory of constraints	Root cause analysis and current reality tree	Automotive
Haefner et al. (2014)	To reduce rates of defects and lower quality-related costs	Failure mode effect analysis (FMEA), visualization and quality value stream analysis	Electronic assemblies for automotive industry
Alves & Alves (2015)	Achieving productivity gains and improvements on customer satisfaction, as well as develop the ability to provide quick responses to market changes in a globalised economy	5S, Single-Minutes Exchange of Dies (SMED), Total Preventive Maintenance (TPM) and poka-yokes	Empirical
Hellono et al. (2017)	Contributing to the development of assessment models and indicators to increase sustainability in production processes	VSM and sustainable operations	Multinational cosmetic , thermoplastic products and aluminium for kitchen utensils

CHAPTER 3
LEAN CONCEPT AND VALUE STREAM MAPPING

3.1 Lean Manufacturing Philosophy

Lean production is a philosophy and way of thinking that aims to define and eliminate processes without added value and all kinds of activities that cause customer dissatisfaction and to minimize all kinds of wastes such as stock, excessive labor, error. The aim of lean production is to be sensitive to customer needs and meet the requirements at the right time by eliminating each component defined as waste. (Bhamu & Singh Sangwan, 2014)

Waste in manufacturing is referred to as "muda" in Japanese and these wastes are; over-produced products, faulty products that require rework, unnecessary process stages, transport of workers and parts and delays due to previous stages. (Womack & Jones, 2003). There are different lean manufacturing tools and techniques to eliminate these wastes. Some of these techniques are;

- Kaizen
- Single minute exchange of die
- Heijunka
- Value stream mapping
    - Current- state value stream mapping
    - Future- state value stream mapping
- First in first out
- 5S
- Just in time
- Yamazumi
- Poka- Yoke
- Jidoka
- Visual Management
- Problem solving and reporting

- One- piece flow

In this study, VSM technique was chosen among the many lean manufacturing techniques listed above because it provides a short, clear and visual communication between management and employees in relation to material and information flow.

3.2 History of Lean Manufacturing System

Toyota is the first and best implementer of the lean manufacturing system. Lean manufacturing approach was originated by Taiichi Ohno. Toyota and Ohno's aim was to develop production systems and increase sales to compete with American and European companies. After reviewing, Ohno and the Toyota team decided to build a new production system and call it the Toyota Production System (Türkan, 2010).

At the beginning of 1980s, Toyota Motor Company putted 3,5 million cars on market and thus ranked to second among the manufacturers in the world (Ohno, 1996). The Toyota Production System has two basic principles. These are just-in-time production and autonomation. These principles aimed at improving quality by eliminating the structural and uncontrolled obstacles and constraints of the mass production system. The structure known as the Lean Manufacturing House or Toyota Production System House, which includes the techniques of the Toyota Production System, in other words, the lean manufacturing system, is indicated below.

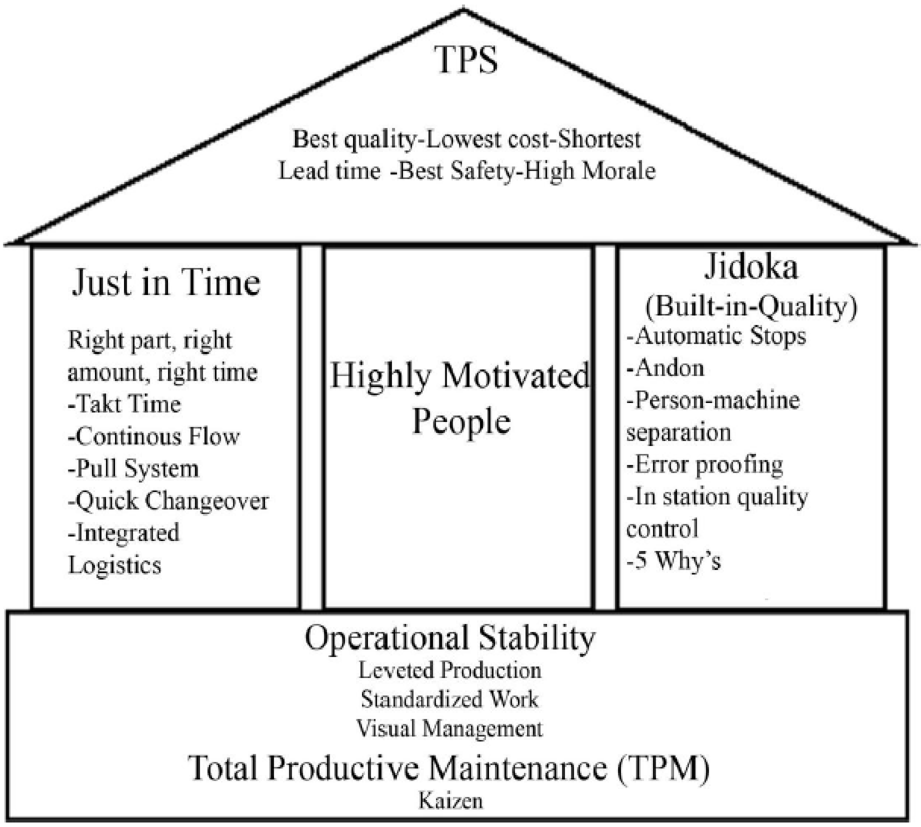

Figure 3.1 Toyota production system house (Ohno, 1988)

The two main pillars that sustain the Toyota production system (TPS) are Just-in-time and Jidoka (autonomation) techniques. The basis of these two main pillars are Total Productive Maintanence (TPM), visual management, Kaizen, operational stability and standardized work.

In addition to these, important individuals and companies on the development of production systems around the world from 1750 to 2000s are shown below.

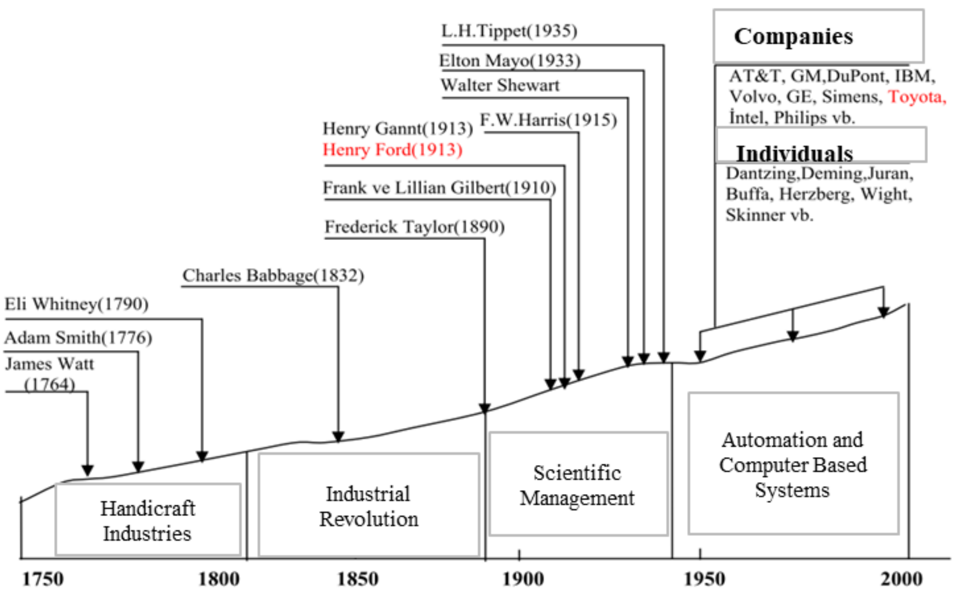

Figure 3.2 Important individuals and companies on the development of production systems (Monks, 2001)

Here's a brief description of the Figure above:

- James Watt invented the steam engine
- Adam Smith introduced the division of labor concept
- Eli Whitney introduced the interchangeable parts
- Charles Babbage brought performance-based salary system forward
- Frederick Taylor introduced time study and standards
- Frank and Lillian Gilbert did the analysis of the motion economy
- Henry Ford brought out the concept of mass production based on assembly line
- Henry Gannt contributed the using of programming systems
- F.W. Harris presented the model of economic order quantity
- Walter Shewart identified the statistical process control
- Elton Mayo made a contribution about behavioral factors
- L. H. Tippet presented the working sampling

In conclusion, the development of production systems can be expressed as three divisions: Labor- based production, mass production and lean production. From the second world war to the present day, the lean production system continues to develop itself and continues to dominate.

3.3 Principles of Lean Manufacturing Philosophy

Lean manufacturing philosophy has adopted the basic principles for the implementation. The main purpose of these principles is to reduce costs by eliminating waste. Waste is a set of activities that do not add value to the product and the quality of the product through the eyes of the customer. The concepts of "value", "value stream", "continuous flow" and "pull" are in line with the ultimate simple goal of "perfection" or continuous efforts to improve the performance of the business (Locher, 2008). In addition to, all lean principles are shown below figure.

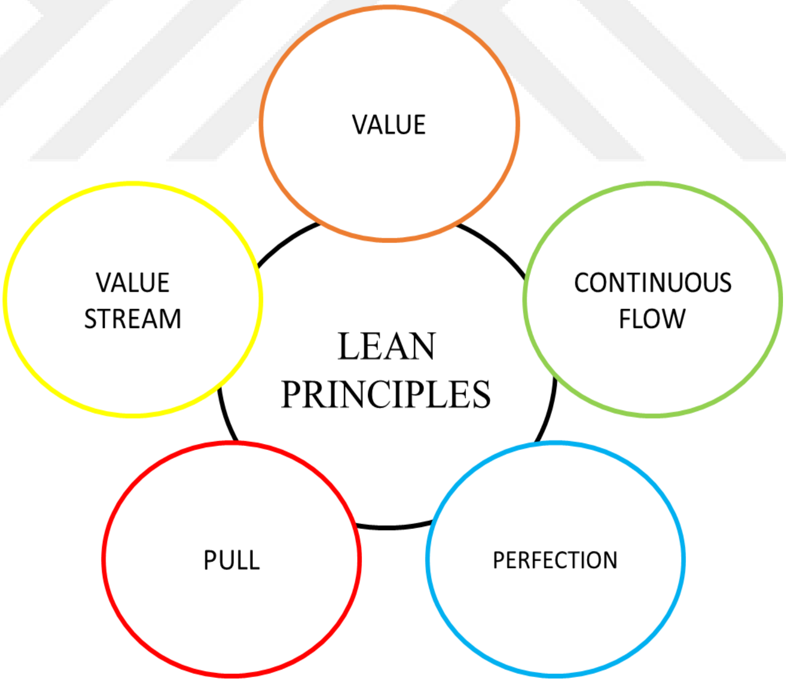

Figure 3.3 Lean principles

3.3.1 Value

Value is a lean manufacturing principle that is defined as the whole of activities which provides an additional benefit to the product or process and create meaning for the customer. In addition, a product or a service that meets the customer's demand at required time, as requested and at a predetermined price is called value. All activities that do not benefit the product or the service and have no meaning for the customer are the resources of waste for companies. The waste should be destroyed to create value and the target cost in of the resources required to produce the product should be determined.

