DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

NONCONFORMING MATERIAL FLOW ANALYSIS VIA VALUE STREAM MAPPING: A CASE STUDY IN AUTOMOTIVE INDUSTRY

by
Nilay GİRAY BİROL

August, 2021
İZMİR

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Nilay GİRAY BİROL

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"NONCONFORMING MATERIAL FLOW ANALYSIS VIA VALUE STREAM MAPPING: A CASE STUDY IN AUTOMOTIVE INDUSTRY"** completed by **NİLAY GİRAY BİROL** under supervision of **PROF.DR. LATİF SALUM** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

Today, with the shift from a product-oriented to a customer-oriented vision, organizations can sustain their competitive advantage if they keep pace with this evolution. One of the essential technology in the automobile industry is lean manufacturing, which has become the standard strategy in many firms. As a result, businesses began to make significant efforts to improve their efficiency. In order to improve service levels and reduce production lead times, costs, lean manufacturing princples are implemented. There are several different lean techniques, which permit lean production and eliminate waste to satisfy customer needs as and when requested. One of the most useful and visual technique is value stream mapping (VSM) which defines all value-added and non-value-added process activities in the system in terms of time, cost, and labor. In this study, the value stream map of an automotive oil pump company is drawn and the improvement actions are discussed with the management team using the technique for order preference by similarity to ideal solution (TOPSIS), and corrective actions are made using lean manufacturing system techniques such as kaizen, 5S, and the future state value stream map was drawn.

Keywords: Value stream mapping, lean manufacturing, kaizen, automotive, TOPSIS

DEĞER AKIŞ HARİTALAMA İLE UYGUNSUZ MALZEMELERİN AKIŞ ANALİZİ: BİR OTOMOTİV SEKTÖRÜNDE BİR UYGULAMA

ÖZ

Günümüzde kuruluşlar, ürün odaklı bir vizyondan müşteri odaklı bir vizyona doğru evrimle rekabetçi yaklaşımlarını sürdürebilmektedir. Organizasyonlarda ana yaklaşım haline gelen yalın üretim, otomotiv endüstrisinin de temel araçlarından biridir. Sonuç olarak, şirketler verimliliklerini artırmak için muazzam bir çaba göstermeye başlamıştır. Bununla birlikte, üretim tedarik sürelerini, maliyetlerini azaltmak ve hizmet seviyelerini iyileştirmek için yalın üretim ilkeleri uygulanmıştır. Yalın üretime izin veren ve talep edildiğinde müşteri ihtiyaçlarını karşılamak için israfı ortadan kaldıran birkaç farklı yalın teknik vardır. Bu tekniklerden en kullanışlı ve görsel olanı, sistemdeki tüm katma değerli ve katma değersiz süreç faaliyetlerini zaman, maliyet ve işçilik açısından tanımlayan değer akış haritalandırmasıdır (DAH). Bu çalışmada, bir otomotiv yağ pompası firmasının değer akış haritası çizilmiş ve iyileştirme aksiyonları yönetim ekibi ile tartışılmış ve ideal çözüme benzerlik yoluyla tercih sıralama tekniği (TOPSIS) ile değerlendirilerek kaizen, 5S gibi yalın üretim sistemi teknikleri kullanılarak düzeltici faaliyetler yapılmıştır ve gelecekteki durum değer akışı haritası ortaya çıkarılmıştır.

Anahtar kelimeler: Değer akış haritalama, yalın üretim, kaizen, otomotiv, TOPSIS

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CHAPTER 1
INTRODUCTION

In today's competitive environment, all production plants face operational efficiency difficulties and are forced to reduce costs. The customers require improvement in production lead times, costs and service levels and the companies need to meet customer requirements to survive. So, companies have become more customers focused. As a result, companies began making a significant effort to improve their efficiency.

There are several lean techniques, which permit lean production and eliminate waste to satisfy customer needs as and when requested. One of the most useful and visual techniques is value stream mapping (VSM), which defines all value- added and non-value-added process activities in a system in terms of time, cost and labor.

Value stream mapping allows to visualize a whole production process by observing information and material flow, as well as identify waste and its sources to enhance the process (Sullivan & et al., 2002). The value stream perspective provides improvement not only on single parts or single process, mainly improving the whole process. Based on the VSM technique, the process steps are sorted according to information and material flow within the factory for a product family and a tableau is drawn with related VSM symbols. In a timely manner, mass production has been common for lots of companies, and carrying out serious problems. Especially for companies in the automotive sector, VSM is the most important technique to analyze processes and eliminate wastes.

In this study, the VSM technique is used in a company which is the supplier of original equipment manufacturer in the automotive industry, and lots of the lean manufacturing philosophy methods is used to manage production system in effective way. By assessing nonconforming material flows, the goal of this study is to reduce cycle time, inventory, and internal logistics time, as well as eliminate mixes of similar materials and, most significantly, save scrap cost. According to future state results, new coming project’s process will be invested considering improvement points.

In this study, the ideas of the management team are evaluated and the priorities of corrective actions is determined according to the importance of the improvements by using the TOPSIS technique.

This study consists of five parts. Chapter 1 is the introduction part and in this chapter, a brief information about lean production and the scope of the study is given. Chapter 2 gives brief information about production systems and lean manufacturing systems and an overview of literature information on VSM. Chapter 3 describes value stream mapping and implementation steps. Chapter 4 contains the case study in automotive industry and examples of lean manufacturing techniques. In addition, the current state map is prepared and improved with kaizen studies. The kaizen studies, which are developed for improvement points, are evaluated by TOPSIS technique with the company management team. Finally, in Chapter 5 the results and the conclusions are presented.

CHAPTER 2
DEVELOPMENT OF PRODUCTION SYSTEMS

2.1 Basic Concepts of Production Systems

Production systems begin to develop firstly with the improvement of the industry after the Second World War. The investigations show that the first production flow-line systems have begun to develop after 1900's. There is a lot of work done on this subject up to the day.

When we look at the development of production systems from the past to the present, we see that there is a development in the form of labor-based production, mass production and lean production. Lean production has a dominant role in today's automotive sector.

Lean manufacturing (LM) is focused on the whole picture and the approach is eliminating wastes in a system and working to increase the efficiency of system continuously. According to Shah & Ward (2007) study, they define the lean manufacturing system as an integrated socio-technical system that eliminates waste by optimizing supplier, customer, and internal variability at the same time. According to Womack & Jones (1994), they define lean manufacturing as an alternative integrated production model since it integrates many tools, methods, and strategies related to the product and supply chain into a unified whole.

When many studies in the literature are examined, it is seen that lean manufacturing is defined as a superior method in different ways. Lean production is defined as a philosophy, a process, a concept, a set of principles, a model, an approach, a practice, a system, a manufacturing paradigm, a group of tools and techniques.

According to Ohno (1998), beyond Ford Mass Production, lean manufacturing is often regarded as the next important step in the evolution of manufacturing in 1990s (Womack & et al., 1990).

There are three types of operations in internal manufacturing, according to Forno & et al. (1990). These can be classified as follows:

- Non-value adding (NVA);
- Necessary but non-value adding (NNVA); and
- Value-adding (VA).

According to Forno & et al. (1990), the Toyota production system (TPS) has seven broadly accepted wastes:

- overproduction;
- waiting;
- transport;
- inappropriate processing;
- unnecessary inventory;
- unnecessary motion;
- defects.

2.1.1 Lean Manufacturing Philosophy

Comm & Mathaisel (2000), as mentioned in their article, Womack gathers the features of lean production in 4 items:

1. Lean is a dynamic process of change driven by set of principles and best practices aimed in order to improve continuously;
2. Lean is a view of the entire enterprise, from the shop floor to the top management, and from the supplier to customer;
3. Lean requires eliminating everything that is non-value-added; and
4. Becoming lean is a complex business; there is no single thing that will make an organization lean.

The primary goals of this methodology are to reduce the cost of the product and improve productivity by eliminating wastes or nonvalue-added activities. Also, “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).

According to the articles and case studies, there are many type of lean manufacturing tools and techniques to eliminate these wastes. Some of these techniques are 5S, single minute exchange of die (SMED), heijunka, value strema mapping, first in first out (FIFO), kaizen, just in time (JIT), poka- yoke, and jidoka.

Among the techniques mentioned above, VSM will be used for this study. With this study, the information from the shop floor to the management team is gathered thanks to the VSM technique.

2.2 VSM Literature Review

VSM presents the whole process, from supplier to customer through the different processing steps. In addition, different type of value stream mapping strategies are in usage. The main strategy is the process starting with the customer's product demand and the process examined until the delivery of the product to the customer.

Hines (1997) uses a value stream mapping and supply-chain mapping typology. This seven-map typology is predicated on the different wastes inherent in value streams. This is the first research of its kind in the field. The new typology aims to decrease waste which occurs internally or externally. After many studies, Hines (2013) report a new approach on value stream mapping methodology for complex manufacturing process. New approach named as “Improved Value Stream Mapping”. To be able to handle with complex BOM with multiple level and multiple flows, this new method is used. In the meantime, McDonald & et al. (2010) apply a simulation model for value stream mapping. The case study is related with engineer-to-order motion control products manufacturing plant. Romero & Chávez (2011) analyze strengths and weaknesses of the mapping techniques. The Main idea is to consider how they are adapted to real environments with different characteristics. Value network mapping is introduced by their studies. Paranitharan (2011) aims to investigate the internal materials flow in lean manufacturing on a Bosch factory assembly line in the automobile sector. The goal is to create a small-space handling system that can solve problems with work-in-process (WIP) parts. An improvement is studied adopting the milk run handling system in accordance with the advances by means of lean metrics. On a product case study in the automotive sector, Ar & Al-Ashraf (2012) exhibit VSM

methodologies and discuss their implementation in a lean production principles program. As a result, work instruction and standardization are key items of improvement. Venkataramana & et al. (2014) study applying lean manufacturing techniques in the crankshaft manufacturing plant.

There are many studies in literature related with value stream mapping. Some of those are only focus to the review of academic papers. Most of those include case studies. In this study, priority is given to examining studies containing case studies. From the past to the present, the VSM tool is used for many industries as well as in automotive. The literature studies mentioned below are a good source to create knowledge on VSM. In particular, the studies on VSM in automotive sector have supported this study. To be able to visualize literature research and ranking in the historical order, a list is prepared (see Table 2.1).

Table 2.1 Literature review

Authours	Country & Year	Include a case study	A short detail	Summary of results
Hines P.	UK-1997	no	This is the first article. A new value stream or supply-chain mapping typology is included. This seven-map typology is based on the several wastes that value streams contain.	The new typology aims to decrease waste which occurs internally or externally (outside of the company).
Hines P. Rich N. Bicheno J. Brunt D. Taylor D.	UK-1998	no	The method is described in detail in this study, which also includes a summary of the previous value stream mapping approach and its flaws.	This new approach encourages important changes and improvements with dynamic and lean thinking.
Hines P. Rich N. Hittmeyer M.	UK-1998	yes	The value stream analysis tool named as valsat is described as a comprehensive supply chain or value stream analysis and decision-making tool. This method includes quality function deployment during new product design.	Valsat is a dynamic methodology for using both technic.
Braglia M. Carmignani G.	Italy-2006	yes	The primary idea is to use the temporized bill of material to perform a preliminary analysis to determine the critical path.	A new approach for value stream mapping methodology is reported for complex manufacturing process. New approach named as Improved Value Stream Mapping. To be able to handle with complex BOM with multiple level and flows, this new method can be implemented. Standard VSM approach & a set of tools. Applied in refrigerator company.
McDonald T. Aken E. Rentes A.	Brazil-2010	yes	Includes a case study, applied by simulation model for value stream mapping. The case study is related with engineer-to-order motion control products manufacturing plant. Two primary contributions is defined in the article. One of them is an application of VSM and the second one is the use of simulation.	For the complex models, simulation results should be performed.

Table 2.1 Continues

Authours	Country & Year	Include a case study	A short detail	Summary of results
Tommelein I. Weissenberger M.	Germany-2010	yes	A case study in construction industry. Includes a study on optimizing buffer locations for structural steel supply.	Stocking material may cause additional cost if the work in process product needs maintaining.
Romero L. Chávez Z.	UK-2011	no	This study examines the evolution of mapping approaches, as well as their strengths and shortcomings, key considerations, and how they are applied to real-world scenarios with varying characteristics. Value network mapping is introduced.	VNM VSM Engineering to order scheme
Rajenthirakumar D. Shankar G.	India-2011	yes	A case study using lean tools and methodologies for a consumer durables manufacturing company is conducted. A case study of a single product family, table-top wet grinders, is conducted.	
Paranitharan K.P.	Spain-2011	yes	This study aims to examine the internal materials flow in lean manufacturing at a Bosch factory assembly line in Spain. The goal is to create a handling system that can solve problems with work-in-process (WIP) parts.	Applied in automotive company.
Rajenthirakumar, D. Thyla, P.	India-2011	yes	This study demonstrates how value stream mapping and other lean tools like kaizen may be utilized to map a manufacturing line's current condition and construct a desired future map.	Reduced change over time and enhanced productivity. Applied in automotive company, Delphi.

