DOKUZ EYLÜL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

# WASTE ELIMINATION THROUGH A3 REPORTING METHOD: AN APPLICATION IN A BRAKE MANUFACTURING COMPANY

by

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October, 2019

İZMİR

# WASTE ELIMINATION THROUGH A3 REPORTING METHOD: AN APPLICATION IN A BRAKE MANUFACTURING COMPANY

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**by**
**Duygu İNCİ**

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**İZMİR**

## M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"WASTE ELIMINATION THROUGH A3 REPORTING METHOD: AN APPLICATION IN A BRAKE MANUFACTURING COMPANY"** completed by **DUYGU İNCİ** under supervision of **Doç.Dr. DERYA EREN AKYOL** 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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**WASTE ELIMINATION THROUGH A3 REPORTING METHOD: AN APPLICATION IN A BRAKE MANUFACTURING COMPANY**


## ABSTRACT

In today's competitive business environment, there is an increasing need of businesses who aim to make a difference in order to maintain the existence and growth of their companies. For this reason, continuous improvement activities are emerged against to increasing number of actors in the market prices. By eliminating wastes, businesses can reduce their costs which are directly effective on value-adding process and profit. In this case, lean philosophy creates a solution to identify necessary activities and then eliminate unnecessary actions that cannot be evaluated as value-added. Furthermore, companies can increase the qualification of the use of labors and technological equipment to cause to make mistakes during production. Lean philosophy, which is described as "Lean Manufacturing System", achieves the whole emphasized continuous improvement actions by producing highest yield of product with minimum input. At this point, the A3 approach is one of the core methods involved under the lean philosophy followed by the Plan-Do-Check-Act (PDCA) cycle which allows continuous healing.

This study performs in a company that produces brake systems and approaches Muda elimination covered by A3 method. This method has been selected to reduce rework losses in the company. At the first step of the study, literature research was made on lean manufacturing system and experimental design methodology. In case of initial experimentation of the analysis, one of the problem-solving techniques called fishbone were applied. After, Pareto analysis was performed to understand the main root-causes of reworks on the surface roughness. The processing parameters providing the minimum surface roughness value were obtained by using the Full Factorial Experimental Design Method in addition to methodology part of this study.



**Keywords:** A3 thinking, lean philosophy, Toyota production system, muda elimination, full factorial experimental design, problem solving, PDCA

# A3 RAPORLAMA YÖNTEMİ İLE İSRAFIN YOK EDİLMESİ: FREN SİSTEMLERİ ÜRETEN BİR İŞLETMEDE UYGULAMA


## ÖZ

Günümüzün rekabetçi iş ortamında, şirketler, varlıklarını ve büyümelerini sürdürebilmek için fark yaratmayı amaçlamakta ve artan bir ihtiyaç duymaktadırlar. Bu nedenle, piyasa fiyatlarındaki artan rol oynayıcı sayısına karşı sürekli iyileştirme faaliyetleri ortaya çıkmıştır. İşletmeler, katma değer yaratma ve kar etme üzerinde doğrudan etkili olan maliyetlerini atık eliminasyonu ile düşürebilirler. Bu bağlamda, yalın felsefe, gerekli etkinlikleri tanımlamak ve daha sonra katma değer olarak değerlendirilemeyecek gereksiz eylemleri ortadan kaldırmak için bir çözüm oluşturur. Ayrıca, şirketler işçilik ve teknolojik ekipman kullanımının niteliğini artırarak üretim sırasındaki hataları azaltabilir. "Yalın Üretim Sistemi" olarak tanımlanan yalın felsefe, asgari girdi ile en yüksek ürün verimini üreterek, vurgulanan sürekli iyileştirme eylemlerinin tümüne ulaşır. Bu noktada, A3 yaklaşımı, sürekli iyileşme sağlayan Plan-Do-Check-Act (PDCA) döngüsü tarafından takip edilen yalın felsefede yer alan temel yöntemlerden biridir.