3.3.2 Continuous Flow

Continuous flow is to eliminate the waste that creates obstacles to produce the customer-defined value at the requested quality, at the required time and at the cheapest price. During the continuous flow, steps that do not create value should be removed and processes should be continued with value creation steps. Cellular production is generally adopted by organizations that implement the lean manufacturing philosophy, each cell containing all the resources necessary for the production of a particular product to ensure continuous flow (Ward & Graves, 2004). The main purpose of this principle is to create a system that can continue production without pauses along the production line.

3.3.3 Value Stream

Value stream is an all-inclusive action plan and activities in the process of transforming inputs into outputs, thus creating the ultimate value for the customer (Onofrejova & Janekova, 2015). In production, each product family follows a particular value stream, and a product family is a typical group of parts, sharing a common set of processes (Tapping & Shucker, 2003). The value stream contains many waste, as it covers the whole process starting from the production process to the end user. Wastes in value streams cause the company's resources to be deployed for activities that do not create value. The companies adopting the lean manufacturing philosophy try to eliminate these wastes through continuous improvement efforts.

3.3.4 Pull

The pull system is an information system that controls the process and production quantity and ensures that the stock quantity is kept to a minimum. Production in pull systems does not start without customer demand, the product is produced when requested (Huntzinger, 2007). Pull system in the lean manufacturing starts with the customer demand and follows all steps until the product is delivered to the customer. All the steps in production start with the next step triggered by the previous one. In traditional production systems, the push system is adopted, while in lean enterprises the pull system is adopted. The differences between the push and pull systems are briefly shown in Figure 3.4.

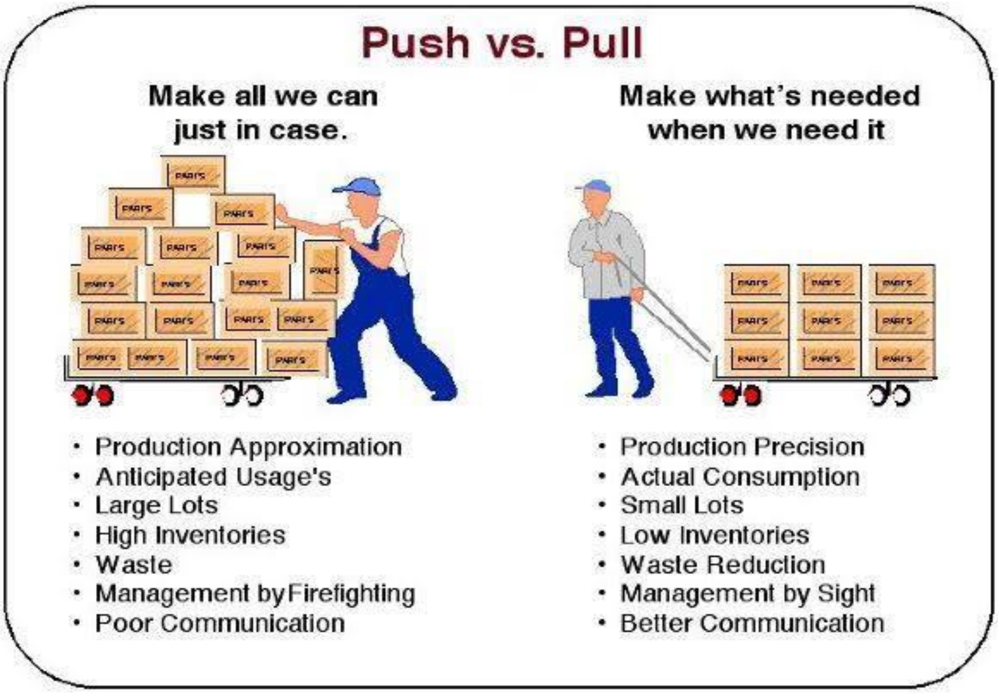

Figure 3.4 Differences between push and pull system (Industryweek, 2017)

3.3.5 Perfection

There is the principle of "doing the right job at a time" instead of "doing the job right" on the basis of lean manufacturing philosophy. This has led to the understanding of perfection, the final principle of lean manufacturing.

Lean businesses striving for perfection should establish a system that everyone can understand easily. In this way, feedback will be accelerated and ways of creating value will be revealed more easily. Since all employees in the lean businesses are knowledgeable about the system, they accelerate the intervention process by being aware of the problems occurring during production. Such a transparent production process also helps to achieve excellence. The most important support for excellence is transparency. This is the fact that suppliers, system components, integrators, distributors, customers and employees, in short, all elements of the system can see everything in full transparency, whether in a simple system or in a complex system. So finding ways to create value is always quite easy (Womack & Jones, 2003).

3.4 Current State Value Stream Map (CS-VSM)

A current state value stream map (CS-VSM) shows how all products and information are transferred from one process to another through all process workflows in the current system. The CS-VSM should be based on a data set collected directly from the first stage of the production system until the product reaches the end user. It is drawn using the standard VSM objects available in the literature shown in Figure 3.5.

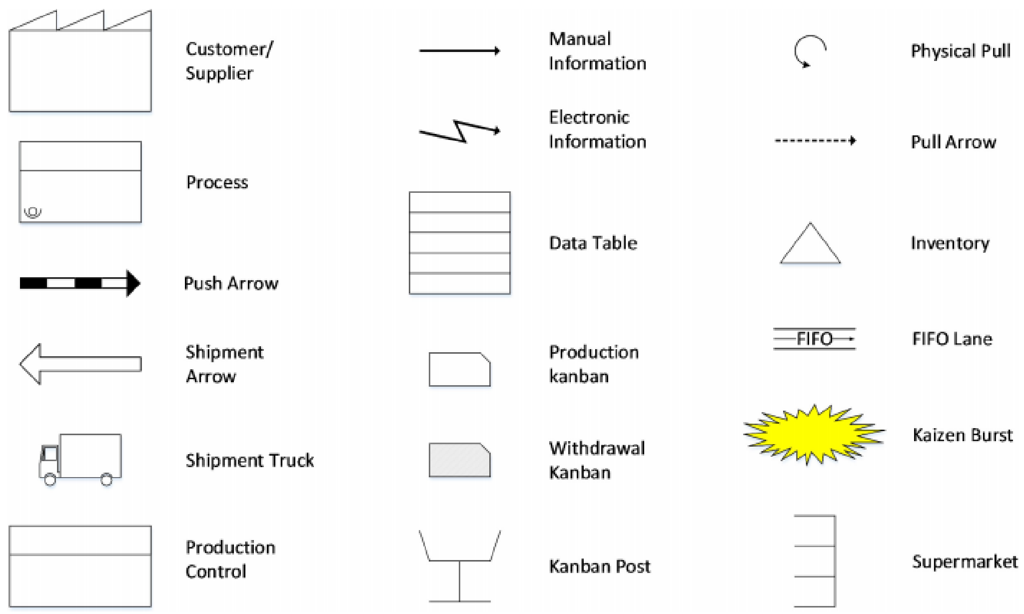

Figure 3.5 Basic mapping icons (Batra et al., 2016)

CS-VSM captures the whole evolutionary life- cycle process from raw materials to finished products. This map uses many icons to visualize the flow of materials and information as a product goes through all stages from one process to another, and is created only with pencil and paper.

Before mapping by Seth & Gupta (2005), the principles of lean manufacturing that constitute the backbone of the CS-VSM must be clearly and fully understood. These principles are as follows:

- Identify value from your customer's perspective,
- Define the value stream,
- Eliminate the wastes,
- Make the flow chain,
- Pull the work rather than push it,
- Follow the perfection level.

CS-VSM works on the determination of 7 basic wastes of lean production in the system where these principles are applied. The 7 basic wastes of lean production are as follows:

1- Overproduction

2- Delay

3- Over processing

4- Transportation

5- Unneeded inventory

6- Unneeded motions

7- Errors

The first stage in creating a VSM is to choose a project, product, service or product family according to Rother & Shook (2003). The second stage is to create an current state value stream map using paper, pencil and visualize material and information flows for the selected project, product, service or product family. Woehrle & Abou-Shady (2010) refer to the third step as identifying and analyzing the seven possible waste sources identified by Toyota from the CS-VSM that can be encountered during the stream of value. The fourth and last step is to remove the waste resources from CS-VSM and to develop a future state value stream map (FS-CSM) after all the necessary process development, kaizen projects.

Most of the information on the current state value stream map available in the literature was collected according to the approach proposed by Rother & Shook (2003). In addition, Storch & Lim (1999) argue that the effective work of simple philosophy requires a clear and clear communication between all segments of the value stream, not only between the operational units. Moreover the VSM technique has many advantages as well as many limitations encountered during application.

3.5 The Advantages of Value Stream Mapping (VSM)

There are many advantages provided by the VSM technique:

• It uses process parameters such as Takt Time, which identifies at which stage each step in the system will work by transferring production plans and customer demand estimates to both the production planning unit and logistics stock control.

• It provides a common language to use the same communication tool between all administrators and employe.

• According to Braglia, Frosolini & Zammori (2009), it includes information about inventory levels as well as production time.

• It shows the link between product, material and information flow.

• Tiwari & Sharma (2014) express that; It forms the basis of business action plans and helps to design the system with the necessity of running all flow without waste, from entry to exit.

• It is a qualitative tool that explains in detail how the plant should work to generate flow.

• It includes information on production and cycle times as well as information on raw material and finished product stock status.

• It forms the basis of a well-structured production plan.

3.6 The Limitations of Value Stream Mapping

VSM, one of the most important methodologies of lean manufacturing system, has its disadvantages and limitations encountered during application. These limitations can be listed as follows:

• The accuracy level is limited due to being a paper and pencil-based technique, and the number of variations that can be used with the error level is low.

• Dal Forno et al. (2014) proposes the technique called heijunka in Japanese, which is a stockless production method that is free from demand fluctuations, where each model or variety can be made sequentially in each shift.

• It cannot reveal the effect of ineffective material flows on process work (WIP), order efficiency and production costs.

• It lacks the ability to quickly and precisely develop, reveal, and evaluate root cause analyzes and for multiple ne-ne, which are necessary to prioritize various options.

• It is difficult to apply to engineering processes due to differences between manufacturing and engineering methods.

• It can not always respond quickly to situations in which production and assembly lines are very flexible, adapt to changes in sales and product demand.

• It can not put forward a practical and flexible method due to settlement problems, product and process complexity when cycle time and process time data and quantity measurements are made.