Table 2.1 Continues

Authours	Country & Year	Include a case study	A short detail	Summary of results
Yadav R. Shastri A. Rathore M.	India-2012	yes	This case study considers the implementation of value stream mapping technique in manufacturing helical springs by railway spring manufacturing company. Product family approach has been followed. Future state map has been prepared to visualize action plans status and improvement from current state map.	If the VSM technique performed in the company could reduce the manufacturing lead time from 36.86 days to 34.06 days.
Kumar V. Belokar R. Kharb S.S.	India-2012	yes	In this study, VSM as one of the lean tools is used for a case study to avoid waste, and maintain production procedures and productivity.	The application of value stream mapping
Fernández-Solís J. Rybkowski Z.	US-2012	no	This case study considers the implementation of value stream mapping technique in construction sector.	The waste cannot be eliminated at one time but it has been visualized at least with this study.
AR R. Al-Ashraf M.	Malaysia-2012	yes	On the basis of a product case study, this paper presents VSM methodologies and analyzes their implementation in a Lean production principles initiative.	At the end work instruction, standardization are key elements of improvement.
Bo M. Mingyao D.	China-2012	no	In order to eliminate costs, increase efficiency and improve product quality, Chinese emprises focus on VSM implementations.	VSM implementations.

Table 2.1 Continues

Authours	Country & Year	Include a case study	A short detail	Summary of results
Marquesa A. Alvesa A. Sousaab J.	Portugal-2013	yes	This study is based on lean principles that are used to design and to assess the robustness of the production system for handling small series and frequent changes in the productive processes due to customized production.	Some lean techniques are considered suitable for all types of systems. Nevertheless new approaches are needed to adapt small and personalized products to the flexible production system.
Venkataramana K. Ramnathb B. Kumarc V. Elanchezhiand C.	India-2014	yes	A case study: Applying lean manufacturing techniques in the crankshaft manufacturing plant in South India.	In this study, VSM methodology is applied due to handling with the various waste types and also to create flexibility for product mix in the manufacturing cell.
Saraswat P Sain K. Kumar D.	India-2014	no	Includes the method of Value Stream Mapping and its aim in different industries.	Value Stream Mapping and its aim in different industries.
Haefnera B. Kraemera A. Staussa T. Lanzaa G.	Germany-2014	yes	In this study a new approach named as Quality Value Stream Mapping (QVSM) is defined. Convenient tool for the visualization, analysis, and design of quality assurance measures within manufacturing process chains based on the design elements of VSM.	Implementation of value stream mapping of a manufacturer in the electronic industry.
Rajenthirakumar D.	India-2014	yes	This case study considers the implementation of value stream mapping technique	Lean tools is implemented at a wind mill-electrical control panel manufacturing company.

Table 2.1 Continues

Authours	Country & Year	Include a case study	A short detail	Summary of results
Gunaki P. Teli S.	India- 2015	yes	This study includes an Arena simulation software case study in the die casting industry.	simulation with VSM
Patel N. Chauhan N. Trivedi P.	India- 2015	no	A description of VSM techniques and their benefits in the machining sector is studied.	a case study and its results shown
Azizia A. Manoharanb T.	Malaysia- 2015	yes	In this study, identifying wasteful processes and production processes are studied with the designed Future Value Stream Map (FVSM).	Bottleneck station is improved by SMED techniques, kaizen and VSM.
Rohania J. M. Zahraeea S. M.	Malaysia- 2015	yes	The goal of this research is to use Value Stream Mapping (VSM) to increase the efficiency of the production line.	Combination of the VSM and computer simulation to decrease wastes.
Rosaa C. Silvaa F. Ferreiraa L.P.	Portugal- 2017	yes	Application of lean and PDCA methodologies have been performed. Not for only the main stream, methodology applied also for all sub processes.	Improvement in efficiency.
Stadnickaa D. Litwina P.	Poland- 2017	yes	This case study includes VSM analysis, considering current state and future state maps. And system dynamics have been analyzed with the use of Vensim software.	A case study: a manufacturer of door seals in automotive industry.
Sousaa E. Silvaa F.J.G. Ferreiraa L.P. Pereiraa M.T. Gouveiaa R. Silvab R.B.	US-2018	yes	SMED VSM applied	Workplace environment, trust in employee, standardization.

CHAPTER 3
VALUE STREAM MAPPING

3.1 Definition of Value Stream Mapping

Below are the definitions of several researchers on value stream mapping:

The value stream mapping process is defined as the observation of all the activities related to the value stream of a product or group of products (Womack & Jones, 1996).

Another description of value stream mapping is the straightforward technique of immediately observing existing information and material flows, visually summarizing them, and then visualizing a future state with much improved performance (Jones & Womack, 2000).

The VSM's primary goal is to identify all types of waste in the value stream and take steps to eliminate them (Rother & Shook, 2009).

Value stream mapping provides a visual example of all necessary processes from receipt of customer demand to demand fulfillment. Value stream mapping helps you see with fresh eyes.

The benefits of value stream mapping is listed below:

- Observe the total value stream
- Observe the flow, or lack of flow, and improvement points
- Notice what is happening between processes
- See where the interactions may cease
- Identify kaizen improvement
- The shortest way to reduce lead time by maintaining flow and removing waste

Value stream mapping can apply any type of organization or value streams. In this study, the operations studies are the main topic, because the case study is conducted in automotive sector (see Figure 3.1).

Figure 3.1 Type of organizations

In order to overcome these constraints, in addition to the VSM technique, VSM's other techniques is used to confirm the results.

Value stream mapping is conducted using a six-step process (Rother & Shook, 1998):

- Defining product / process family
- Creating the current state map
- Appling lean guidelines
- Creating the future state map
- Creating the implementation plan
- Executing the plan

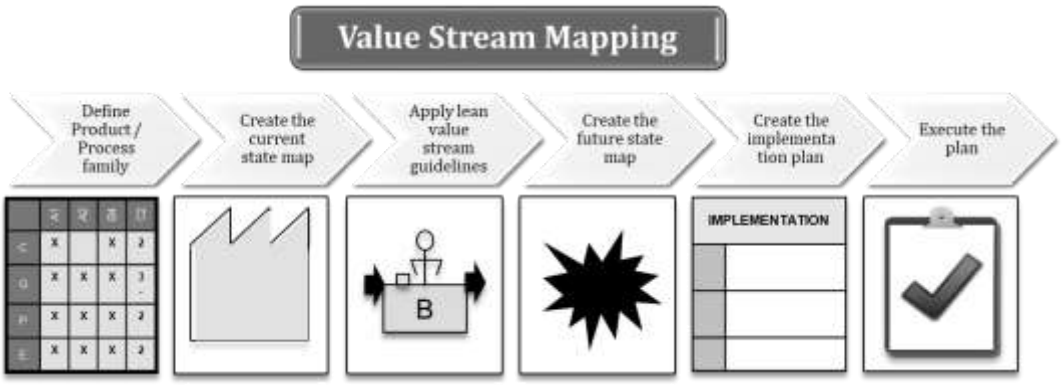


Figure 3.2 UTC value stream mapping training presentation (UTC Value Stream Mapping Training, Rev.7, Sept 2013)

After selecting the product family according to the VSM technique that operated in six steps as mentioned above (see Figure 3.2), it is also evaluated whether there is machine sharing that will affect the product. This product flow about is shown below (see Figure 3.3).

Figure 3.3 Value stream mapping procedure

Likewise, the VSM technique that carried out in the six steps as mentioned above will be combined with the DMAIC technique, as in many studies in the literature, to make the study more efficient. As shown in Figure 3.4, DMAIC and global value stream mapping approach is set a base for this study.

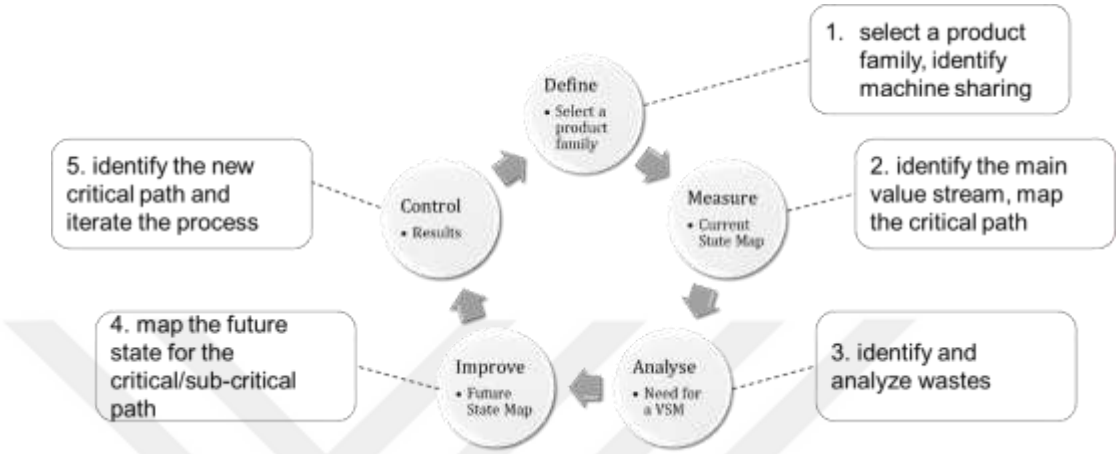


Figure 3.4 DMAIC with VSM approach

3.1.1 Selecting a Product Family

When a study is carried out considering all the products within the organization, it will be quite complex and difficult to analyze the process structure. At the same time, all processes within the organization may not serve the "value" defined by the customer. Therefore, the study can be carried out more effectively by choosing a product group regarding similar production stages. The product family is defined as product groups in which the same machinery or equipment is used in the production of similar processes.

Priority should be given to the flows with the most waste in the work flow process when determining the product group on which the value flow mapping study will be performed (Adalı & et al., 2017).

When choosing a product family group; the product families with the most scrap rates, the most costly, the most referred to the customer claim or produced using many machines and equipment in the production area can be selected. Although many studies in the literature are examined, while the product family is selected, methods

such as pareto analysis, AHP analysis, ABC analysis, product family selection matrix formed by Rother & Shook have been used (see Figure 3.5).

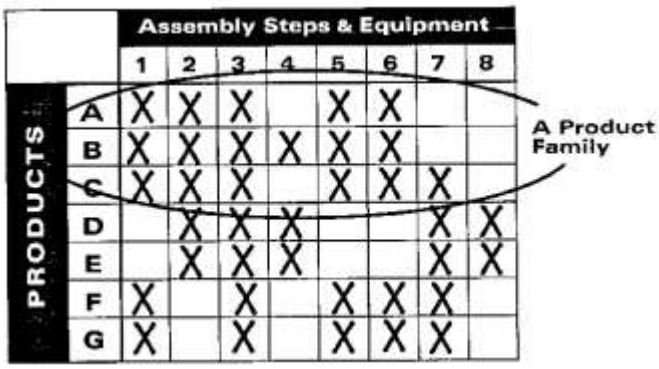


Figure 3.5 Product family matrix (Rother & Shook, 1998)

3.1.2 Current State Map

The product family is selected as defined in the previous topic. The next step, it is time to display the material, information and service / production flow of that product with simple symbols.

The most important point in creating a current state map is to collect information in advance. Field analysis is a very important stage in order to ensure that the information is accurate and consistent with each other.

The current state map is drawn with standard symbols and data obtained from direct production related to the product family.

Today, various computer-based programs is used in drawing the current state map. These are MS Office Visio, Proteus, and VSM Professionals etc. Therefore, the symbols used in the past studies are still used today.

Rother & Shook (1999) as mentioned in their book, various symbols used in creating the current state map and their explanations are given in the table below (see Table 3.1).