Bu çalışma, fren sistemleri üreten bir şirkette gerçekleştirilmiş ve A3 yöntemiyle kapsanan Muda eliminasyonunu uygulamıştır. Bu yöntem, şirketteki yeniden işleme kayıplarını azaltmak için seçilmiştir. Çalışmanın ilk aşamasında, yalın üretim sistemi ve deneysel tasarım metodolojisi ile ilgili literatür taraması yapılmıştır. Analizin ilk denemesinde ise, problem çözme tekniklerinden biri olan balık kılçığı yöntemi uygulanmıştır. Ardından, yüzey pürüzlülüğü üzerindeki paslanmanın ana kök nedenlerini anlamak için Pareto analizi yapılmıştır. Bu çalışmanın metodoloji kısmına ek olarak, minimum yüzey pürüzlülüğü değerini sağlayan işleme parametreleri Tam Faktöriyel Deneysel Tasarım yöntemi kullanılarak elde edilmiştir.



**Anahtar kelimeler:** A3 düşünme yolu, yalın felsefe, Toyota üretim sistemi, tam faktöriyel deney tasarımı, muda eliminasyonu, problem çözme, PUKO

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# CHAPTER ONE
# INTRODUCTION

Today, companies aim to obtain the highest profit by taking place in the market by adopting cost, time, and quality oriented approaches in the intense competition environment. In the global market, companies are open-minded to continuous improvement and they need to offer new products, services and solutions to the market. Companies that do not adopt this perspective lose their market share.

The TPS is also known as production without stock, or JIT production, and its most common use is "lean manufacturing". Since the beginning of the 1980s, it is a production system that is always in demand and in consideration. The success of many different companies with the use of lean production, increase the courage of other companies to switch to lean production.

Lean production has adopted the principle of not doing a single operation without added value throughout the production processes and removing all waste (muda) in the system. The lean manufacturing system built on this simple philosophy takes advantage of a wide variety of techniques and methods for its implementation. A3 reporting is one of these methods.

A3 Thinking is used to solve problems, gain agreement, mentor team members, and lead organizational improvements. that makes A3 methodology fundamental of Toyota’s benchmark management philosophy and to their lean production system. A3 Thinking builds improvement opportunities through experience.

The purpose of this study is to model surface roughness, which is one of the most important quality characteristics in manufacturing. In machining, minimum surface roughness values are a critical target to be achieved. Selection and estimation of optimum cutting paremeters for good surface finish and dimensional precision play a very important role in manufacturing quality and process planning. In metal cutting processes, machine operator's experience is generally relied on while determining the cutting parameters. However, it is difficult to determine the optimum values even if there is a good and experienced operator.

There are five chapters in the thesis.

In the very first part, in order to give an overview of the thesis, brief information about the lean production and the content of the study will be given.

In the second chapter, “Lean Production” will be introduced. General information about lean production, how it emerged and developed, comparison with other production systems, principles and techniques will be given.

In the third chapter, general information about A3 reporting which is the main subject of the thesis will be given. This section will cover A3 reporting studies in the literature. Studies on waste elimination will be explained.

In the fourth chapter, experimental design used in the analysis stage of A3 reporting will be given. In this study, Full Factorial Experimental design was used to minimize the surface roughness value by using the data obtained from a real system. In addition, experimental design that is mentioned in the literature will be discussed.

The fifth chapter is devoted to implementation. The solution of surface roughness problem was investigated by using A3 reporting methodology. Full Factorial Experimental design was used for problem solving. In the course of the study, detailed planning and realization of the experiments and finally the evaluation of the obtained data and results are given. The effects of cutting speed, cutting depth, and feed rate factors on surface roughness and the interactions between these factors are interpreted according to the experimental results. The most effective parameter levels affecting performance were found.

In the sixth chapter, conclusions and findings are given. The applicability and benefits of implementation of the study will be evaluated. The comparison with the examples in the literature and the gain provided to the literature will be discussed. Finally, suggestions will be made for future studies on this subject.

# CHAPTER TWO
# LEAN MANUFACTURING

## 2.1 Lean Manufacturing

Henry Ford, the founder of the mass production system, had the approach of "takes you wherever you want" and "choose the color you want as long as it is black" for his products in the 1920s. His approaches were highly demanded by the mass of customers who were not expecting customization. The Ford production system, the first modern assembly production system, produced one standard type of automobiles. Henry Ford considered the consumer of his time worthless, and he thought he could sell the products he produced effortlessly. For this reason, all losses in this inflexible production system are reflected to the customer and the consumer's comments about the products were not taken into account (Apillioğlu, 2016).