3.7 Future State Value Stream Mapping (FS- VSM)

Future state value stream mapping can only be performed after the current state value stream mapping work is complete. Yu, Tweed, Al-Hussein & Nasseri (2009) emphasize that the focus of FS-VSM is to eliminate the main causes of waste and to bind the flow of value in a soft flow. The different researchers in the literature suggest questions that will guide businesses to a future situation and thus bring out the FS-VSM. It is important that these questions are directed to the sector in which the business operates. Some of these questions are as follows: 'What is Takt time?', 'Where can queue time be reduced?', 'What are the botteleneck processes?' and 'What are the necessary improvements?' etc.

According to Solding & Gullander (2009), FS- VSM is used in all different kinds of manufacturing and can easily be learned and then used by just about everyone. FS-VSM is the most accentuated road map in order to obtain a lean manufacturing system that is constantly evolving and progressing and to observe the difference with the previous situation. This permits validation of the result, which may include the managers performance index, that is, the volume of work, the cycle time, and the WIP. Lu, Yang & Wang (2011) impart VSM can help work plan and develop in a short time. To clearly understand the basic wastes of the Lean manufacturing philosophy, CS-VSM applies FS-VSM tools to eliminate waste and to observe improvements after removal.

CHAPTER 4
CASE STUDY IN TURKISH AUTOMOTIVE SECTOR

4.1 XYZ Company Background

XYZ company was founded in 2012 to meet the electronic needs of the automotive industry. The company manufactures automotive lighting and signaling products and produces various electronic components demanded by the automotive industry. The company's main product is the printed circuit board (PCB). The figure below shows a sample PCB. In XYZ company's state-of-the-art facility, the majority of the production is realized in high standards and fully automatic facilities required by the automotive industry and today's technology and quality control is ensured.

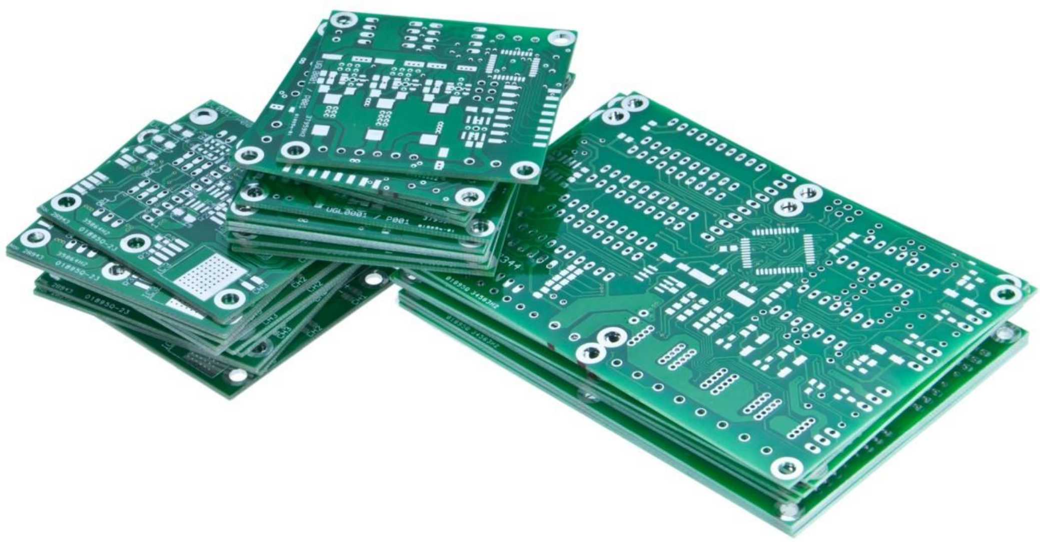

Figure 4.1 Example of the PCBs (Predictable designs, 2019)

The company is certified with all sectoral quality certifications such as ISO 9001, IATF 16949. The company's customers include major automotive companies such as BMW, Mercedes-Benz, Toyota and the Wolkswagen Group. In addition, it has succeeded to be the only supplier of the parts which it produces. In addition to its production, XYZ offers high value-added services such as design, manufacturing, logistics concept design, life cycle management and alternative sub-parts.

Finally, to specify; this study, and all the data analysis, value stream maps, root cause analysis and cost calculations included in this study were actually performed at XYZ company.

4.2 Research Methodology and Methods

The research methodology and methods of this research is case study. McCutcheon & Meredith (1993) mention that case study research is the primary way to investigate the conditions of the production area. In the simplest way, a case study uses a variety of methods, techniques and tools for collecting data in a single environment. It evaluates the temporal and related aspects of the case being examined by the observer or observers directly (Meredith, 1998). Groundbreaking methods and theories in operational and production management have been developed from case study (Voss et al., 2002). The purpose and subject of the case analysis research should be determined by propositions and theoretical relationships, but different constraints affecting case analysis are possible. These restrictions include access to the data needed, resources and available time, and the level of detail of the subject to be investigated (Rowley, 2002).

Because of all these reasons, this study aims to create a value stream mapping framework in automotive electronics sector by using case study methodology and thus to minimize losses by uncovering losses. This study is performed in XYZ company, which is the only Turkish company operating in the automotive lighting electronics, and this study will help to guide all companies and employees operating in similar sectors. The research framework of this study is shown in Figure 4.2.

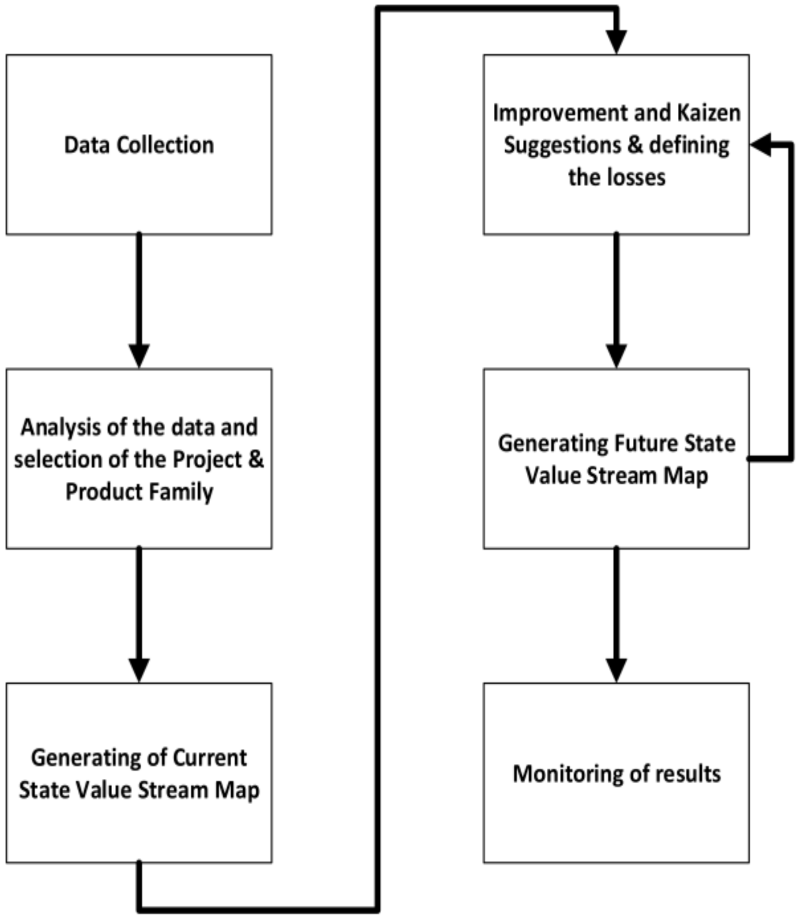

Figure 4.2 The research framework

The research framework includes of the following six steps:

- *Step 1- Data collection:* In order to understand which printed circuit board (PCB) product family has the highest production stop and problems, and to express the data numerically, a total of 10 projects underway at XYZ company were observed. For 3 months, all PCB production was directly observed by engineers at the machines and lines and all downtimes were recorded. At the same time; all process times, product changeover times, inter lines transport times, waste product quantities, as well as production stop reasons for future root cause analysis studies were noted.

- *Step 2- Analysis of the data and selection of the project & product family*: At the company, the product corresponds to each PCB used in the stop tail light or headlamp of any car. There are many separate PCBs with functions such as signal, fog in a stop tail light or headlight. The whole PCB production for each car model is called a project. All of the stop tail light and headlight PCBs of a car model project, along the right and the left, are called the project product family. According to these definitions and production stops at the data collection step are collected; the project with the highest production stop rate is selected.
- *Step 3- Generating the current state value stream map*: CS-VSM is generated to reveal all the current status of the selected project as a whole table. Thus, all the problems and all the processing times that can be improved can be seen in one simple and complete form on a single sheet of paper.
- *Step 4- Improvement and kaizen suggestions & defining the losses*: At this stage, the CS-VSM is examined and losses are determined. Afterwards, kaizen suggestions that will eliminate these losses or reduce them to the lowest level are determined. Finally, these suggestions are transformed into improvement activities.
- *Step 5- Generating the future state value stream map:* At this phase, a FS-VSM is generated in accordance with the company's vision, mission and goals. As can be seen on the research framework flowchart, this phase and the previous phase are the steps that feed each other. Therefore, these are steps that can be carried out in parallel.
- *Step 6- Monitoring the results:* Monitoring the results indicates that the latest production state will be constantly monitored, will continue to be observed and improvement activities will never end. The meaning of the word kaizen in lean manufacturing philosophy also means continuous change and improvement. For these reasons, the results are constantly monitored by engineers and responsible personnel, and improvement activities are continually realized through feedback from production operators, managers and all employees.

As a result of all these studies, FS-VSM was generated for the company and production processes continued to be monitored. Therefore, the effects of improvement and kaizen studies can be observed. This study also shows that with the help of analysis and kaizen and improvement studies VSM, the wastes and production stop can be reduced and production efficiency can be increased.

4.2.1 Step 1 and Step 2 of The Research Framework

XYZ company creates production plans according to customer demand and realizes the production according to the work flow of projects. The workflow of the production subject to this study is shown in Figure 4.4.

As stated in the research framework (see Figure 4.2), relevant data was collected in the production area for three months (April, May, June 2019). Since production numbers of PCBs belong to Project *K* were higher in April, May and June, which is the second quarter of the year, the data collection phase was carried out during this period. After the data collection phase, the data were transferred to computer and analyzed by means of pivot table and graphs. The graph in Figure 4.3 shows the total minutes of production stop for each project for three months. Each project in the graph represents its own product family. All the data in the graph are obtained by filtering through the production management system software in the time interval determined on a project basis.