Table 3.1 Basic symbols used in the value stream mapping

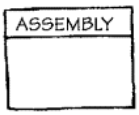
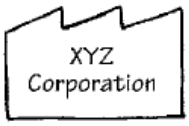
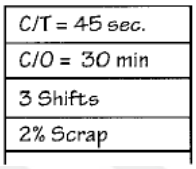
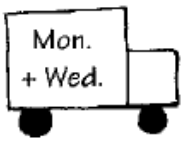
Material Icons	Represents	Details
	Manufacturing Process	All processess should be named.
	Outside Sources	Defines customer, suppliers and 3rd party processes.
	Data Box	Record information related to production, customer demand, etc.
	Inventory	Quantity and time should be recorded.
	Truck Shipment	Shows shipment's frequency

Table 3.1 Continues

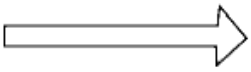
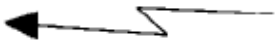
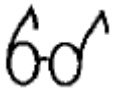
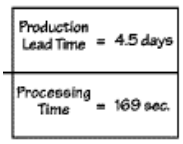
Material Icons	Represents	Details
	Movement of production material by PUSH.	Shows material flow
	Movement of finished goods to the customer	
	Supermarket	Shows inventory of parts that can be transport anytime to the next step.
	Manual Information Flow	

Table 3.1 Continues

Material Icons	Represents	Details
	Electronic Information Flow	
	Information	
	"Go See" Production Scheduling	optimizing schedules dependent on inventory levels
	Kaizen Bulletins	Noted improvement actions
	Operator	Responsible of each process
	Time line	It is the field where the lead time and the processing times are written.
	Total Time Box	Shows the total time for whole process

Rother & Shook (1999) as mentioned in their book and Braglia & Carmignani (2005) as mentioned in their article, data collection begin at shipping, working backwards in the production process to raw materials or suppliers and collecting data on inventory level at each stage of the value stream. VSM is the unique technique that record, the information flows related with the material flows within the same tool.

To be able to draw a current state map of VSM, below information should be gathered:

Information Flow:

- Orders released by customers,
- Orders released to first tier suppliers,
- Ordering frequency;
- Forecast frequency;
- System used to plan production;
- Time to plan production;

Machines:

- set up time;
- up time;
- cycle time;
- number of operators;
- number of shifts/hours per day;
- cycle time;

Production Flow:

- average customers demand;
- shipping frequency;
- pallets dimension;
- production batches;
- inventory levels;

- type of flow between machine (push-pull).

After information as mentioned above are collected, it is time to draw the current state map.

According to Tapping (2003), while drawing the value stream, the following issues should be considered.

1. Drawing the external customer and the supplier and recording their requirements.
2. Drawing the each of process to the value stream.
3. Drawing each of process between the start and end of processes.
4. Listing all process attributes.
5. Calculating queue times between processes.
6. Drawing all communication and interactions of processes.
7. Drawing push or pull icons to identify the type of workflow.
8. Completing the map with any other data (See Figure 3.6).

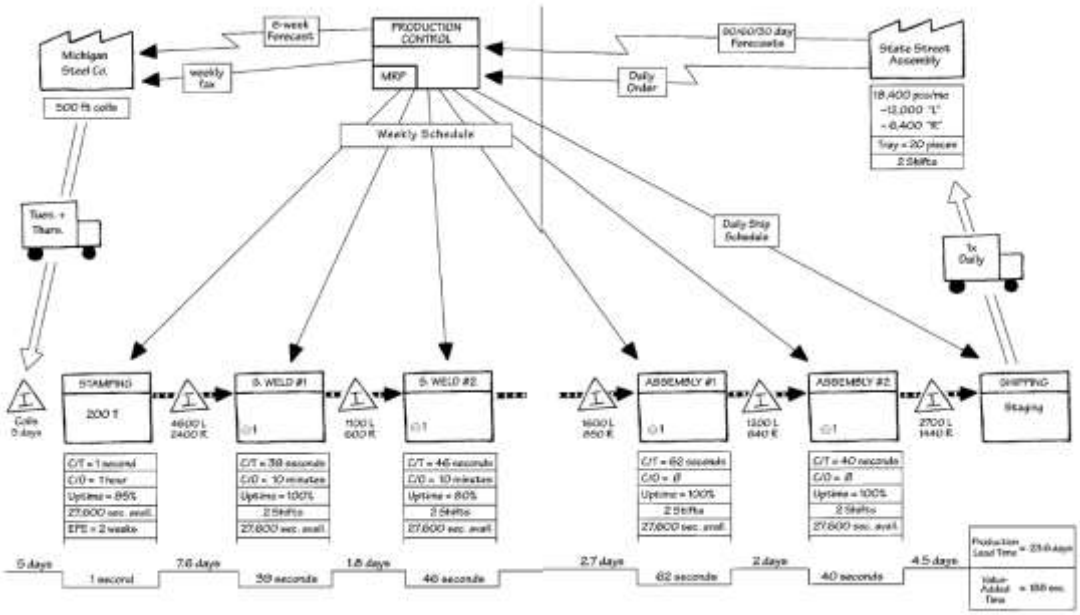


Figure 3.6 Sample of a current state map Rother and Shook (1999)

-Cycle Time Calculation: According to Rother and Shook (1999); it can be defined as a length of time from one part exiting the process to the next part exiting.

-Takt Time Calculation: Takt is a German word and called as "Taktzeit". Takt determines how fast a process needs to run in order to meet the customer demand. Takt time can be defined as the pace of customer demand (Tapping, 2003).

Takt time=Net available operating time ÷ total daily quantity required (3.1)

-Change Over Time: According to Rother and Shook (1999); time to switch from producing one product type to another.

-Value Added Time: It is defined as the duration of the operations performed to create the product requested by the customer.

- Non-Value Added Time: It can be defined as the time spent on the product, which does not add any value for customer requests, but still performed.

- Lead Time: The time a product spends in the value stream from the first point to the last point.

- Available Production Time: The time obtained by subtracting breaks such as tea, lunch and planned breaks from the total workable time.

-Process Improvement: After the operations that do not add a value related with the customer requests on the product are detected by drawing the current state map, improvement steps should be determined in order to eliminate these problems.

In order to ensure the lean production flow, steps that do not comply with this lean philosophy should be arranged and studied.

The essence is the examination of non-value-added activities depicted on the current state map. A set of techniques built specifically to identify and remove waste sources in each of the value streams can be helpful in this regard (Hines and Rich, 1997).

To be able to analyze the problems, root cause analysis such as 5-Why techniques, fishbone diagrams, 4M analysis, and fault tree analysis methods are used. Additionally, 5S methodology is conducted to improve flow of work, reduce waste, increase productivity and optimize quality. The meaning of the 5S is five words that are sort, set, shine, standardize and sustain. The names of these 5 steps are listed below also in Japanese:

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

In the lean approach, where the 5S system is included as an improvement method; Kaizen studies mentioned in the actions are another technique that the lean manufacturing system uses to improve and regulate the current situation. The other tools of lean manufacturing include Kanban, total productive maintenance (TPM), cellular manufacturing, pull production and visual controls.

In the light of the techniques mentioned above; changes for improvement are made on the current state map by the team members doing VSM study. A future state map is created in the light of suggestions for improvement.

3.1.4 Future State Map

According to Tapping 2003, at the heart of lean is just-in-time production, or continuous flow. The continuous flow refers to producing what the customer need, when it is required, and in what quantity.

The open issues to improvement that arise while drawing the current state map constitute a source for the future state map drawing. 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 future state map is one assuming the inventory levels and other flow changes based on the answers to questions. Some of

these questions are as follows: “Where can you apply continuous flow?”, “Where is the bottleneck process?”, “What level of flow do you need?” and “What is Takt time?”.

The purpose of value stream mapping, according to Tapping (2003), is to create a production chain in which processes are linked to their customers by continuous flow or pull, and each process gets as close as possible to providing only what its customers need when they need it.

The main goal of value stream mapping is to create a future state map to be able to visualize the improvement points. In order to create a future state map, the points to be improved on the current state map are studied and marked with symbols. Thus, the improvements that is made on the process are decided and a future state map is created (see Figure 3.7).

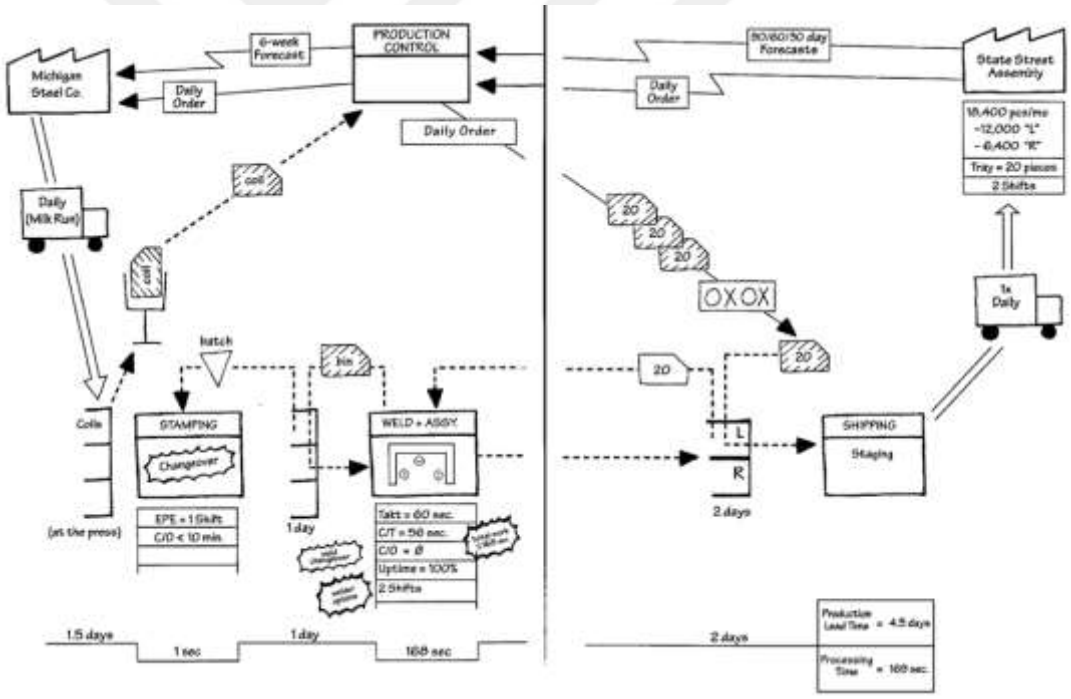


Figure 3.7 Sample of a future state map Rother and Shook (1999)

3.1.5 Identifing The Action Plan

An action plan come out while drawing the future state map. In fact, the current state is transformed into the designed new state by this action plan. The answers to the questions such as who will be assigned for the improvements and when the improvements will be made are included in the prepared action plan. The action plans for the future state are conducted, these items will be a new current state in a time period and thus a new future state map will be created and the mapping process will be studied. In this way, the monitoring, control and continuous improvement of the applications will be provided.

After the action plan is implemented, the results are compared with the current state and it is checked whether there is any improvement and whether the actions are work. By taking these improvements into consideration, new improvement points are determined and continuous improvement is achieved.

CHAPTER 4
A CASE STUDY IN AUTOMOTIVE INDUSTRY

4.1 Problem Definition and Business Understanding

The process that needs improvement is essential because the time spent on work is short and valuable. The implementation is carried out in a well-known Company X in the automotive sector, located in Izmir Free zone area. In the value stream mapping process, a part of an oil pump production process is analyzed, and the non-confirming material flow is the focus point. One type of product is selected for initial studies as a pilot project.

Reduction of the lead time and cycle time is aim of this study, as well as the reduction in inventory levels, internal logistics time, and repetitive movements and jobs. According to future state results, the new project's process will be invested considering improvement points.

In this section, the process of nonconforming product management is examined. The flow chart of this process is drawn. The current problems are examined. The root causes of the problems are determined and solution suggestions are evaluated. In addition, the risks in the process and the actions that can be taken are also determined. Tack times, total lead times, and total process times are determined with current status data. Then the current state map is created.

In accordance with the current problems, an improved process is designed with the developments. The value stream map of the future state is created and the current state and future state maps are compared.

This study aims to increase employee satisfaction by increasing efficiency and effectiveness in the management of nonconforming products, as well as to reduce scrap costs and the workload of operators.

4.2 A Brief Information about the Company and Product

An automotive company that exports all of its products to several countries in Korea, India and Europe is chosen as a case for this study. Company X is the leading 'black box' oil pump supplier for engines and transmissions. The pump consists of several components. The pump's body and cover are machined in the factory, and the other parts are supplied from the suppliers. Company X's vision is to be recognized as the global leader in the design and manufacture of highly engineered systems through innovation, technology, and people. In addition, Company X is committed to building in quality to be able to meet customer requirements through continual improvement of their systems, processes, and innovative product designs. Some of the oil pump samples are presented in Figure 4.1.