In the past, there were limited producers because of high production costs. There was an environment where the number of customers could be counted as unlimited compared to the number of producers, and this customer had to demand the goods for which the manufacturer provided the supply. With the beginning of the mass production system, the cost of production has declined at a high rate (Murat, 2016). This situation facilitated entry into the sector and created new competitors. With the increase in the number of producers, the number of customers increased in the same proportion, accordingly, the number of options for the customers increased in the same amount. Competition conditions had changed and producers had begun to produce what the customer wanted. The producers should also be able to meet customer demands alongside production efficiency, which is the only success metrics in the period they were in the market (Apillioğlu, 2016; Murat, 2016). In the new era, they had to develop flexible customer-focused systems.

At the beginning of the 1950s, Taiichi Ohno, who worked as an engineer at Toyota, in the light of Toyota's trip to the United States to study the Ford Company, showed that Ford's mass production system, which represents production in large parties pioneered since the turn of the century, is not applicable to production systems Japan (Apillioğlu, 2016). The Toyota team did not follow the new system that Ford followed up with a wrong decision, which was Mass Production, and headed for a different direction. The reason Toyota chose this way was that the market conditions in Japan were very different from the 1920's America, when Ford set up its mass production system. While Ford used the single Model T case at Highland Park, Ford's first factory, Toyota had to produce many different models, in small numbers. Because the Japanese automobile market was very small and divided (Ohno, 2008).

According to the post-trip assessment, mass production involves many unnecessary operation or waste (İpbüken, 2018). In all these circumstances, the extremely rigorous examination of the production processes under the leadership of Toyota Company Taiichi Ohno and Shigeo Shingo led to the emergence of the so-called lean manufacturing system and its expansion into the whole world (Ohno, 2008). Since the origin of this model is accepted, this production system is called the Toyota Production System.

"The Machine that Changed the World," written by Dan Jones and Jim Womack during the 1985-1990 as a result of their research for the International Motor Vehicles Program (IMVP). Lean Thinking was first mentioned in that book. In fact, this study, which makes a serious comparison between the TPS and the Classical Production System that Henry Ford pioneered, is a real benchmark study by the American automotive giants about the Japanese Automotive Industry (Womack & Jones, 1998).

In Table 2.1 the comparison between the classic production system and the lean production system is presented. There are very profound differences between the two production systems, resulting from their objectives and organizational structures (Jackson & Jones, 1996).

Table 2.1 Differences between classical production system and TPS (Jackson & Jones, 1996)

| **Subject** | **Classic Production** | **Lean Production** |
|---|---|---|
| Planning | Forecasting (Push System) | Customer Demands (Pull System) |
| Production | Excess Inventory | Zero Stock |
| Standby time | Long | Short |
| Party Size | Wide | Small - Continuous Flow |
| Examination | Sampling | Control at Source |
| Allocation | Functional | Based on Production Flow |
| Flexibility | Low | High |

## 2.2 Five Principles of Lean Production

The basics of lean production with the five principles are, specify value, identify value stream, make the value-creation flow, embrace pull and strive for perfection (Womack & Jones, 1998). The value is determined according to the point of view of the customer. While defining all the steps during the value stream, steps that do not create value are eliminated. At the same time, value-creating activities are systematically organized. Lean Production is a methodology of thought that enables this value to be drawn, and in this way aims to achieve perfection.