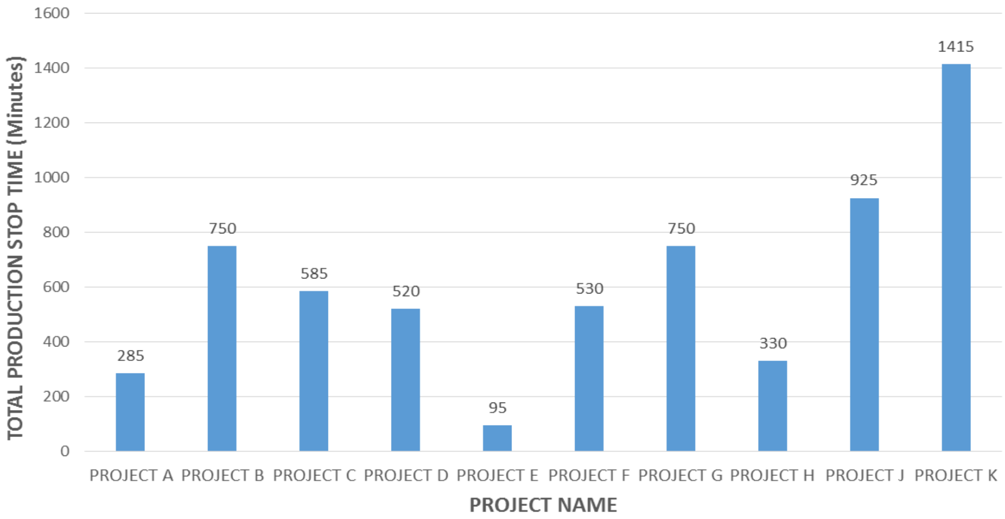

Figure 4.3 The graphs of total production stop time for each project

As it can be deduced from the graph; the project selected for VSM and improvements is Project *K* as a result of the data analysis. Because the Project *K* has the highest total production stop time and unproductiveness. The figure below shows Project K's production workflow. All intermediate, main and control stages from the entrance of the factory to the shipment of the products and raw materials are specified in the figure. This workflow is also a common workflow for all projects of the company.

The letters *A* shown in the workflow mean acceptance, *R* means rejection, and S means scrutiny. Hereunder; if the result of any process is rejection, all materials are scrapped. If the result of any process is scrutiny, all materials are evaluated by the quality experts and the next process is proceeded according to the evaluation results of the quality experts. As can be seen from the workflow in Figure 4.4, the panels and surface mount technology (SMT) materials to be used in the production of Project *K* are first passed through the incoming quality control process. Panel is a combination of several printed circuit boards (PCB) with various connection modes.

All the materials to be used in PCB production are taken into stock after passing through the incoming quality control process and sent to the production area when it is in the production plan. In the production area, unique barcodes are printed on the panels in the Laser process, the first process. In the next process, the printer process, lead-free solder is pasted to the panels and the panels are passed through the solder paste inspection (SPI) machine for solder control. SMT materials are placed on the panels in the pick & place process.

The panels, which are SMT materials placed and solder pasted, are exposed to heat according to predetermined process parameters in the reflow process. After the reflow process, the panel is optically controlled with SMT materials in the automated optical inspection (AOI) process. Besides, all processes from the printer process to the AOI process are called the SMT line.

At the end of the SMT line, all panels are subjected to quality control and sent to the In- Circuit Test/ Functional Control Test (ICT / FCT) process. The panels passing through the test process in accordance with the control plan conditions are separated into PCBs in the milling process. PCBs are visually controlled and packaged by trained personnel. Before being taken into the logistics warehouse, PCBs are inspected by final quality control personnel according to the packing specifications. Finally, the PCBs that are okay after the inspection are taken to the logistics warehouse and sent to the customer according to the date of shipment.

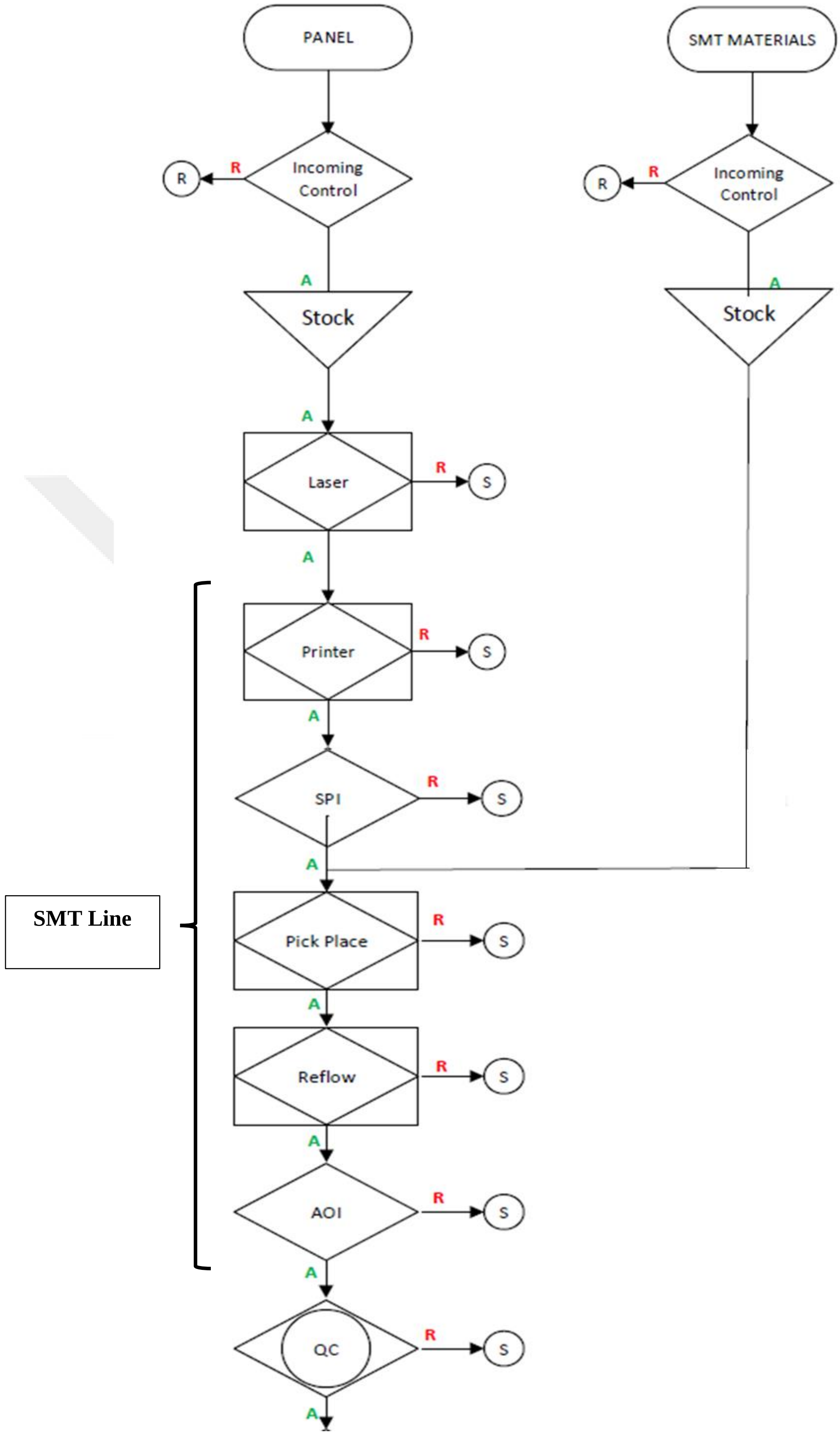

Figure 4.4 Workflow of the production

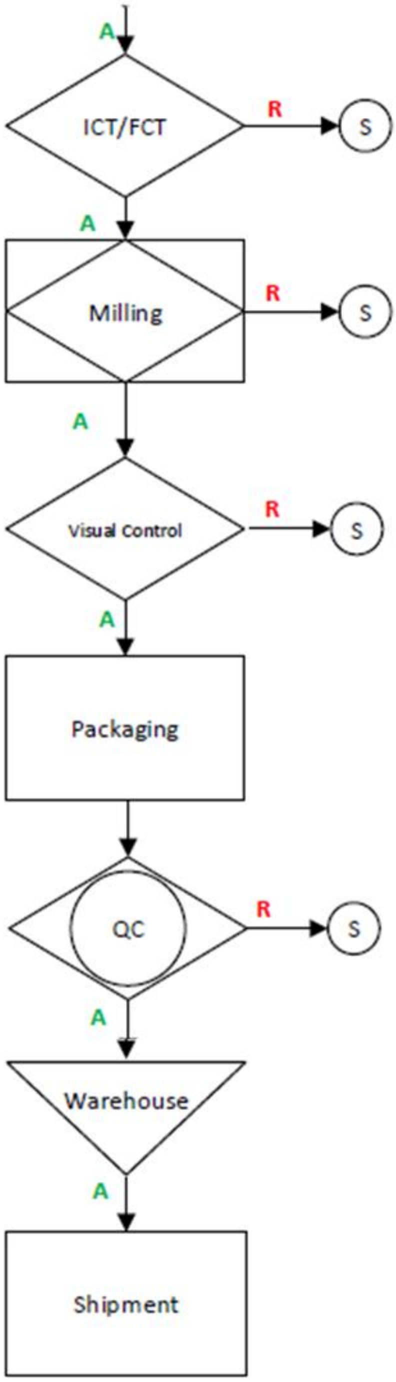

Figure 4.4 continues

This case study carried out the steps outlined in Figure 4.2 in order, improved the process and implemented VSM tools in the automotive electronics industry, increasing efficiency and reducing costs. As a result of the case study, the next section describes the CS-VSM, which includes the K Project.

4.4 Step 3 of The Research Framework- Value Stream Mapping to Develop Current State

In the step 3 of the research framework, it was mentioned that the first stage of creating a value stream map was to select a product or product family and the next stage was to draw the map using paper and pen, and visualize the material and information flows related to the selected product family. Therefore, firstly, the collected data were analyzed and Project K PCBs were selected as the product family. During the data collection phase, time study was conducted in order to obtain the standard time information to be used in value stream mapping. The data related to the issues that the purchasing, logistics and planning departments are responsible for, were obtained from the supply chain department. These data are the period of purchase order from suppliers, forecast information from customers and the period of production planning. Data related to the error rates of the processes were determined as a result of the joint studies carried out with the production and process departments. As a result of all these studies, the CS-VSM based on Project K product family was created (see Figure 4.5).

XYZ company operates 3 shifts a day, 8 hours a each shift, 6 days a week. Customer orders are delivered to the project and planning departments by the customer on a weekly basis. The customer weekly shares demand forecasts covering one month. According to the capacity planning, the production planning department shares the raw material and material needs with the purchasing department on a weekly basis, as in demand forecasting. The purchasing department orders raw materials and materials to suppliers on a weekly basis. Suppliers do the delivery to the plant weekly. After evaluating customer demands and material stock status, production planning department publishes daily production plan and work orders via production system. The production team starts production and processing activities for the specified product family according to the issued work orders. Additionally, the operative mapping procedure approach proposed by Braglia, Frosolini & Zammori (2009) was taken as an example in collecting all these information and data described in this study.