Figure 4.1 Examples of the oil pumps (Personal archive, 2020)

Company X complies with the requirements of IATF 16949 Quality Management System Standard, ISO 14001 and ISO 45001 Management System Standard.

Company X supports its customers on production of oil pumps as well as the design of oil pumps and production of spare parts.

The general process flow diagram is presented in Figure 4.2, which explains production flow briefly.

Figure 4.2 The process flow diagram

A standard oil pump consists of approximately 15 parts. The number of parts may increase to around about sixty parts according to the design of oil pumps regarding the customer requirements. Company X does not produce whole parts of the oil pump internally. Sub-components are supplied by external providers. Raw body parts machining is done in the Company X. Other sub-components are used and assembled as is.

In order to explain the production flow briefly, the cast body parts are supplied from an external provider from one of the approved suppliers. According to the production plan prepared weekly, the raw body parts are machined in-house. After the quality laboratory approves the measurement, the machined parts are moved to the washing process and then buffered before going to the assembly line. Parts wait for processing in the buffer area. The machined parts are used according to the FIFO rule. According to the production plan, the parts are transported to the assembly line. The machines and assembly lines are operated in three shifts. The machined body and the other parts are assembled at the relevant assembly line. At the end of the assembly line, the oil pumps are packaged regarding to customer packaging requirements. Finally, the packaged oil pumps are transferred to the warehouse, where they wait until the customer shipment date.

In Figure 4.3, some processes are highlighted:

- Area 1: Machining process
- Area 2: Measurement process
- Area 3: Washing process
- Area 4: Assembly process

- Area 5: Final control process
- Area 6: Quarantine area
- Area 7: Recovery area

These areas and processes may cause any nonconforming material.

To investigate the non-value-adding activities, a value stream mapping approach is implemented. Many product families may pass through in the above-mentioned areas for many purposes. To be able to understand which product family has the highest production inefficiency and problems, and to express the data numerically, a total of six projects underway at Company X is observed. According to the progress of the study, the current state map and future state map are derived.

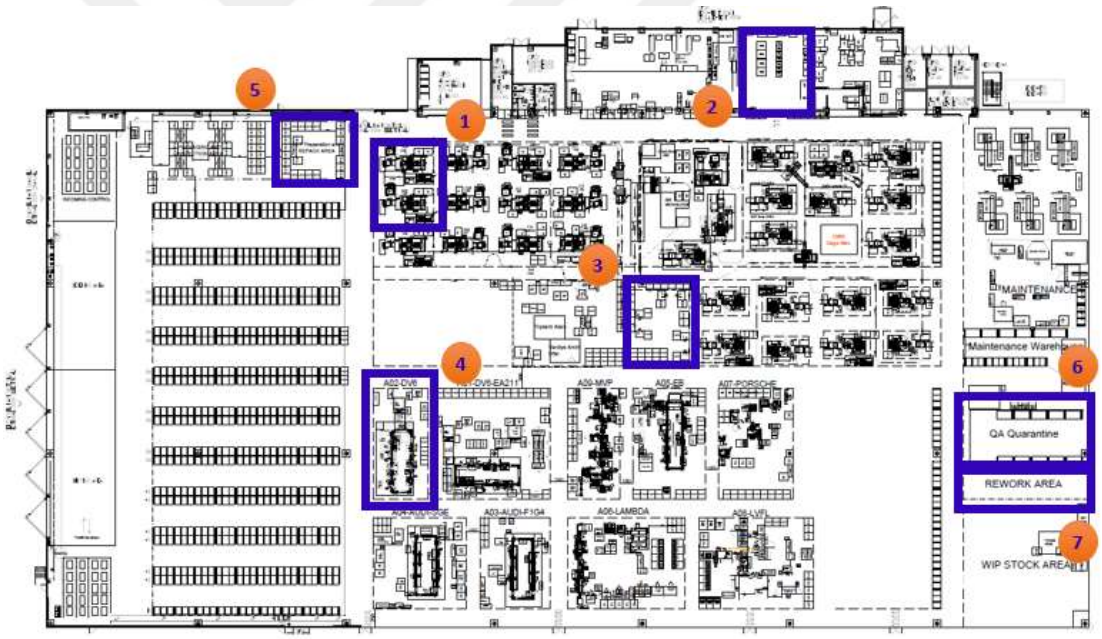


Figure 4.3 Company X layout

4.3 Method For The Case Study

In this study, the value stream mapping technique is used to determine the problems arising in the management of nonconforming materials in Company X. In addition, the troublesome points in the processes, and the bottleneck areas are determined. Next, solution alternatives are investigated in order to eliminate the problems in these areas and to prevent bottlenecks and unnecessary movements.

Then, the TOPSIS technique, a multi-criteria decision-making method, is used to decide the sequence of implementation regarding solution alternatives. The choice of this method is the decision of the management team. TOPSIS is preferred because it is more practical than other multi-criteria decision making techniques. The relationships between solution alternatives are analyzed. Brainstorming is done with the management team for the selection of criteria. The obtained information is compiled by using the major criteria in academic studies as an example.

The global value stream mapping approach and TOPSIS technique is set as a base for this study. TOPSIS technique is used in the step six. The basic stages performed within the scope of the study are presented in Figure 4.4.

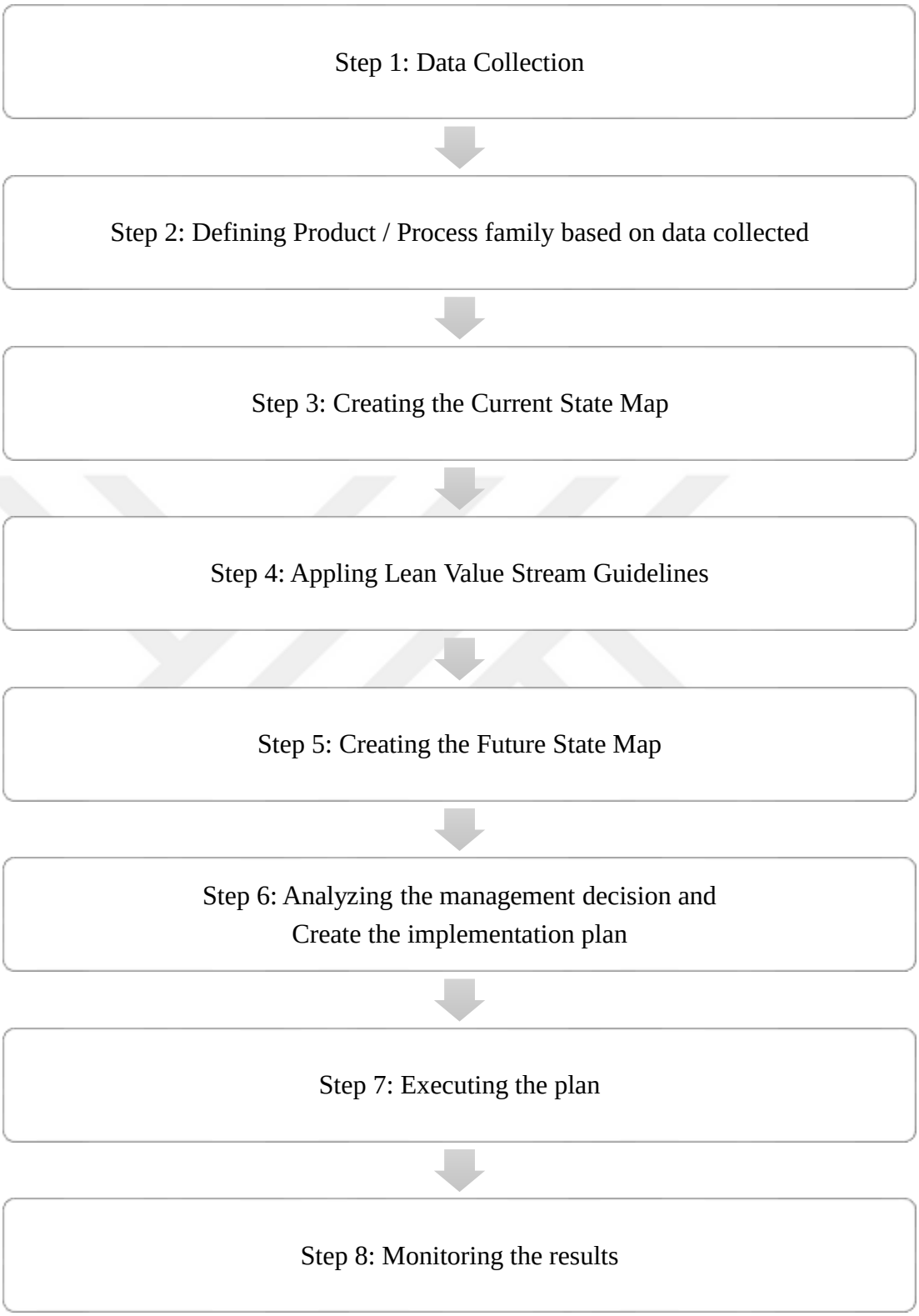


Figure 4.4 The framework of the research

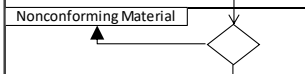
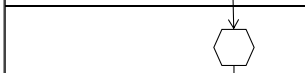
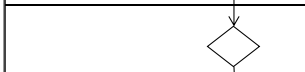
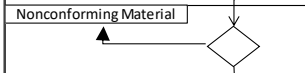
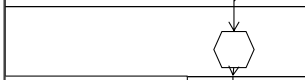
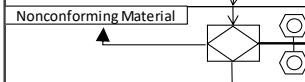
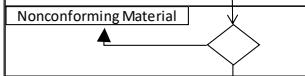
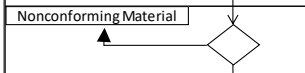
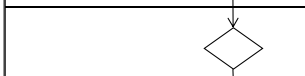
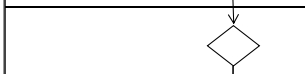
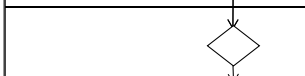
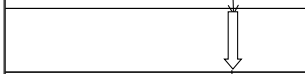
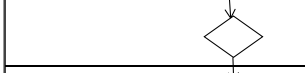
4.3.1 Data Collection

Company X receives customer orders in a weekly manner via electronic data information (EDI) by an Enterprise Resource Planning (ERP) system. Accordingly, the planning department prepares weekly production plans for assembly lines.

The reports of production are gathered for the past six months from the starter of July 2019 to the end of December 2019. Products manufactured over less than three shifts time span are ignored due to low volume production. Products that are easy to monitor for every criterion are included in the analysis. The approximate unit price of products is collected.

Additionally, the internal quality claim ratio (QCR), the process flow for each product, and total process time are gathered for the six months period. The relevant data with the research study is collected for the production flow (see Table 4.1). This production flow is the main flow for all products. Some changes according to the design and subcomponent complexity can be derived. Internal quality issues, highlighting issues, and reasons for future root cause analysis studies are also noted. In the end, all collected data are transferred and typed into a computer-based program such as MS Office Excel and Minitab.

Table 4.1 The production flow chart

Process Step	Operation Number	Operation	Machine/Line	Cell
	10	Receive Sub-Components	Warehouse	
	20	Incoming Quality Control	Laboratory	
	30	Stockage	Warehouse	
	40	Machining of Body	Machining Line	CNC
	50	Washing machined body	Washing machine	
	60	Measurement	CMM/ Gage controlling	Quality Laboratory
	70	Transportation to the Firewall Control		
	80	Body and other subcomponents control	Firewall Desk	Firewall
	90	Transportation to the assembly line		
	100	Customer DMC Marking	Subline	Assembly Line
	110	Sub- components assembly	Mainline	Assembly Line
	120	Air Test	End of Line	Assembly Line
	130	Final Control	End of Line	Assembly Line
	140	Packaging	End of Line	Assembly Line
	150	Hyrolic Test		
	160	Cleaning Test		
	170	Transportation to the warehouse		
	180	Stockage	Warehouse	
	190	Packaging	Warehouse	
	200	Shipment	Truck	

4.3.2 Define Product Family

A product family is a set of parts that operate in similar processes and share similar work content.

According to six months data, production volume and unit price of each product are calculated in order to define products with high quantities via a Pareto analysis (see Table 4.2).