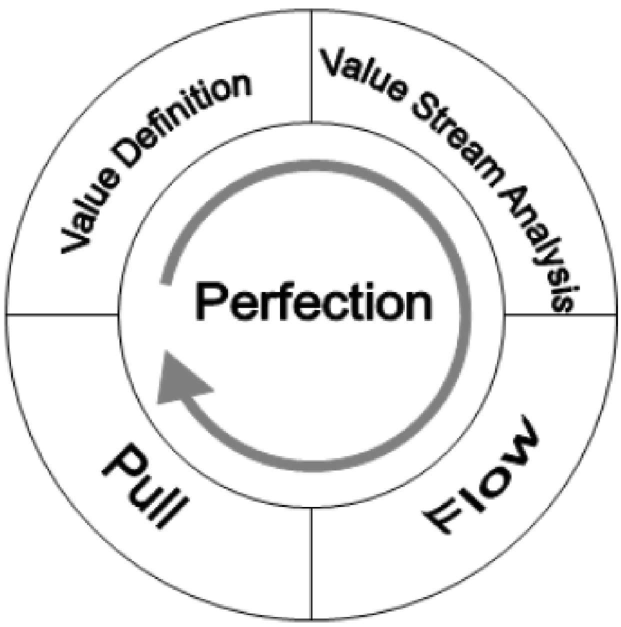



Figure 2.1 Principles of lean (Yingling, Detty, & Sottile, 2000)

### *2.2.1 Value*

The core of lean thinking are the concepts of "value" and "waste". At first glance, these concepts seem to be very simple, bringing a great effect to the transformation of an organization and increasing its competitive power when it is properly understood and used effectively together with lean tools (Ohno, 2008). A good understanding of the concept of value is the first and most important step to be taken in defining the Muda. Mudas are operations that consume resources without creating value.

Value is the activities involving product conversions that customers are willing to pay. Primarily the ‘value’ perceived by the customers must be determined. (Duggan, 2002)

Handicrafts in enterprises (manual operations) take place in one of the following three basic categories (Monden, 1983):

1. Waste: Actions that are completely unnecessary and must be removed immediately.
2. Non-added value, Inevitable work: Operations that are generally considered waste but may be required under certain operating conditions.
3. Added Value Work: Operations that increase the value of raw materials and semi-finished products due to the labor force involved.

As a result of the lean conversion studies, the value generating activities constitute only 5% of total activities. Activities that do not produce value constitute 75% of total activities. The remaining 20% includes activities that do not add value but should be done (Apillioğlu, 2016). These activities are tasks that does not add value to the product and the customer does not want to pay for, but it is necessary for the job to be done, such as adjustment, mold binding, waiting for the paint to dry out (Ohno, 2008).

Three basic concepts are used in defining waste in lean factories. These concepts are Muda, Muri and Mura. These three terms, commonly used together in the Toyota

Production System, and which collectively contain wastes that need to be eliminated, are referred to as “Three M” (Worth, Shuker & Keyte, 2013).

Muda are activities that do not add any value to the product or service, but only consume resources. Activities that do not create any value, but which are inevitable with existing technologies and production possibilities are called type 1 Muda. Operations that do not add value and can be eliminated by kaizen application are the type 2 Muda.

Muri is overloading equipment or operators, asking them to work with greater force and effort than the right workforce management and equipment design allow. It also includes working at a higher or more demanding speed for a longer period of time. This may have consequences such as malfunction, defective product, quality and safety problems. Muri may also be the result of unbalanced loading due to inefficient planning of resources. This problem, which is frequently encountered in a business that cannot compensate for fluctuations in production demands and customer demands, is called Mura, which means unbalanced load in Japanese (Worth, Shuker & Keyte, 2013).

**Seven Types of Waste**

In Toyota, Fujio Cho describes waste as; “Anything other than the minimum amount of equipment, material, space and workmanship required to add value to the product“. In short, everything that does not add value can be defined as wastage (Suzaki, 2005). Taichi Ohno, one of the founders of lean production, classified the waste in the value chain into seven types. These losses are seen in Figure 2.2.


Figure 2.2 Seven types of waste that Taichi Ohno classified (Ohno, 2008)

1. Overproduction:

There are two types of overproduction Muda. The first is to produce more than needed. Another is to produce more than necessary speed. Excess production often occurs when jobs are done fast. When this is the case, more raw materials are consumed and wages are paid for non-needy work, thus creating unnecessary stock. This requires additional material management and space for stock. Additional human, computer, vehicle, etc. may be required to carry and maintain stocks (Toyota Production System, 2006). Excessive production also increases the flow time that affects the flexibility of responding to customer requests (Rother and Shook, 1998). Overproduction is also the source of many of the other waste types (Ohno, 2008).