The current state value stream map shown in Figure 4.5 lists the real-time information determined by observing 3 shifts. Other information on the map is process-based as follows:

- Work in process inventory
- Cycle time (CT)
- Lead time (LT)
- Defect rate
- Process name
- Type of product
- Changeover time (C/O)

Work in process inventory means the total amount of product in the process phase where it is currently in production. Defect rate is the ratio of the amount of faulty products coming out of a line or process to the total amount of products. Each box in VSM represents a process and is the name of the current process written at the top. At the company, changeover time means product exchange time. In short, it is the total time of transition from one product to another on a line. The timeline lines shown on the map also contain two types of information: the first is the total lead time at the top of the timeline and the second is the total cycle time at the bottom of the timeline. The total cycle time for Project *K* products to complete production by processing in a total of 11 processes is 455.42 seconds and the total lead time is 88.64 hours. At the same time, the cycle time is the value added time. These times are calculated by adding the process times for each process in the value stream. In addition to this, takt time should be calculated to be used in the analysis and improvement studies of the CS-VSM. The following formula, which is given by Rohani & Zahraee (2015) , is used in the calculation of takt time.

$$Takt\ Time = \frac{\text{Total available minutes for production}}{\text{Total required unites of production}} \tag{4.1}$$

XYZ company has two 10-minute breaks per shift and a 30-minute lunch break. Accordingly, the net available time of each shift with a total duration of 480 minutes is 430 minutes. The total available minutes is 7.740 minutes since the plant operates a total of 6 days and 3 shifts per day. The weekly customer order for Project K is 900 units.

$$Takt\ Time = \frac{7740}{900} = 8.6\ minutes \tag{4.2}$$

Takt time plays a critical part in the lean activities of the enterprises and in uncovering transactions that do not added value. Takt time contributes to the lean journey of enterprises by helping to facilitate the calculation activities in a complex and long flow. In addition, the operating speeds of all lines, machines, processes and vehicles are determined. Using all these data and takt time, minimum lot sizes are tried to be calculated when any change occurs.

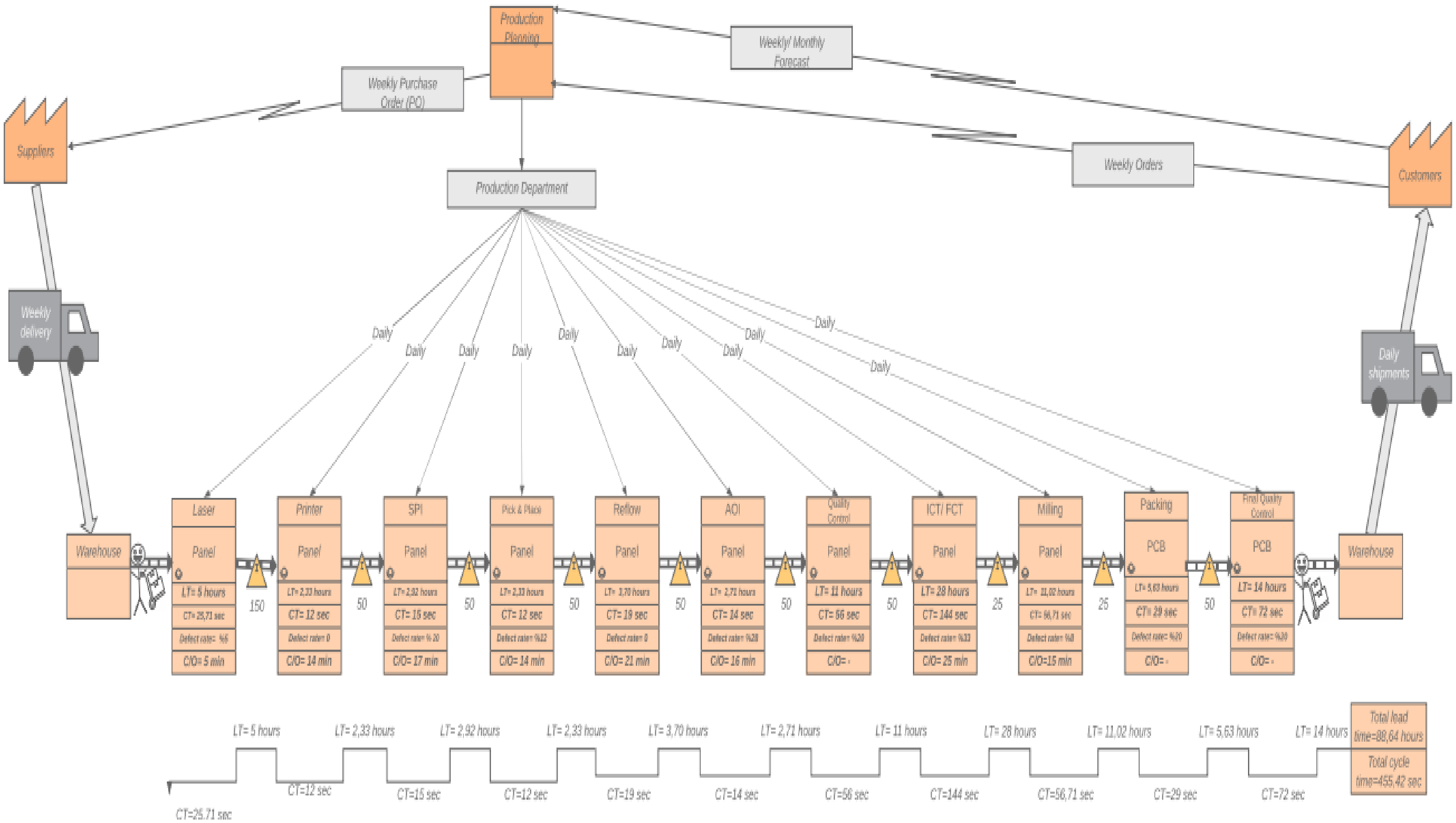

Figure 4.5 Current State Value Stream Map of Production Line for Project *K* Product Family

4.5 Step 4 of The Research Framework

After the current state map is created, the next phase is to develop the future state map correctly, in order to identify waste and reduce cycle times and time losses. For this reason, all processes in the CS- VSM were scrutinized and analysis and kaizen studies were performed by using the necessary lean production and management techniques. The VSM application is an eye-opening experience for businesses to identify their weaknesses. In addition, employees are engaged in addressing issues and organizational issues that are specific to their area through VSM (Seth, Seth & Dhariwal, 2017). One of the observations carried out for three months in this study is the determination of downtime in all processes of production as previously mentioned and then analysis of production stop time data. Production stops for the 11 stages shown in the CS- VSM are splitted into three categories according to the production activity classification:

1. Value added activities
2. Non- value added, but required activities
3. Non- value added and avoidable activities

In line with the lean manufacturing approach, non- value added and avoidable activities should be eliminated absolutely and non- value added but required activities should be reduced as much as possible. For this purpose, firstly non-value added and avoidable production stops are analyzed and shown in the graph below. All the data in the graph was obtained from the data collected in April, May and June 2019 during the data collection phase as described in the previous titles. These data are listed as 6 items under the heading non- value added and avoidable production stops. The ratio of the time for each item to the total non-value added and avoidable production stop time is calculated and shown on the graph.

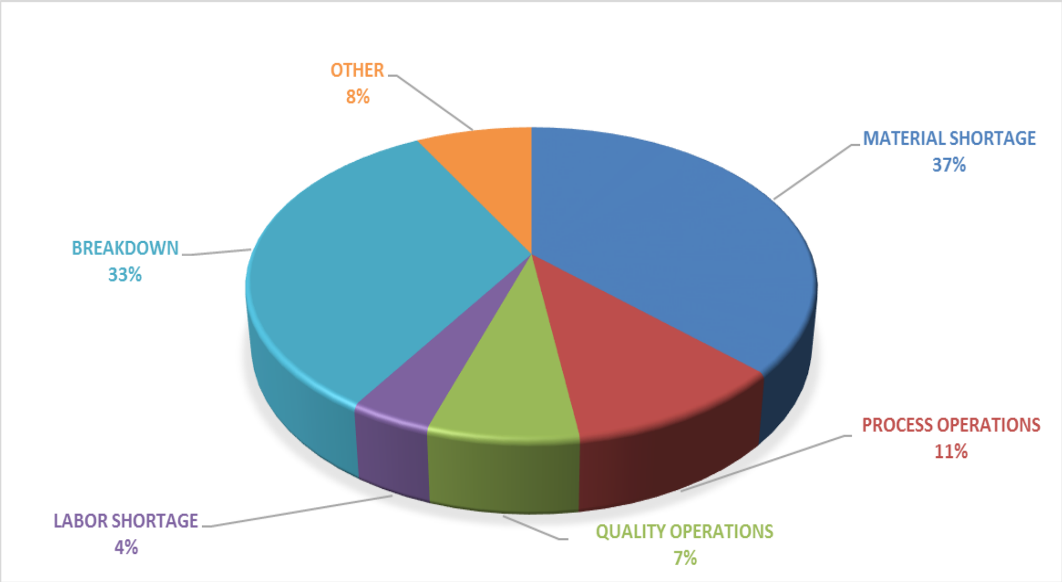

Figure 4.6 Non- value added and avoidable production stops

As can be seen from the analysis results, the highest rate of non-value added and avoidable production stops is material shortage with 37% and breakdown with 33%.

4.5.1 Root Cause Analysis

Root cause analysis was carried out on the production shortages due to material shortage, since the improvement studies should be started from waste which has the highest rate and this analysis is also shown in Table 4.1.

Root cause analysis/ 5-Why techniques is one of the most widely used problem solving techniques in the automotive sector. The basic elements of root causes are material, equipment, human, method or work environment, measurement and procedures and management systems (Serrat, 2017). Cause is a transaction / input factor that reveals the root cause and time of occurrence of the problem. The most obvious difference between root cause and possible cause is that the root causes directly affect the outcome and output, and potential causes only affect the output, if it exists. (Sarkar, Mukhopadhyay & Ghosh, 2013). According to Wilson, Dell &

Anderson (1993), the root cause is the most basic cause of an unwanted and inappropriate situation. In order to eliminate all unwanted and wasteful problems that are not suitable for the quality of the product, the root causes of these problems must be found first. Root cause analysis/ 5- Why techniques, is a valuable and simple logic analysis and management tool that can be easily learned and easily implemented by administrators and all office and field workers (Williams, 2001). One of the aims of root cause analysis is to prevent recurrence of similar events (Peerally, Carr & Waring, 2016). There are many techniques of root cause analysis. 5- Why technique was used in this study.