Table 4.2 Construction of product families with Pareto analysis

Part	Unit Price(€)	Production Volume	Income (€)	% of Total Endorsment	Cumulative total
Pump A	27.86	381,270	10,622,182	41%	41%
Pump B	22.34	410,000	9,159,400	35%	76%
Pump C	20.7	100,052	2,071,076	8%	84%
Pump D	20.2	89,346	1,804,789	7%	90%
Pump E	80.72	18,600	1,501,392	6%	96%
Pump F	37.4	27,000	1,009,800	4%	100%
Total		1,026,268	26,168,640	100%	

Based on Table 4.2, pump A and pump B have the 80% volume. Therefore, pump A and pump B behave similarly, 41% to 35%. Due to close results, the Pareto analysis needs to be supported with different approaches.

Additionally, 80/30 guidelines of family matrix and quality claim ratio (QCR) is used to define which product will be selected. According to Duggan and Healey (2016), as a general guideline, look for roughly eighty percent similarity in the activities performed among the different processes, and the variation of the total work content time for all the processes in a potential family should not exceed thirty percent.

According to 80/30 guidelines of family matrix approach, pump A and pump B are selected (see also Table 4.3).

Table 4.3 Manufacturing sample over a six month period

Product	Machining Prep.	Machining Body	Machining Cover	Body Firewall	Cover Firewall	Assembly	Hydraulic Test	Final Control	Packaging	Total Work Content
Pump A	✓ 15	✓ 82.5				✓ 14.2	✓ 69		✓ 300	480.7
Pump B	✓ 15	✓ 75				✓ 13	✓ 69		✓ 300	472
Pump C		✓ 100.5	✓ 100.5	✓ 82	✓ 82		✓ 69	✓ 48	✓ 300	782
Pump D		✓ 65.5	✓ 65.5	✓ 78	✓ 78	✓ 30	✓ 69	✓ 48	✓ 300	734
Pump E		✓ 120				✓ 34	✓ 69	✓ 97	✓ 300	620
Pump F		✓ 225	✓ 225	✓ 112	✓ 112	✓ 141	✓ 69	✓ 102	✓ 300	1286

Is there approximately 80% similarity between the process flow of the products?

Pump A and Pump B : Yes

Pump D and Pump F: Yes

Is there no more than 30% difference in total process times?

Pump A and Pump B : Yes → 480.7-472= 8.7 8.7/480x100=%1.8

Pump D and Pump F : No → 1286-734= 552 552/1286x100=%42

Finally, the last decision approach is QCR in this study. QCR value is calculated monthly basis and by-product family with the below formula.

$$QCR = \frac{\text{the number of internal claims in a month}}{\text{the number of produced parts}} * 1\,000\,000 \qquad (4.1)$$

After the QCR comparison (see Table 4.4) the pump A has the highest claim ratio over the six months period.

Table 4.4 Parts per million

	Number of Internal Claim					
	Jul 2019	Aug 2019	Sep 2019	Oct 2019	Nov 2019	Dec 2019
Pump A	333	583	200	500	125	250
Pump B	158	0	0	53	56	0
Pump C	0	0	0	0	0	0
Pump D	0	0	0	0	0	0
Pump E	54	63	48	34	83	44
Pump F	17	8	8	0	0	0

As a result, pump A is selected. Note that the process flow of pump A is similar to the main production flow, as stated in Table 4.1. From the sub-component reception to the pump delivery, all common steps are mentioned in Table 4.1. Raw body parts machining is done in the Company X. Before materials are transferred to the production, all parts need to be examined at incoming quality control by quality

auditors. If any suspected part is detected, parts are sent back to the supplier. Therefore, this part of the flow is not included in this study.

Row casting body and other sub-components are taken into stock after passing through the incoming quality control process and wait until the production sequence. According to the production plan, parts are transferred to the production area by the warehouse operator. Row casting parts are machined and controlled in accordance with the machining production plan. Sub-components are controlled at the firewall area in accordance with the assembly line production plan. If any suspected part is detected, parts are sent to the quarantine area in order to provide quality auditor observation. Accurate and confirmed parts are sent to the assembly line. In the subline, a unique barcode (customer DMC barcode) is printed on the machined body. A machined body is used as housing and other components installed in the body part with the support of a semi-automated and human-based assembly line. If any of the parts are not in accordance with the other parts that take part in the pump, these parts are rejected from the process as nonconforming parts. Hence, this part of the flow will be included in this study.

The pumps assembled successfully are subjected to the control at the end of the line, cleaning test, and performance test. At the end of the line, the pumps are controlled according to visual control instructions and packaged according to customer packaging instructions. Finally, the packaged pumps are sent to the warehouse and wait until the date of shipment.

This case study is focused on nonconforming material flow related to firewall and assembly line rejected parts. To be able to analyze the flow and point out the improvement items, value stream mapping is used. Besides, the TOPSIS technique is used to gather the ideas of the managers.

4.3.3 Creation of the Current State Map

Nonconforming material means the material that is not used for the oil pump dimensionally, visually, or functionally during oil pump assembly. Therefore, it should be ensured that nonconforming materials arising during production do not re-introduce

to the production. In order not to re-introduce the production of nonconforming materials, they are pulled to the end of the assembly line at the end of each shift.

The decision-making authority regarding to the nonconforming materials drawn to the end of the line is the quality auditors. According to the currently operating procedure, quality auditors can make four types of judgments on nonconforming materials. These decisions are scrapping nonconforming materials, reusing nonconforming materials, reusing nonconforming materials after the rework, and sending nonconforming materials to the quarantine area.

On the other hand, although the decisions regarding to the use of the parts are important, the accuracy of the amount and the systematic location (the ERP warehouse) are also important. Quality auditors must systematically mark the form to select the ERP warehouse while making decisions about the quality of parts.

In addition, if the quality auditors select the rework process for nonconforming parts or select the scrap process, then the parts must be counted and transferred to the rework area. Also, a warehouse operator carries out inventory counting, ERP system transfer, and physical transfer.

Consequently, the lead hand is responsible for identifying the nonconforming material and collecting them at the end of the assembly line. A warehouse operator is responsible for supplying materials to start production and responsible for counting the nonconforming material, identifying it in the ERP system and transferring it to the required place. Quality auditors are responsible for providing accurate information about the use or disposal of the nonconforming material.

To be able to start value stream mapping, firstly the needed processes for nonconforming material management should be known. According to material flow, the production process causes the nonconforming material to rise.

The interview method is used with one-to-one interviews with the person doing the job. Besides, work analysis is made with camera recording. At this stage, process flow

charts are used to better understand the processes. The current state process flow chart is created with the work steps determined based on the interview conducted.

The part receiving planning, logistics time production planning, and customer orders are obtained from the production planning and control department.

Microsoft Office Visio program is used to create process flow charts.

The data presented in the current state map are changed by taking a percentage of real data due to the non-disclosure policy of Company X.

Calculation of the Current State Standard Time: To be able to draw the current state map, process times need to be calculated.

The appropriate number of observations is determined to repeat three shifts with ten measurements per shift. Then, measurements are taken at the workstation with a stopwatch. The working times are measured randomly by direct measurement. The measurement values taken are added to the observation record form. The arithmetic mean of the measurement values taken for each activity, $\bar{X}$ is the value to be used for the calculation of the standard time. Additionally, tiredness and rest time additions (%15 in general) need to be made to the normal time found by multiplying the measured time by the appreciated tempo.

The total cycle time for pump A products to complete the flow in a total of eleven processes is 2044 seconds and the total lead time is 8.7 days.

The analysis and calculation steps that the research study is included are mentioned in the following headings:

Takt Time Calculation: Company X works twenty four days each month on average, and three shifts each day. Working hours are between 07: 00-15: 00 (B shift), 15: 00-23: 00 (C shift) and 23: 00-07: 00 (A shift). That is, eight hours of work is done in a shift, in which there are a thirty-minute lunch break, and two ten-minute tea breaks.

The production time calculation is presented below:

Available production time:	3 shifts × 8 hr × 60 min	= 1440 min.
One lunch break:	3 × 30min	= 90 min.
Two tea breaks:	3 × 2 × 10 min	= 60 min.
Actual available production time:	= (1440 − 90 − 60)	
	= 1290 min.	
	= 1290 x 60 = 77 400 sec./day	

According to the above formula, the Takt time is calculated below.

$$\text{Takt time} = \frac{\text{Actual available production time}}{\text{Daily part produced}} = \frac{77400}{6120} = \sim 13sec \qquad (4.2)$$

The Cycle Time is the measured time between two good quality products produced. The time between an operator finishes the process before starting it again. The cycle time is the value-added time.

The Process Time is the time of a process from a machine to another. How long it takes a part to travel through a process: this is used in the lead-time ladder analysis.

The lead time is the time it takes for a production process to start and finish. In other words, it is the time between receiving an order and delivering it to a customer.

Value Added Time Calculation: It is the time mentioned by the customer as "value". The customer can be external or internal. An internal customer is the upstream process and provide semi-products to the next processes.

Non-Value Added Time Calculation: It describes the duration of operations that the customer does not pay for. Storage, handling, controlling and rework are common non-value added activities.

In this study, the focus point is nonconforming material flow analysis of pump A. If the complete pump production was analyzed, the nonconforming material flow would be the non-value-added activity in the complete production process and the elimination of the nonconforming material process and handling would be one of the items in action plan. As a fact that the recovery of nonconforming products rejected from each process has a very important role in terms of profit for the organization in the automotive industry. This study focuses on the only nonconforming material flow in order to reduce the time spend for this non-value added process. So, according to the VSM approach, the nonconforming material flow analysis is studied.

The process of nonconforming material flow of pump A is carefully observed and studied. The mapping is done through the system starting at the material receive and going upstream towards customer end. The calculation of value added activities is presented in Table 4.5. Finally, the current state map is created (see Figure 4.5).

Table 4.5 Time calculation for current state map

Time Calculation of Value Added Activities				Measurement																													
			Shift	A										B										C									
Process step	# of Operator	Definition of process	Unit	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	Ave.x̄ Normal time
1	2	Visual Check & Sorting (1 part)	sec.	20	22	27	23	22	26	21	22	23	23	23	20	21	21	22	24	27	23	22	20	28	26	32	24	22	28	28	24	26	26	24
3	1	Rework	sec.	12	11	14	11	12	12	13	15	17	12	14	13	13	11	12	12	13	12	12	11	14	16	14	14	13	17	16	14	13	11	13
5	1	Visual Check	sec.	20	22	27	23	22	26	21	22	23	23	23	20	21	21	22	24	27	23	22	20	28	26	32	24	22	28	28	24	26	26	24
7	-	Pump assembly (automation)	sec.	13																														13
8	1	End of line nonconforming part picking (various of parts has been observed)	sec.	428	362	430	423	328	336	342	360	327	280	402	384	382	230	408	359	346	328	358	337	300	312	403	324	351	378	360	412	403	422	361
9	1	Prepare quality record form	sec.	182	167	183	184	186	182	174	182	187	106	122	127	156	172	133	149	173	175	171	123	193	182	197	184	176	172	173	183	187	160	168
10	1	Quality Resp. Check	sec.	246	195	247	239	142	154	168	178	140	174	280	257	226	58	275	210	173	153	187	214	107	130	206	140	175	206	188	229	216	262	193
11	1	Transfer to counting desk	sec.	630	542	603	545	457	630	622	634	524	545	527	367	605	630	582	585	630	630	547	592	503	515	606	527	554	581	563	615	606	625	571
12	1	Dispaching parts to per location and counting parts	sec.	158	136	151	136	114	158	156	159	131	136	132	92	151	158	146	146	158	158	137	148	126	129	152	132	139	145	141	154	152	156	143
13	1	Assign the parts to quarantine	sec.	384	347	356	306	315	476	454	456	384	371	247	110	379	572	307	376	457	477	360	378	396	385	400	387	380	375	375	386	390	363	378
14	1	Assign the parts to rework	sec.	384	347	356	306	315	476	454	456	384	371	247	110	379	572	307	376	457	477	360	378	396	385	400	387	380	375	375	386	390	363	378
15	1	Quality Engineer Check	sec.	638	553	649	616	498	557	553	578	521	474	594	529	588	441	610	565	571	544	551	536	496	509	633	518	547	596	574	628	620	641	564
16	1	Prepare rework instruction by Quality resp.	sec.	59	62	77	65	64	72	62	67	72	66	68	60	62	60	64	68	76	66	64	58	80	77	89	70	65	83	82	70	74	72	69
17	1	Rework	sec.	12	11	14	11	12	12	13	15	17	12	14	13	13	11	12	12	13	12	12	11	14	16	14	14	13	17	16	14	13	11	13
18	1	Transfer the parts to shelf	sec.	630	542	603	545	457	630	622	634	524	545	527	367	605	630	582	585	630	630	547	592	503	515	606	527	554	581	563	615	606	625	571
19	1	Count and visual check	sec.	99	74	74	71	50	86	94	92	59	70	64	32	89	98	82	78	82	92	73	90	46	52	63	62	74	62	59	84	78	84	74