For example; transportation, stocking, loss of space, and scrapping due to non-availability are the direct cause of overproduction. It causes 5S incompatibilities due to being a source of clutter. It degrades the business operation and prevents hidden losses from being appearing.

2. Waiting:

Waiting is a wasted time for any work that does not add value. In practice, an employee waiting for a machine, or a machine waiting for the operator to run it, or it may be in the form of waiting materials in stock (Toyota Production System, 2006).

No value-added work is done; time is wasted. In practice, if an employee waits for a machine, or a machine waits for the operator to run it, or the goods may be in the stock, so that time will be wasted. (Ohno, 2008). The resource that comes in before the need of that resource will cause Muda in the stock class, and the resource that comes after the need will cause waste in the waiting class. For this reason, JIT, also known as non-stock production or inventory, is as important as being one of the two pillars of a lean house in lean production philosophy. This waste class leads directly to the prolongation of the process time.

3. Transportation:

Inventory multiplicity naturally leads to excess transport. Transport is the transportation of materials, parts, assembly parts or finished products from one location to another for any reason. Unnecessary equipment, raw materials, semi-finished goods and finished product transports are waste. Therefore, a single forward-flow line is installed to minimize the inter-process distance to the end product. For example; in a food company, packaging and shipping units must be located one after the other, in the shortest distance. Long distance or wandering is a waste of work and time. (McBride, 2003).

4. Non-Value-Added-Processing:

Business steps that do not create added value and / or transactions that do not add value to the customer are waste. It is a waste to put more work or labor on a part than the customer needs. Processing waste is unnecessary operations and processes. The increase in errors results from inappropriate or invalid operations or processes. Increased labor hours result in process waste and errors (Ohno, 2008).

5. Excess Inventory:

Inventory is products that are waiting inside or outside the factory at any time. The stock of anything is inventory. The inventory includes raw materials, in-process work, assembly parts and finished products. Everything that is held too much for work is wasted. Regardless of the raw material, production equipment, product and worker, stock should not be made more than necessary, need and demand. (Ohno, 2008).

6. Defects:

The waste of errors includes the errors themselves, the costs of inspection for the errors, the customer complaints and repairs. All this increases due to the errors themselves. Errors result in additional time, material, energy, capacity and labor costs (McBride, 2003). For example; data entry errors, reprocessing, lost or damaged goods, production scrap.

7. Excess Motion:

Unnecessary actions due to poorly organized work environment are wasted. This refers to the movement of employees and machines. Excessive movement in the factory may cause accidents, delays or material wear. (McBride, 2003).

### *2.2.2 Value Stream*

According to Lean Philosophy, value stream is the whole of the VA and NVA activities needed to bring a product along the main flows that are essential to each product. The value stream is all the steps needed to get past three management task in a product (Womack, Jones & Roos, 1990).

- Problem solving task: Includes detailed design and engineering studies, beginning with conceptual dimension and continuing until production begins.
- Information management task: This includes the period from receipt of orders until delivery and detailed scheduling studies.
- Physical transformation task: Involves the transformation from raw to final product.

The second principle of lean philosophy is the analysis of this value stream and the determination of waste. A comprehensive analysis and reinterpretation of the process of uncovering a product and / or service is defined as VSM. With value flow analysis, these wastes are determined, they are eliminated using various lean techniques and great improvements are obtained in terms of time and cost (Ohno, 2008). Figure 2.3 shows the costs that make up the total value stream cost. (Kittredge, 2003).

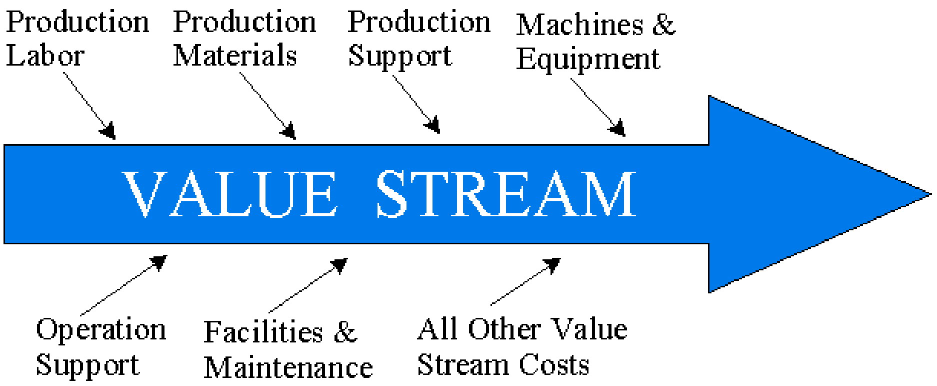



Figure 2.3 Stream costing (Kittredge, 2003)