Table 4.1 Root cause analysis of material shortage production stop

Identified Problem/ Probability 1	Material Shortage-Wrong Material			
1-WHY?	2- WHY?	3-WHY?	4- WHY?	5-WHY?
Failure to check manufacturer part number (MPN)	A technical supervisor is not assigned to that MPN checking job			
Identified Problem/ Probability 2	Material Shortage- Material is not available at the plant			
1-WHY?	2- WHY?	3-WHY?	4- WHY?	5-WHY?
Failure to supply material on time	Failure to determine material needs at the right time	Customer does not share demand information at the specified time		
Identified Problem/ Probability 3	Material Shortage- There is material, but its location is not known			
1-WHY?	2- WHY?	3-WHY?	4- WHY?	5-WHY?
No material classification	No field separation and identification in the storage system and Failure to comply with 5S rules			

Table 4.1 continues

Identified Problem/ Probability 4		Material Shortage- LED materials error warning on pick & place machine		
1-WHY?	2- WHY?	3-WHY?	4- WHY?	5-WHY?
Failure to supply LED materials with the correct number of reels	Led-bin code information can not be provided until led shipping operations are performed	Requesting feeder information in material pick & place references on the machine (feeder reference match)		
Identified Problem/ Probability 5		Material Shortage- Scrap of pick & place materials		
1-WHY?	2- WHY?	3-WHY?	4- WHY?	5-WHY?
Scrapping of pick & place materials without machine using	Drop of material during intentionally faulty part preparation, electronic unit operations and / or feeder installation	Failure to carry out detailed analysis of scrap rates		

In Table 4.1, all possibilities of material shortage production stops were determined and until the root cause of each probability is found, the same question (Why?) is continued to be asked. The following actions are described for each of the root causes found and a total of 5 possibilities are identified for material shortage production stop.

Action for probability 1: A technical supervisor should be assigned to that MPN (Manufacturer Part Number) checking job.

Action for probability 2: If the customer does not share their demand information on the date specified in the project plan, the information that the project plan will be postponed for each day of delay should be shared with the customer.

Action for probability 3: Area separation, material classification and area definitions should be made in storage systems. Also, 5S rules must be followed.

Action for probability 4: The LED bin codes and feeder reference matches of the common and frequently used LED materials in all projects should be recorded by the process engineers on the pick & place machines.

Action for probability 5: Kaizen team should be organized for detailed analysis of scrap rates and improvement works.

4.5.2 5S Study

The 5S and Kaizen studies mentioned in the actions are some of the techniques that the lean manufacturing system uses to improve and regulate the current situation. 5S provides a organized work environment and also uses visual management tools to achieve standardized operational results; It is a set of methods used to reduce waste, increase productivity and optimize quality (Bayo- Moriones et al., 2010). 5S systematics is a very useful methodology to start, maintain and standardize continuous improvement and development processes. The 5S methodology consists of a total of 5 steps and takes its name from the initials of these 5 steps:

1. Sort- Seiri
2. Set- Seiton
3. Shine- Seiso
4. Standardize- Seiketsu
5. Sustain- Shitsuke

The names of these 5 steps are listed above in both English and Japanese. In the first step of the 5S methodology, the necessary equipment and tools are accurately distinguished from the unnecessary and the things we need to throw away. The second step is the arrangements we have made so that we can easily find and use the equipment we decide to keep when needed and at the time of use. The third step is to clean the entire factory area periodically and keep everything clean.

The fourth step is to ensure the continuity of the first three steps and to standardize them. We should record the point reached in a standardized manner, if possible, with instructions and writing, and do not allow return. The fifth and final step is the creation of a lasting habit to ensure the continuity of the correct procedures. It is necessary to ensure the continuity of compliance with the procedures determined by the discipline to be obtained. The following figure shows an example of a 5S methodology study from the company where this study was carried out.

Figure 4.7 Example image of 5S methodology study about action for probability 3 (Personal archive, 2019)

In addition, the 5S methodology is referred to as CANDO in different sources. CANDO takes its name from the initials of the words clean up, arranging, neatness, discipline and ongoing improvement (Brandao de Souza, 2009). Another lean production methodology mentioned in the actions is the Kaizen studies that arise from the philosophy of continuous development.

4.5.3 Kaizen Activities

Kaizen activities are one of the most critical activities of production and business management. In the literature, the participation of employees in kaizen studies is seen as one of the main inputs in Japanese manufacturing success (Elgar & Smith, 1994). In addition, Kaizen techniques are one of the best ways to improve performance in companies all over the world as their implementation costs are low and can only be implemented with company employees and the company's own resources (Titu, Oprean & Grecu, 2010).

Kaizen's activities are the totality of strategic activities in order to achieve the goals defined in the vision of the company in which enterprises observe improvement in economic and operational results with small and continuous steps. Kaizen takes its name from the combining Japanese words kai/ change and zen/ better. Kaizen is a set of improvements that everyone who work at the company should contribute to, including both managers and employees. In this study, as stated in action for probability 5, kaizen study was carried out to reduce pick & place material scrap and scrap rates. The methods followed in this study include a total of 10 steps:

1. Selection of the Kaizen issue

a. Kaizen issue was defined as detailed analysis of scrap rates and improvement works.

2. Determination of quantitative target

a. Kaizen target is determined as minimum 10% reduction in pick & places material scrap rates

3. Organization of the Kaizen team

a. The Kaizen team was established, consisting of 1 process engineer, 1 lean manufacturing engineer, 1 production engineer, 1 team leader and 3 operators.

4. Analysis of the current situation and problem details

a. In the current situation, the reasons for the scrap of pick & place materials; operator failure, machine failure, machine process program setting failure. The reasons of failures were discussed and examined by Kaizen team.

5. Realizing the Kaizen activities plan

a. In line with the determined Kaizen goal, the 12-week time plan was formed by gathering the team once a week.

6. Performing the data analysis

a. Kaizen team of process engineers received information on how many materials were placed and how many materials were scrapped from the database on pick& place machines for 6 months (January-June 2019). On the other hand, pick& place materials scrap cost information was obtained from the planning unit in line with the request of the kaizen team. These data are graphed below to understand the relationship between quantity of scrap pick& place materials and their costs.

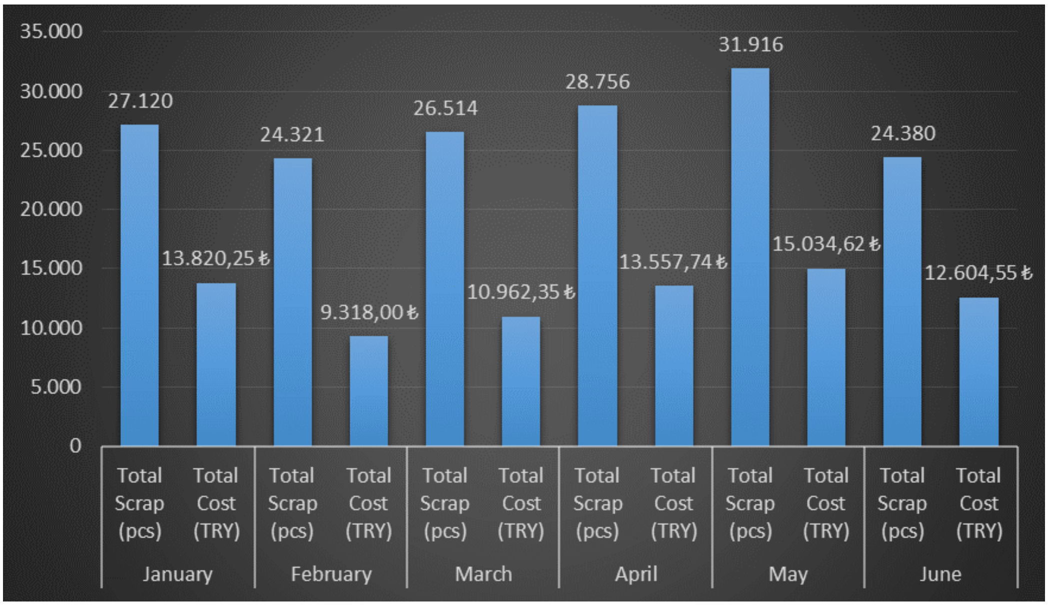

Figure 4.7 Quantity of Scrap Pick& Place Materials and Their Costs

7. Process improvement

a. Suggestions for improving the varieties specific to the failures identified for this kaizen were put forward by the team and the related actions were assigned to the responsible members. In this direction, production engineers prepared instructions for use of pick & place materials related to operator-induced failures and provided one-point lessons to operators. The maintenance department was informed about the machine errors and the required machine maintenance activities were determined and the missing machine maintenance was completed. As it was determined that the failures in the machine process program were generally made by newly started process engineers, technical trainings about program settings were given to newly started process engineers by expert engineers.

8. Verification and gain

a. This step looks at whether the target set in step 2 has been achieved and examines the Kaizen gain. After the process improvements, the pick& place materials scrap rates of July were examined and the annual profit of this Kaizen study was also calculated. As can be seen in the graph above, the average pick& place scrap material in the first 6 months of 2019 is 27168 pieces. After the Kaizen improvements, the amount of pick& place scrap material realized in July is 24452 pieces.

As can be seen from the figures, the pick& place materials scrap rate has been reduced by approximately 10% and the Kaizen target determined in step 2 has been achieved. According to the information received from the planning department, the monthly gain of this improvement to the company is approximately 3020 Turkish Liras. The average annual gain is calculated by the following formula.

$$Average\ annual\ gain = 3020 * 12 = 36240\ ₺ \tag{4.3}$$

9. Standardization

a. This step includes standardization methods that have been deployed to prevent the result from being restored. These methods may include instructions and methods, technical drawings and even company contracts. In this Kaizen study, all instructions for production operators, engineers and maintenance operators are published in the company's documentation system.

10. Dissemination

a. In the 10th and last step, the same instructions are placed on all homogeneous lines other than the pilot line where Kaizen work is carried out and the related trainings are repeated for all operators on these homogeneous lines in order to adopt Kaizen by all relevant employees. As a result, kaizen activities eliminate the basic waste of lean production and transform the company into competitive and profitable. Each Kaizen project that reduces waste is a step forward in continuous improvement. Go over the problems; Instead of concealing and ignoring the problems, it is an important goal in contemporary, technological production and management approach.

4.5.4 Single- Minute Exchange of Dies (SMED)

SMED (Single Minute Exchange of Dies), known as the Change of Molds in Single Minutes or Model Change in Single Minutes, is one of the lean manufacturing techniques that provides power of flexibility and agile manufacturing in production. SMED shortens the time spent on model change, thereby paving the way for increasing production efficiency and / or producing with small batches. Increasing machine efficiency by reduction the setup time or working with the current activity by increasing the number of setups, also prevents production with unnecessary stock as it facilitates keeping up with the rapid changes in production plans.

The main purpose of SMED is to reduce the product exchange preparation time to less than 10 minutes. Product exchange is the preparation time between 2 products according to the production plan. According to the production plan; For product *Y*, which will be in line after product *X*, which is currently in production, the necessary setting and mold changes in all processes on the line, and all setup preparation activities are product exchange operations. SMED consists of 3 steps in total:

1. Separation of Internal and External setup processes

a. The operations performed by stopping the machine or line are called internal setup operations, and the operations performed without stopping the machine or line are called external setup operations. In order to distinguish between internal and external setup processes, the process should be fully observed by the responsible persons and necessary notes should be taken during the observation.