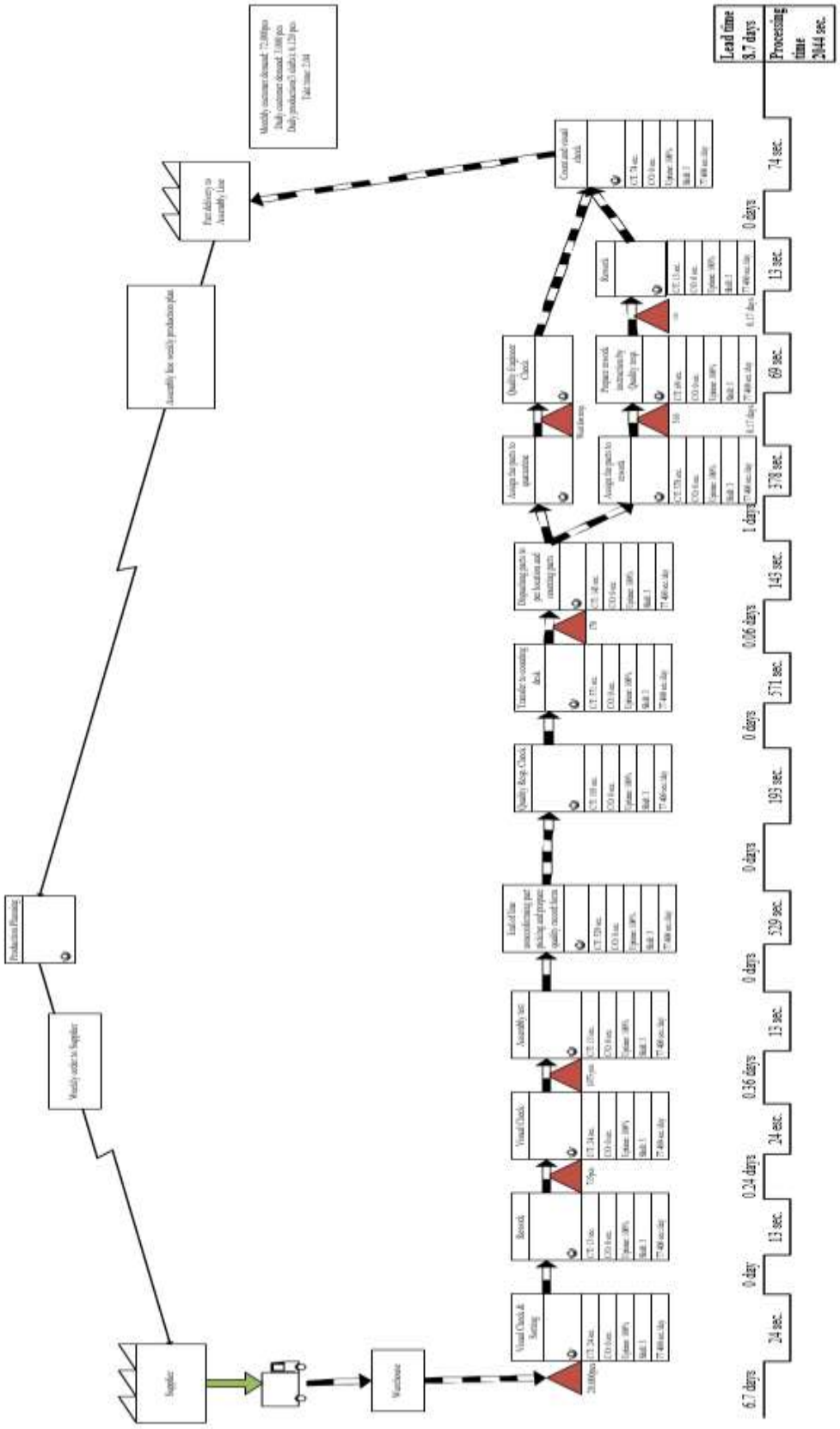


Figure 4.5 Pump A current state map

4.3.4 Applying Lean Value Stream Guidelines

The current state map is stated at the previous phase. After the current state map is observed and analyzed, the next step is to point out the improvements according to kaizen philosophy. To be able to eliminate waste, time losses and reduce cycle times are important goals. If there are serious gaps between takt time and cycle times, then this indicates production problems resulting from unplanned (Haque, 2004). Value stream mapping is provided to see the whole picture and interrelation between the processes. At the same time, there is an opportunity to interview and study with everyone, from the operator to the management level. During the six months observation and analysis, the most significant time losses arise from the undefined works and decision mechanisms.

There are three types of operations in internal manufacturing, according to Forno & et al. (1990). These can be classified as follows:

- non-value adding (NVA);
- necessary but non-value adding (NNVA); and
- Value-adding (VA).

Firstly, the non-value added activities should be defined and eradicated to avoid lack of flow. The non-value added but still important and critical activities need to be analyzed and reduced, and focus on how to create and improve flow.

According to defect analysis of pump A during six-month period, most of the problems are caused by the rotor part (a sub-component of pump A). The analysis is prepared via Excel pivot table and stated below in a more visualized graph (see Figure 4.6). The highest pie by 39% of non-conformation and defective production is the rotor part.

After the part that tracked for this study is determined, a line walk is made in the production area at intervals for six months. In order to determine open issues, observations are made throughout the nonconforming material flow for the rotor sub-component.

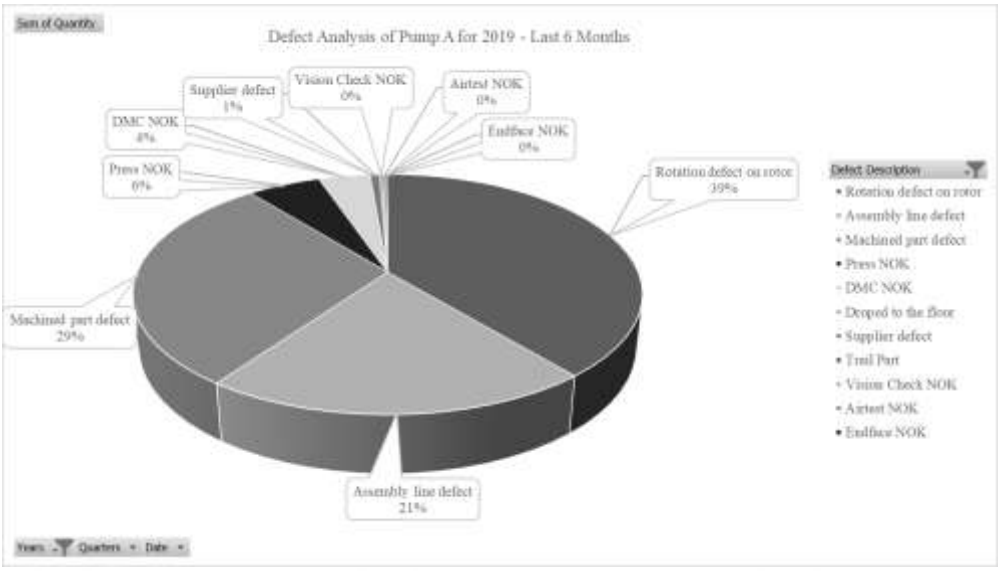


Figure 4.6 Defect analysis of pump A for 2019 - last six months

Data of the nonconforming material flow in Figure 4.5 is summarized as follows:

- Lead time for the nonconforming material flow of pump A is 8.7 days.

- The main reason of the long lead time period is related with the supplier. The part is not received in good quality at the first time from supplier. Besides, site visits and development activities with the supplier are not planned. Because of this reason, at the beginning of flow the four processes are non-value added but necessary activities.

- The supplier issue also affects the stock volume. Hence, the stock volume before the first process corresponds to approximately a week.

- Secondly, recording the nonconforming material information is taken a lot of time. Although the company has automation in the systems used in the production, it is observed weaknesses in terms of working with automation in support processes that are not included in the product structure. Additionally, error types are not classified. The definition of error differ from people to people. Due to these reasons, completing the nonconforming material form takes a long time.

- Similarly, in the process flow of the product, the operators' standard work instructions are available. However, it is observed that there are no instructions in support processes such as rework, handling, part placement, etc.

- In all processes, the parts are counted before transferred to the next process and counted one more time by the warehouse operator before conducted a stock movement in the system.

- On the other hand, the reworked parts are repeatedly included in the system. It is not monitored whether the parts are used effectively after they are processed.

- The material collection route is quite complex and has no specific timing. The equipment, e.g., forklifts, is difficult to use in the production area. Besides, access to collection points of parts is limited. Warehouse operators carry parts inconveniently in terms of the ergonomic point of view.

4.3.5 Creation of the Future State Map

Corrective actions are identified based on the above-mentioned. It can be listed as follows:

- Preparing default rework instructions for the standard error codes (A1)
- Improving transportation equipment and type (A2)
- Usage of computer based forms for recording of nonconforming material (A3)
- Clarifying material count operations (A4)
- Improving the supplier process and supplier product to avoid rework operation in-house (A5)
- Marking reworked parts (A6)
- Defining a standard error codes for the product family (A7)

4.3.6 Analysis of the Management Decision and Creation of the Implementation Plan

It is critical to accurately assess the importance and precedence of implementation of corrective actions due to limited implementation time and time to follow up. For this reason, the TOPSIS technique is used. Accordingly, the managers responsible for the operations and supply chain processes at Company X are participated in the decision process. At the end of the study, the opinions of all participants are in line.

4.3.6.1 Applying TOPSIS Technique

TOPSIS is one of the techniques of the multi criteria decision making methods. TOPSIS is a superior technique to make the most ideal choice and define the precedence among multiple alternatives.

The TOPSIS was first developed by Hwang & Yoon (1981) and stated in Büyüközkan's study (Büyüközkan, 2011). The TOPSIS technique is based on the notion that the chosen alternative should have the shortest geometric distance between the positive ideal solution and the negative ideal solution, and the longest geometric distance between the two.

TOPSIS technique's calculation procedures are as follows, and they consist of a sequence of steps (Hwang & Yoon, 1981) (see Figure 4.7).

Step 1: Construction of the Normalized Decision Matrix $r_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}}$ (4.3)

Step 2: Construction of the Weighted Normalized Decision Matrix

$$v_{ij} = w_{ij} r_{ij} \quad (4.4)$$

Step 3: Determination of Ideal and Negative Ideal Solutions

$A^*: The\ ideal\ Solution, A^-: The\ Negative\ Ideal\ Solution$

Step 4: Calculation of the Seperation Measure

$$S_i^+ = \sqrt{\sum (v_{ij} - v_j^+)^2} \quad S_i^- = \sqrt{\sum (v_{ij} - v_j^-)^2} \quad (4.5)$$

Step 5: Calculation of the Relative Closeness to the Ideal Solution

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^+} \quad (4.6)$$

Step 6: Ranking of the Preference Order

Figure 4.7 The calculation processes of the TOPSIS technique

The TOPSIS technique is used to determine the precedence of implementation of corrective actions. There are seven open items in the action plan. These open items are considered as alternatives in this study. The alternatives used in this study are as follows:

1. Setting core rework instructions for standard error codes (A1)
2. 5S and transportation equipment and type (A2)
3. Creating computer based forms to record of nonconforming material (A3)
4. Assigning material counting operation (A4)
5. Improving supplier process and supplier product to avoid extra operation in-house (A5)
6. Marking recovered parts (A6)
7. Maintaining standard error codes for the product family (A7)

The criteria used in this study to evaluate the alternatives are as follows:

- Quality
- Productivity
- Cost
- Flexibility
- Transportation

Explanations of the determined criteria are given below.

Quality (C1): How urgent and necessary the action to be taken is rated with this criterion. In the comparison between the alternatives, the highest quality ratio is evaluated positively.

Productivity (C2): This criterion is determined in order to evaluate the estimated effect of the action to be taken on productivity. In the comparison between the alternatives, the highest productivity ratio is evaluated positively.

Cost (C3): When the action to be taken requires an investment, cost criterion is evaluated as negative.

Transportation (C4): Transportation is one of the wastes defined in lean philosophy. Then, excessive distances between processes are evaluated as negative.

Flexibility (C5): Taken actions related to product groups specified in this study are expected to be adaptable to other product groups and processes. In the comparison between the alternatives, the highest flexibility ratio is evaluated positively.