2. Conversion of internal setup processes to external setup processes
3. Reduction of internal setup times and optimization

Researchers suggest that up to 90% improvement in setup times is possible in SMED applications. However, it is important at this point how the business and the responsible people define success and failure in SMED studies. As a result, the results in the literature review revealed that the actual applications did not confirm the 90% improvement claim (Ferradás & Salonitis, 2013).

In this study, SMED was determined as one of the improvement activities of the FS- VSM. It was decided by the SMED team of XYZ company to implement the SMED work on the SMT line in order to improve the 7% quality operations and 11% process operations indicated in Figure 4.6. As shown and explained in the workflow of Project *K* (see Figure 4.4) the general name given to all Printer, SPI, Pick & Place, Reflow and AOI processes is SMT line. During the first 6 months of 2019, the data processed in the shift and production reports are examined, the product exchange steps performed on the SMT line are listed and the setup operations are grouped as internal setup and external setup. According to these data, Table 4.2 has been created in which product exchange losses and steps are specified. In this table, while the external setup operations are specified only as the external setup, the duration of the internal setup processes is calculated and specified individually.

As a result of this table, the SMED team has determined suggestions and methods on how to shorten the return time. According to this; The proposal to cancel production of confirmation panel and Function confirmation steps is one of the first suggestions.

However, there are several risks of removing the function confirmation step and the approval of the Quality Department is required. These risks are itemized as follows:

- It should be noted that the resistor matrix shared in the production order matches the variable materials in the set-up output.If the set-up is prepared according to the different led-bin code during the preparation and if this situation is not detected in the subsequent quality approval, there is a risk of wrong pick & place.
- If the material reel labeling made in the logistics department is done incorrectly (the XYZ company label is not the same as the manufacturer's label) and if the production operator and the material control operator cannot detect this, incorrect production can be made. In addition, the reel is a circular plastic structure with electronic components inside.
- Improper identification of the led bin-resistor match by the planning department can also lead to incorrect production.
- The supplier's misidentification of the component, for example defining the 1 nanofarads material reel as 2.2 nanofarads, can also lead to wrong pick & place due to the wrong material selection.

On the purpose of evaluate the risks mentioned above, the following questions were also reviewed.

- How often are these risks likely to happen?
- By whom the errors are detected until the function confirmation phase? (i.e by the production operator or the material control operator)?
- Can the specification of material differences can be detected by the quality operators in the set-up control?

Table 4.2 Before the SMED study exchange of dies activities

EXCHANGE OF DIES ACTIVITIES			
Production Stop Mode	**Time (min.)**	**Description**	**Production Stop Mode Specified in the Production Tracking Form**
Preparation of feeder	External Setup	Placing the components in the feeders	Exchange of Dies
Installing feeder	19.4	Placing feeders in the machine	
Setup confirmation	6.4	Setup control and confirmation processes of the Quality Department	First Product Confirmation
Production of confirmation panel	17.8	Production time of the confirmation panel in line	
Function confirmation	15.1	Approval from the ICT / FCT process	
First product confirmation	6.5	Microscope control for the first product of the Quality Department	
Production of the first product	14	Production of the first panel after approval	
TOTAL	71.4		

Data related to the product exchange was collected with the product return losses registration form for one month. Operators working on all SMT lines related to the new form prepared were given one point lesson by production and lean production engineers. According to this; between May 1 and June 1 2019, data on product exchanges of all SMT lines is collected in detail. Through this form, it was possible to find out how much error was detected in set-up control and function confirmation. A draft sample of this form named as “Product Exchange Losses Registration Form” is given below.

PRODUCT RETURN LOSSES (Form will be filled by 3 shift operators between 1 May - 1 June 2019 , for All SMT Lines)												
The Panel, which is Still in Production	Panel to be Produced After Product Return	EXCHANGE OF DIES	FIRST PRODUCT CONFIRMATION					Production Date & Hour	Line	Operator Registration Number	Error Detection in Set-up Control (X: No ; √: Yes)	Error Detection in Function Confirmation (X: No ; √: Yes)
		Installing feeder & reel	Quality Department Set-up Control	Production time of the confirmation panel in line	Approval received in ICT/ FCT process	Quality Department, microscope control for the first product	Production of the first panel after approval					
		SET-UP PREPARATION	SET-UP CONFIRMATION	PRODUCTION OF CONFIRMATION PANEL	FUNCTION CONFIRMATION	FIRST PRODUCT CONFIRMATION	PRODUCTION OF FIRST PRODUCT					
PROJECT A 2819	PROJECT D 3363	10	5	15	5	5	15	24.04.2019-15:50	SMT-8	23002	X	X
PROJECT D 3363	PROJECT K 5596	10	5	15	5	5	15	20.05.2019-22:00	SMT-8	34528	X	X
PROJECT K 5596	PROJECT G 1261	10	7	16	8	5	15	20.05.2019-01:50	SMT-8	12227	X	X
PROJECT G 1261	PROJECT E 2483	10	5	16	10	5	15	20.05.2019-09:25	SMT-8	33267	X	X
PROJECT E 2483	PROJECT F 5107	30	5	15	10	10	15	20.05.2019-04:30	SMT-6	42656	X	X
PROJECT F 5107	PROJECT B 9622	30	5	15	15	5	15	20.05.2019-12:00	SMT-6	3467	X	X

Figure 4.9 Product return losses registration form

All product exchange and first product confirmation processes on SMT lines between the dates of May 1 and June 1 2019 were monitored and recorded with this form. As a result, a total of 456 product exchange and first product confirmations were carried out:

- No error was detected in the set-up confirmation made by quality operators.
- No error was detected in the function confirmation received on the ICT / FCT process.

As a result of these data, the approval for the cancellation of the function confirmation from the quality department was obtained and a new product exchange process was commissioned as a pilot in one SMT line. After all the improvements proposed by the SMED team are put into operation step by step, the result is stated in the table given below.

Table 4.3 After the smed study exchange of dies activities

EXCHANGE OF DIES ACTIVITIES			
Production Stop Mode	**Time (min.)**	**Description**	**Production Stop Mode Specified in the Production Tracking Form**
Preparation of feeder	External Setup	Placing the components in the feeders	Exchange of Dies
Installing feeder	10	Placing feeders in the machine	
Setup confirmation	5	Setup control and confirmation processes of the Quality Department	First Product Confirmation
Production of confirmation panel	cancel	Production time of the confirmation panel in line	
Function confirmation	cancel	Approval from the ICT / FCT process	
Inspection before reflow	5	While mass production is continuing, first panel is stopped and controlled before reflow by quality operator	
First product confirmation	During mass production	Microscope control for the first product of the Quality Department	
Production of the first product	14	Production of the first panel after approval	
TOTAL	34		

In Table 4.3, the stages shortened with improvement suggestions are shown in green, canceled and removed stages are shown in orange, and the newly added step is shown in blue. The duration of the installing feeder and set-up confirmation stages have been reduced thanks to the offline set-up station established as a result of process research & development activities. Production of confirmation panel and function confirmation stages were removed and a total of 32.9 minutes was gained in only one product exchange. However, instead of these two approval steps removed, a short approval phase with a total duration of 5 minutes has been added as the inspection before reflow phase to be performed by the quality operators. The first product confirmation phase, which takes 6.5 minutes and is an internal set-up, has been converted to the external set-up phase.

As a result of all these efforts, a total of 37.4 minutes was gained in each product exchange activity. The average of 3600 times product exchange is performed in a year at XYZ company. In short; the product exchange processes, which are 4284 hours a year, have been reduced to 2244 hours using the SMED technique. Thus, a significant improvement of **47.61%** has been achieved, and time and cost savings have been achieved and losses that lean production defines as waste. In addition to all these gains, there are also advantages that affect different topics and processes:

- SMED study provides the opportunity to face root cause, identify and improve the missing points in case of errors arising from other departments or production operators.
- In the ICT / FCT process, it is expected that the approval stops will be shortened, the efficiency of the line will increase and the accumulation of intermediate stock and the panel magazine will decrease.
- Optimization opportunity was created for common set-up operations used in all projects on pick & place machines.
- With the cancellation of the function confirmation phase, an average of 860 hours of gain per year was achieved on ICT / FCT lines.

As it can be understood from these advantages, the realization of an improvement process at the beginning of the work flow affects other processes positively in many different ways, and also helps to reduce the downtime due to quality and process operations. In addition, Step 5 and step 6 of the research framework will be explained in the next sections.

CHAPTER 5
FUTURE STATE VALUE STREAM MAPPING

The focus of many kaizen studies described and done in the previous chapters of the article; to reduce the total delivery time and to increase the total output. The design of the ideal and targeted process consists of defining and materializing activities that can improve the flow of materials and information to important points determined in the CS- VSM and issues open to improvement (Acero et al, 2020). Continuous flow should be applied in order to be able to produce in certain batch sizes and to perform customer shipments as and when requested. According to this; Value stream map is a very efficient lean manufacturing tool, as it equates the number of semi-finished products as a work-in-process between the process steps as much as possible. It reduces buffer stock levels and also helps to identify many waste. The FS- VSM that was generated and realized for XYZ company as a result of all the works carried out for these purposes is shown in Figure 5.1.

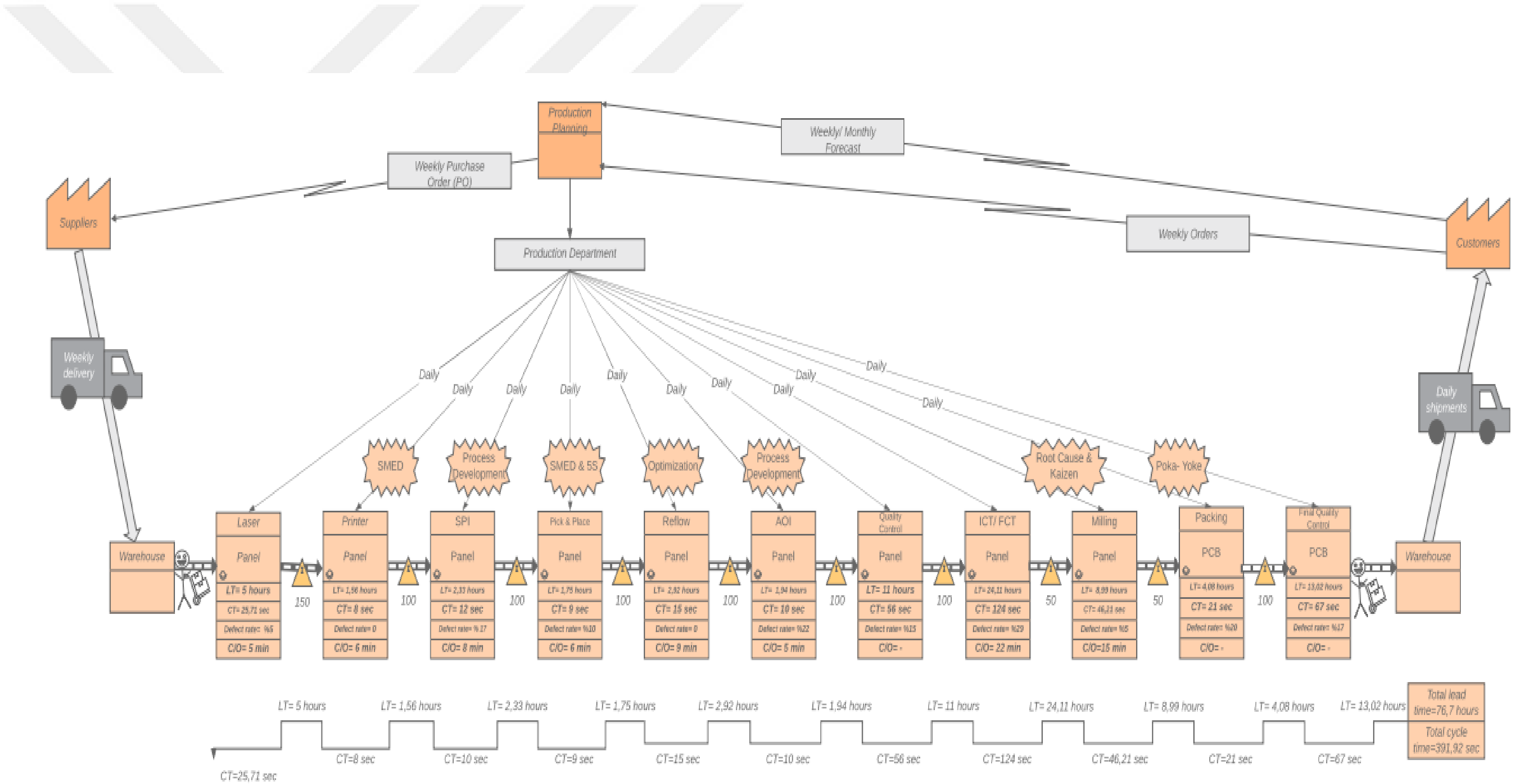

Figure 5.1 Future state value stream map of production line for Project *K* product family

The improvement ratio targeted by XYZ company management was initially set at 10%. When the results from the current state and future state value stream maps are compared; the improvement ratio of approximately 13.5% in total lead time and approximately 14% in total cycle time was observed. In addition, the graph comparing the numerical values of these improvement ratio is given below.

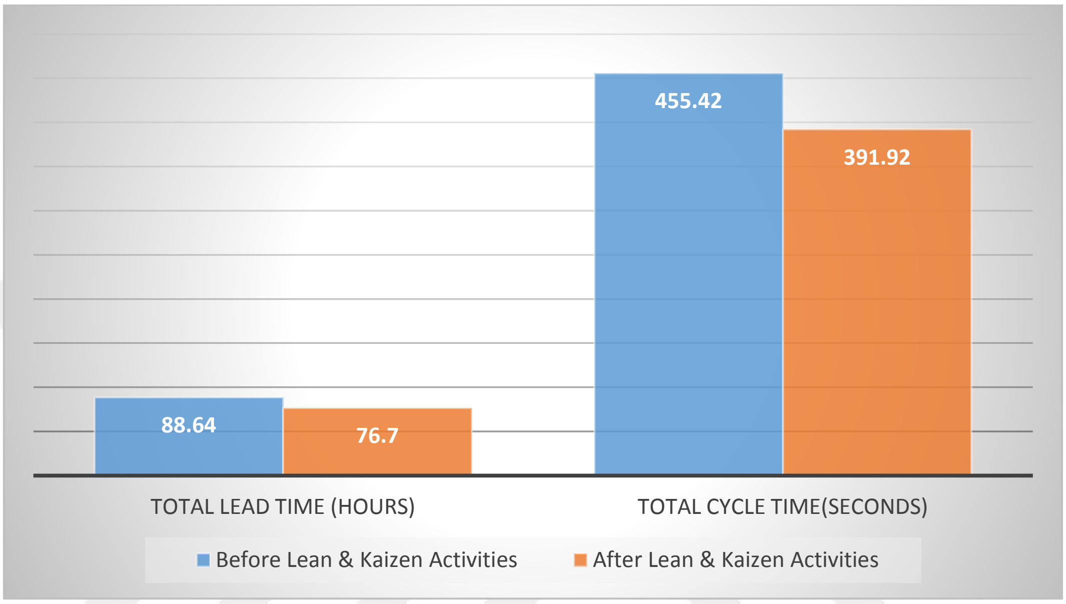

Figure 5.2 Current state vs. future state value stream map

The total lead time has been reduced from 88.64 hours to 76.7 hours, and the total cycle time, also known as total value-added time, has been reduced from 455.42 seconds to 391.92 seconds. For these improvements seen on total lead time and total cycle time, according to the problems identified on Project *K* CS- VSM; some of the problem analysis and kaizen studies conducted were explained in detail in the previous sections. In addition to these kaizen studies, activities such as improvement studies, optimization, process development and creating poka-yoke points on equipment were carried out. As an example of Poka yoke work, during the operations in the milling process, the assembly point marking has been made so that the operator cannot make a direction error on the product. Some of these activities are shown as kaizen burst on the FS- VSM. Furthermore, all of the activities are listed in the table below.

Table 5.1 List of kaizen events

Process or Operation	**Problem found**	**Kaizen Events**
SPI (Solder Paste Inspection) & AOI (Automated Optical Inspection)	High false-error rate during visual control procedures	Analysis of the data in the production database, detection of the panels with the highest visual and false error rate and optical improvement in visual control points
Pick & Place	Missing or trapezoid placed components	Reviewing the datasheets of pick& place materials (component) and rearranging all centering coordinates
Reflow	Deflection occurs in the panels due to the reflow heat value being incorrect	Optimization in reflow heat profile
Quality Control	Low competence levels of quality control operators and no standard working methods	Providing relevant technical trainings to quality control operators and defining standard working methods
Milling	Blade consumption is high and cannot be tracked, parameter change authorization is not limited, engine speed is incorrect	Creating a blade change form and making new blade deliveries with the form, limiting parameter changes with software and defining authorization only to the process engineering department, installing sensors to the machines for continuous monitoring and fixing the engine speed
Packing	Wrong products in the wrong package	Adding poka-yoke control points to packaging equipment and updating the packing specifications to prevent product confusion
Final Quality Control	Error in product controls and insufficient operator competence levels	Designing and supplying individual product control gauges according to the control points of each product and placing them in the final quality control areas, repeating the relevant technical training of the operators

After the kaizen events implemented, the defect rates of all processes decreased and the processes were accelerated. Work-in-process product amounts were tried to be equalized as suggested in the lean manufacturing one-piece flow technique, and the amount of work-in-process products after the printer process was increased. Despite all these efforts, both very low level of improvement has been achieved and the bottleneck process in the production system is still the ICT / FCT process. Current and future state value stream maps were generated for Project *K* and at the same time necessary problem solving analyzes and studies were conducted. However, the important thing is not to do all these studies once, but to ensure its continuity. In order to ensure continuity, lean production techniques and perspective should be included in the vision of the company and should be adopted primarily by the senior management. Lean production activities should be observed and audited regularly by department managers at least twice a year.

CHAPTER 6
RESULTS AND CONCLUSIONS

6.1 Summary and Results

In value streams and value definitions for all companies; all activities that add value to the product from raw material supply to intermediate suppliers, employees, operations and the customer and deliver the product to the end user are interconnected (Shank & Govindarajan, 1993). Therefore, a total of 11 processes, in which raw materials and all other components are included as inputs and the product is sent to the customer as output, are examined in detail at the company. The results are shown in the current and future state value stream maps in accordance with lean manufacturing techniques and value stream mapping rules.

Firstly, a case study was carried out and activities that add value and do not add value were determined. The rates of production stops that do not add value are shown in Figure 4.6. Root cause analysis of material shortage, which has the highest rate of production stop, was carried out. According to the results obtained in the root cause analysis, 5S implementation and kaizen activity related to material scrap were performed. Then, SMED work was executed on the SMT line. Finally, a FS- VSM has been created and a total of 7 kaizen events have been conducted in different lines and processes in order to achieve the targeted improvement ratio.

Consequently, the quantity of products shipped to the customer was doubled from 50 to 100 in daily shipments as shown in the value stream maps, resulting in an approximately 14% improvement in total delivery time and total cycle time.

6.2 Conclusion

This study demonstrates the use of VSM in the automotive electronics industry with lean manufacturing techniques as a complementary and improvement tool. Value stream mapping approach is recommended to determine and eliminate the losses of companies. The aim is to increase overall efficiency, reduce lead time and cycle time, identify areas that need immediate attention, and demonstrate that many lean manufacturing techniques can be applied in the automotive electronics industry. For this purpose, all 11 processes in the production system were examined, observed and their data recorded. In the light of the data collected, value stream map has been revealed and problematic areas have been determined and kaizen studies have been started. The fact that kaizen studies are performed with VSM technique and matched with sector differences differ from the studies in the literature in terms of root cause analysis, 5S study and SMED studies. As a result of all these studies, improvements have been made on cost, total lead time and total cycle time. This study also shows that value stream mapping is a simple format that provides a common language between lean manufacturing concepts and the current production concepts of the enterprise.

One of the advantages of this study to the literature and production businesses has been to show that the same product can be delivered to the customer at a higher profitability level in a shorter time. It is clear that the simplest and most effective method is lean manufacturing technique, since it is known that the enterprises can provide high profit in a short time by increasing the customer satisfaction level. By force of lean manufacturing techniques and Kaizen studies, customers can also supply better quality and cheaper products when all waste in the production system keep to be reduced continuously and resources in the value stream are improved to create more value.

Furhermore, the study is useful for researchers and practitioners of all production systems, especially those in the automotive industry which has complex and multiple sequential processes. This work gives the message that VSM application can be performed in all sectors. One of the most important advantages of the application to the literature is to make all the activities and losses of a multistage automotive difference of the study from its counterparts in the literature is that all the data are real-time data and also all processes in production are fully audited by a large team. Thus, problematic areas and processes can be easily identified and improvement studies can be applied correctly in the right areas. In addition, the decisions needed to eliminate problems in the stream and improve the stream are evident with the clear value stream and the specified waste sources.

Although VSM application and lean manufacturing techniques have many contributions; if the current state cannot be assessed correctly at the right time, it can be misleading for practitioners and have erroneous results. Accordingly, in order to eliminate such constraints and analyze the possible results of the study and to evaluate all other factors that have important effects on production efficiency, VSM and simulation applications can be carried out together in future research. Simulation can also financially compare copies of real life and proposed models to better compare the efficiency of the current system with the proposed future state VSM model. Simulation and VSM can also help estimate inventory levels throughout the production flow for limitations that may arise when using only VSM. In this way, using the simulation together with VSM can be shown as a more convincing tool to adopt the lean manufacturing system, both operational and financial, in company management.

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