Considering five criteria, the normalized decision matrix is presented below (see Table 4.6):

Table 4.6 Weight matrix

Weight matrix	Quality	Productivity	Cost	Transportation	Flexibility
	C_1	C_2	C_3	C_4	C_5
C_1	1	4	5	3	3
C_2	0.25	1	2	4	2
C_3	0.20	0.50	1	5	4
C_4	0.33	0.25	0.20	1	2
C_5	0.33	0.50	0.25	0.50	1
Total	2.12	6.25	8.45	13.50	12.00

Firstly, team members based on the targets and vision of Company X assess the weights for each criterion. While making this weighting, the analytic hierarchy process (AHP) is used. 1-9 Scale is used to prepare the weight matrix (see Table 4.7).

Table 4.7 The fundamental scale of absolute numbers (Saaty, 2008)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

The five criteria mentioned before are quality, productivity, cost, transportation, and flexibility. The weight of each criterion is calculated as 0.44, 0.20, 0.20, 0.09, and 0.08 (see Table 4.8).

Table 4.8 Weights of criteria

Weight matrix	Quality	Productivity	Cost	Transportation	Flexibility	Criteria weight
	C_1	C_2	C_3	C_4	C_5	
C_1	0.47	0.64	0.59	0.22	0.25	0.435
C_2	0.12	0.16	0.24	0.30	0.17	0.196
C_3	0.09	0.08	0.12	0.37	0.33	0.199
C_4	0.16	0.04	0.02	0.07	0.17	0.092
C_5	0.16	0.08	0.03	0.04	0.08	0.077

$$w = \sum_{j=1}^{5} w_j = \sum(0.435\,, 0.196\,, 0.199\,, 0.092\,, 0.077) = 1 \qquad (4.7)$$

Five different criteria for seven alternatives are evaluated by the team and presented in Table 4.9.

Table 4.9 Normalized matrix

Benefit	beneficial	beneficial	non-beneficial	non-beneficial	beneficial
Criteria	Quality	Productivity	Cost	Transportation	Flexibility
Criteria weight	0.44	0.20	0.20	0.09	0.08
A_1	5	6	7	8	9
A_2	3	4	5	7	8
A_3	9	7	5	8	5
A_4	3	5	6	4	8
A_5	2	3	7	9	5
A_6	4	6	7	3	6
A_7	8	7	3	6	4

Based on equation (4.3), the calculated normalized values are shown in Table 4.10.

Table 4.10 The normalized decision matrix R.

	Quality	Productivity	Cost	Transportation	Flexibility
A_1	0.35	0.40	0.45	0.45	0.51
A_2	0.21	0.27	0.32	0.39	0.45
A_3	0.62	0.47	0.32	0.45	0.28
A_4	0.21	0.34	0.39	0.22	0.45
A_5	0.14	0.20	0.45	0.50	0.28
A_6	0.28	0.40	0.45	0.17	0.34
A_7	0.55	0.47	0.19	0.34	0.23

Based on equation (4.4), the weighted normalized decision matrix is constructed (see Table 4.11).

Table 4.11 The weighted normalized decision matrix V

Criteria	Quality	Productivity	Cost	Transportation	Flexibility
A_1	0.151	0.079	0.090	0.041	0.040
A_2	0.091	0.053	0.064	0.036	0.035
A_3	0.272	0.092	0.064	0.041	0.022
A_4	0.091	0.066	0.077	0.021	0.035
A_5	0.060	0.040	0.090	0.047	0.022
A_6	0.121	0.079	0.090	0.016	0.026
A_7	0.241	0.092	0.038	0.031	0.018

The next step is to determine the minimum and maximum values in each column of the weighted normalized decision matrix. According to beneficial or non-beneficial criteria, maximum and minimum values are selected.

The criteria of cost and transportation are non-beneficial. So the minimum values are selected because the cost and the transportation are minimized. In this consideration, the ideal solution A^* is determined as:

$$A^* = [0.272 \;\; 0.092 \;\; 0.038 \;\; 0.016 \;\; 0.040]$$

and the negative ideal solution is determined as:

$$A^{-} = [0.060 \;\; 0.040 \;\; 0.090 \;\; 0.047 \;\; 0.018]$$

By using equation (4.5), the distance from ideal solution matrix is constructed as below Table 4.12.

Table 4.12 The distance from ideal solution matrix

Alternatives	S_i^+
A_1	0.134324875
A_2	0.188309121
A_3	0.040426095
A_4	0.187111411
A_5	0.226523747
A_6	0.160456076
A_7	0.040426614

By using equation (4.5), the distance from negative ideal solution matrix is constructed as below Table 4.13.

Table 4.13 The distance from negative ideal solution

Alternatives	S_i^-
A_1	0.101349907
A_2	0.046445678
A_3	0.219356707
A_4	0.052421409
A_5	0.004393901
A_6	0.079045678
A_7	0.196061862

According to Step 5 and equation (4.6), calculation of the relative closeness to the ideal solution is stated in Table 4.14.

Table 4.14 The relative closeness to the ideal solution

Alternatives	C_i^+
A_1	0.43
A_2	0.20
A_3	0.84
A_4	0.22
A_5	0.02
A_6	0.33
A_7	0.83

According to TOPSIS technique, the preference order of seven alternatives are ranked according to the C_i^* values. Then, the alternatives are ordered as follows: A3, A7, A1, A6, A4, A2, and A5 (see Table 4.15).

Table 4.15 Rank of alternatives

Alternatives	Rank
A_1	3
A_2	6
A_3	1
A_4	5
A_5	7
A_6	4
A_7	2

As a result, the order of the action plan steps is revealed effectively. As a result of this evaluation, Alternative 3 (Usage of computer based forms for recording of nonconforming material) is the first action, because it has the shortest distance to the ideal solution.

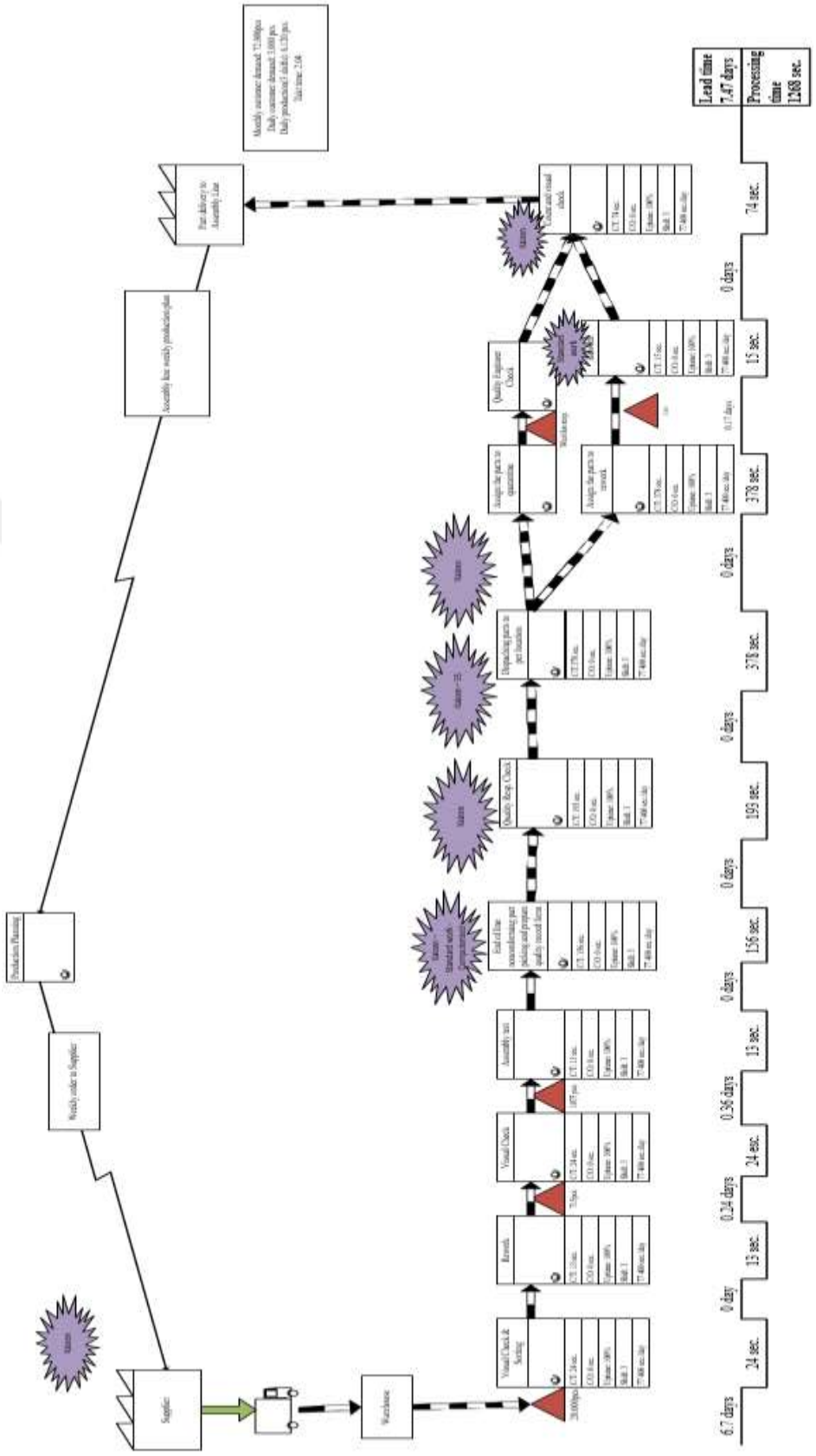


Figure 4.8 Company X future state map

4.3.7 Execution of the Plan

The improvements are marked in Figure 4.8 and the order of corrective actions to be taken in this regard is revealed. In addition, as indicated in Figure 4.8, the improvement actions are applied in the future state map, respectively. The activities carried out for improvement are detailed below.

Action 1 and 2: "Creating computer based forms to record of nonconforming material" and "Maintaining standard error codes for the product family" are conducted simultaneously.

- Error codes of nonconforming material are analyzed for the period of past six months from the start of July, 2019 to the end of December, 2019 for pump A. During this study, lots of suspected parts are identified as "*other reason*".

- Then, the main defect codes and sub-codes are defined. The main codes are mentioned in Table 4.16.

Table 4.16 Company X defect codes.

Number	Error Code
1	Crack
2	Scratch, crushed part
3	Trial part
4	casting cavity
5	Supplier Related defect
6	Missing part
7	Extra part
8	Machining defect
9	Lamination
10	Control Gauge Error
11	Assembly Error
12	Oxidized Part
13	Rusty, Stained Part
14	Press Error
15	Sealing NOK
16	Test Part

- The nonconforming material recording form is examined in detail. A computer-based form is developed with the support of the IT department, taking into account the standards, the expectations of the company's customers and the company's KPI tracking system requirements. The new form is more user friendly. The identification of pumps, parts, shifts, operator ID and defect codes can easily be found on the drop lists. A sample image is available below (see Figure 4.9).

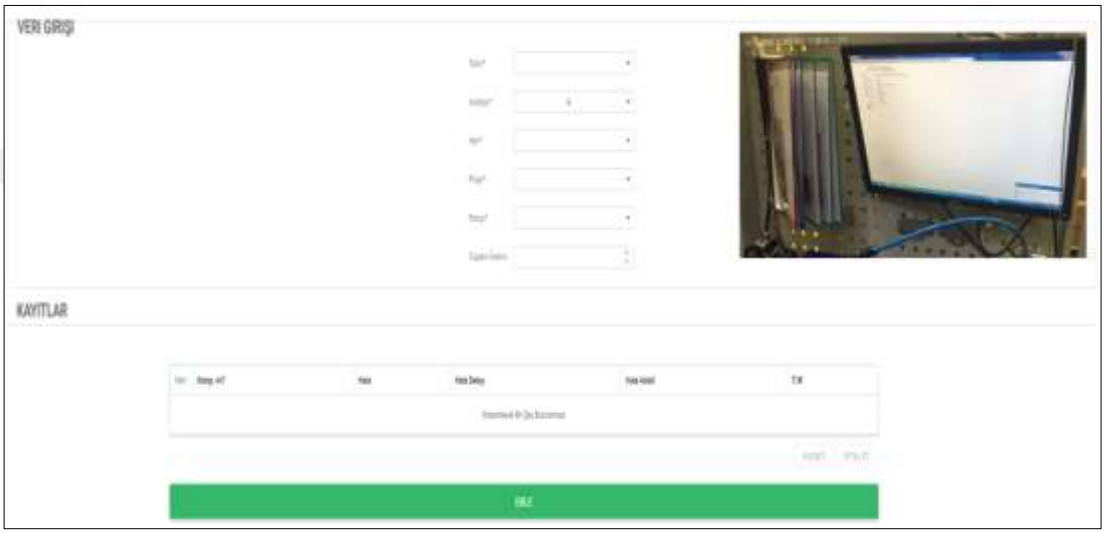


Figure 4.9 A view of assembly line display and nonconforming material report

- The lead hand in three shifts who are responsible for collecting nonconforming parts and filling the form are trained for the new computer based form. After a while, to be able to check if the study works effectively, a time study is conducted (see Table 4.17).

Table 4.16 Time calculation after improvements

Time Calculation of Value Added Activities				Measurement																													
			Shift	A										B										C									
Process step	# of Operator	Definition of process	Unit	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	Ave. $\bar{x}$ Normal time
1	2	Visual Check & Sorting (1 part)	sec.	20	22	27	23	22	26	21	22	23	23	23	20	21	21	22	24	27	23	22	20	28	26	32	24	22	28	28	24	26	26	24
3	1	Rework	sec.	12	11	14	11	12	12	13	15	17	12	14	13	13	11	12	12	13	12	12	11	14	16	14	14	13	17	16	14	13	11	13
5	1	Visual Check	sec.	20	22	27	23	22	26	21	22	23	23	23	20	21	21	22	24	27	23	22	20	28	26	32	24	22	28	28	24	26	26	24
7	-	Pump assembly (automation)	sec.	13																														13
8	1	End of line nonconforming part picking	sec.	128	62	130	123	28	36	42	60	27	20	102	84	82	70	82	59	37	28	58	37	67	34	103	24	51	66	60	112	103	122	68
9	1	Prepare quality record form	sec.	101	95	101	89	104	101	102	101	105	34	50	55	84	100	61	76	101	103	91	43	94	94	94	104	96	92	93	103	102	80	88
10	1	Quality Resp. Check	sec.	246	195	247	239	142	154	168	178	140	174	280	257	226	58	275	210	173	153	187	214	107	130	206	140	175	206	188	229	216	262	193
11	1	Transfer to counting desk and counting parts, dispaching parts to per location	sec.	448	337.5	414	341	231	448	438	453	315	341	319	246	416	448	388	391	448	448	344	400	289	304	418	319	353	386	364	429	418	441	378
13	1	Assign the parts to quarantine	sec.	384	347	356	306	315	476	454	456	384	371	247	110	379	572	307	376	457	477	360	378	396	385	400	387	380	375	375	386	390	363	378
14	1	Assign the parts to rework	sec.	384	347	356	306	315	476	454	456	384	371	247	110	379	572	307	376	457	477	360	378	396	385	400	387	380	375	375	386	390	363	378
15	1	Quality Engineer Check	sec.	638	553	649	616	498	557	553	578	521	474	594	529	588	441	610	565	571	544	551	536	496	509	633	518	547	596	574	628	620	641	564
16	1	Prepare rework instruction by Quality resp.	sec.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1	Rework	sec.	12	11	14	11	12	12	13	15	17	12	14	13	13	11	12	12	13	12	12	11	14	16	14	14	13	17	16	14	13	11	13
18	1	Transfer the parts to shelf	sec.	630	542	603	545	457	630	622	634	524	545	527	367	605	630	582	585	630	630	547	592	503	515	606	527	554	581	563	615	606	625	571
19	1	Count and visual check	sec.	99	74	74	71	50	86	94	92	59	70	64	32	89	98	82	78	82	92	73	90	46	52	63	62	74	62	59	84	78	84	74

Action 3 and 4: “Setting core rework instructions for standard error codes” and “Marking recovered parts” are conducted simultaneously.

- There is no standard work instruction for repeated rework operations. Therefore, the parts redirected to the rework process wait for a while for rework instructions to be prepared by the quality auditor. Besides, there is a waste of time while the parts are analyzed for the same error mode repeatedly.

- In accordance with past experiences, quality and production engineers prepare a catalog for visual defects and instruction for rework types of materials.

- Engineers train the rework operators with standard work instructions. The rework operators select the relevant work instruction while the nonconforming parts are transferred to recovery area. Then, the rework operator starts to the rework operation which is defined previously in the instruction. After a while, to be able to check if the study works powerfully or not, a time study is conducted. (see Table 4.17).

Action 5: Assigning material counting operation.

- After the nonconforming materials are collected from their relevant areas on the assembly line, they are counted and recorded on the form by the lead hand. The big parts are counted part by part. In other words, “eye” counting is used for big parts.

- On the other hand, for the small parts, eye counting is not a convenient method. Therefore, the lead hand makes a random decision for the number of small parts. This counting process is not reliable. So, the warehouse operator counts all the nonconforming parts one more time, before doing the system transitions.

- Due to unreliable and unnecessary counting process done by the lead hand, the lead hand will no longer count the parts. On the other hand, it is thought that it would be more suitable to separate the materials into packages/pallets at the end of

the line, according to the locations they should go. Hereby, the materials scrapped at the end of the line is directly noticed and counted first by a warehouse operator, and correct information is transferred to planning through ERP to keep the system up-to-date. After a while, the proposed process is monitored (see Table 4.17).

Action 6: 5S and transportation equipment and type.

- Currently, the time and energy spent on a pallet is quite high by using electric stacker. The collection time of the parts is long due to the large work machine and the lack of suitable intervals between the assembly lines (see Figure 4.10).

- The warehouse operator performs the part collection process whenever he finds the electric stacker empty and is convenient at that time.

- As a result of these findings, usage of manual trans pallets is proposed, which are flexible and easier to use, to transport small-sized nonconforming materials in production. Electric stacker is used for heavy materials such as body parts. A place is arranged outside the line in a way that the electric stacker could be reached.

- Additionally, the area where the warehouse operator pulls the pallets / packages for counting is also arranged according to the 5S rules.

Figure 4.10 Sample for an electric stacker and a transpallet

Action 7: Improvements for the supplier process

- In this study, it is predicted that the improvements to be made in the supplier processes for pump A causes a certain cost. The processes carried out in Company X must be transformed into an automated process on the supplier side, or the production method of the part must be changed by a design change. Due to the cost, the improvement activities on the supplier side are postponed at a further time.

- On the other hand, there is a way to develop the supplier. In order to make the control process in a more efficient way in the external source; Company X will provide training on accurate sorting techniques for the supplier. The aim of this action is to reduce the scrap yielded by the supplier.

4.3.8 Monitoring the Results

This study showed that processing time is reduced by %38. There is also a significant reduction in lead time. The processing time is reduced from 2044 seconds to 1268 seconds, and the lead-time from 8.7 days to 7.47 days (see Figure 4.11). This decrease enables the company to manage the nonconforming parts more effectively, thus the company can decrease the scrap cost and cost of poor quality. As a result, non-value added activities are reduced significantly.

Lean philosophy activities should be reviewed and tracked regularly by department managers and top management at least for every three months.

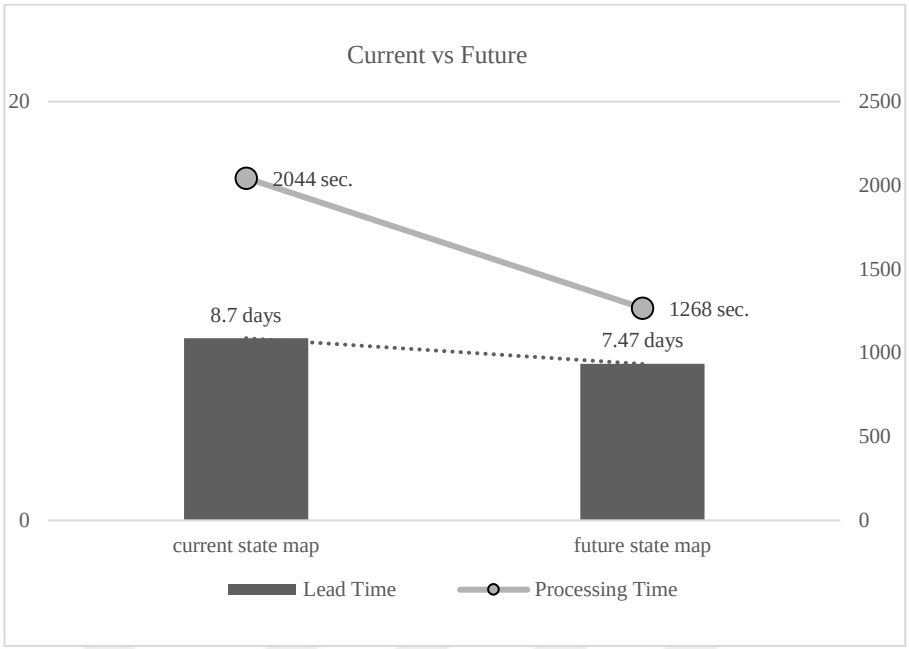


Figure 4.11 Comparison of current state to future state value stream map

CHAPTER 5
RESULTS AND CONCLUSIONS

Value stream mapping corresponds to very useful tool to identify non-value-added activities in the manufacturing industry. This study has discussed processes that take place in oil pump manufacturing and has highlighted problems that exist in the nonconforming material flow. The conducted study has stated the reason for keeping high stock in the management of nonconforming materials. The main and costly reason for the long lead time is based on the inability to obtain materials from external processes with zero defects. Unfortunately, the development of outsourced processes has not been conducted in line with the management's decision.

In terms of efficient use of time the product family has been selected at the beginning of value stream study. More than one method has been used for the selection of the product family. First, the Pareto analysis was used and as a result two pumps came out close to each other. In order to support this result, products with similar processes were analyzed. The same two pumps were revealed as in the Pareto analysis. Thereupon, internal quality claim ratio was examined and pump A was chosen as a product.

The flow of nonconforming material belonging to the selected pump A was examined. In order to make this examination, the material with the most errors among the parts of the pump A was selected. Then, monitoring was made in the production area and the necessary information and data were collected. The lead time in the current state map is 8.7 days. The value adding time was mentioned as 2044 seconds.

As a result of the values, the lead time was quite long for the nonconforming material. A future state map has been created to identify the problems and open items. Accordingly, improvement suggestions have been presented. Corrective actions were identified and management team evaluated with TOPSIS technique and decided the precedence of corrective actions and significant development activities presented in this study are as follows:

- Creating computer based forms to record of nonconforming material
- Maintaining standard error codes for the product family
- Setting core rework instructions for standard error codes
- Marking recovered parts
- Assigning responsible for material counting operation
- Improving 5S and transportation equipment and type
- Improving the supplier process and supplier product to avoiding extra operation in-house

In the light of the actions mentioned above, 15% improvement is achieved by a reduction in the lead time from 8.7 days to 7.47 days, and 60% improvement is achieved by decreasing the processing time from 2044 sec to 1268 sec.

This study has revealed a number of problems such as giving responsibility with lack of authorization, inappropriate layout and repetitive operations and handling, unnecessary transportation in the nonconforming material management in the automotive industry. To present a more efficient facility; companies need to work on solutions to develop more innovative and sustainable approaches. Value stream mapping was accomplished successfully, identified the main problems in the facility, and a visual mapping and observation method of material flows was used. Without the value stream mapping method, most of waste areas would be overlooked. Additionally, Lean philosophy activities should be reviewed and tracked regularly by department managers and top management at least for every three months.

In the literature review section of this study, studies with product families selected using the multi-criteria decision-making technique were encountered. Nevertheless, that multi-criteria decision-making techniques were not used to decide the precedence of the implementation of corrective actions. The TOPSIS technique, one of the multi-criteria decision-making techniques, was used in this study to determine the priority of corrective actions.

According to the conclusion of this study, the reason for keeping high stock in the management of nonconforming materials and the long lead time are based on the

inability to obtain materials from external processes with zero defect. In chapter four, according to the seventh action, high stock quantities will reduce and lead time will decrease to an acceptable level by taking the corrective actions.

Although the development and implementation phases of the study were carried out at the scheduled time, there were pauses in the monitoring phase due to the covid-19 epidemic. It was not deemed appropriate to internal material handling systems such as milk-run, which would take a long time to be commissioned due to the Covid-19 epidemic. In future studies, a milk-run study can be carried out for internal material handling systems.

Additionally, the techniques followed in this study are recommended to be applied within the scope of look-across activities in the near future for pump B, which is close to the pump A in product family selection. For the future studies, elimination of necessary but non-value added activities also can be considered.

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