### *2.2.3 Continuous Flow*

The value is defined by the client's point of view. So that analyzing the value stream is another basic principle of lean thinking, ensuring that after the elimination of the wastes, the activities that create the value are carried out continuously without any interruption (Ohno, 2008).

Once the rate of value-added activities in the process has been increased, it can be said that; carrying out these steps that create value in a systematic way can be described as "value stream". Providing continuous flow allows the entrants to quickly turn into cash. When continuous flow is applied, product development, order taking and physical production work will be completed in a very short time. This gives the customer the ability to design, plan and produce exactly what he really wants. In the application of the continuous flow principle, it is of utmost importance that efficient application of the one-piece flow system from lean tools (Ohno, 2008).

### *2.2.4 Pull*

In classical mass production, the processes that need to be done for design, production, or sales activities are grouped by type. Departments are created for each job type. The product starts to circulate with other products being processed between these departments. Because departments act independently of one another, each department sends the product it produces to the next stage, that is, it "pushes". This leads to intermediate stocks, delays, bottlenecks, errors not noticed or late realized. Creating a stream in the system is not enough alone. Producing non-demanding products with rapid flow will ultimately lead only to waste. Instead of pushing products that the customer does not want, it will remove many waste resources with ensuring that the product is being pulled at the customer's request. In lean thinking, the pull principle predicts that the value will be pulled from the source by the customer. Pulling means that no product or service is produced in the following stages, if the customer does not ask for it. The Pull principle begins with the demand that the final customer makes for a particular product. The product is produced in such a way that the production demands (pulls) from each previous stage, and ultimately starts the production. When this principle is applied; demand stabilize because customers becomes sure that they will be met on time and campaigns are not required to remove stuck goods. This principle can be used for the material flows between the stages of production within the company, with the suppliers in the supply of raw materials and with the customers in delivery of the final product. There are processes that do not produce the product without customer requesting for it. With this system, they "produce" by "pulling" the product from each other. The effective application of the Kanban and supermarket system from lean tools is crucial in the successful implementation of the pull principle (Ohno, 2008).

#### *2.2.5 Perfection*

Manufacturers and service providers recognize that there is no upper limit of the improvements in terms of time, cost and mistakes when defining the value correctly and questioning every single step of the value stream, allowing the product to continuously flow through the stages creating value and attracting customers without operating the value. No matter how many times the improvement activity is repeated, new ways can be found to further reduce waste every time it is repeated. This is the other principle of lean thinking, expressing the quest for continuous improvement and perfection. When a lean approach is applied, it can be seen that the parameters such as labor productivity, time to complete the job, stocks, faulty products reaching the customer and scrap rates, the product presentation period, etc. all improve. In the search for excellence, the PDCA (Plan-Do-Check-Act) cycle is effectively applied (Ohno, 2008).

TPS is based on the elimination of all factors, primarily human and all resources, in the most efficient way, eliminating all unnecessary operations, in other words, all the factors that increase costs but do not have any added value effects (Okur, 1997).

### 2.3 PDCA Cycle (The Shewhart Cycle)

The PDCA cycle is commonly named as Deming or Shewhart cycle (Cowley & Domb, 1997). The Shewart cycle is the repetition of a four step activity. A concise explanation of the Shewhart cycle by Mary Walton (1986) is as follows:

- Step 1: The very first and most critical step is the planning phase. At this stage, it is decided by whom, why, how, where, when and how long the planned work will be performed. Consideration of each point in the planning phase, proper assignment of tasks and objectives, will minimize what will be done in the last step.

- Step 2: It is the stage in which the planned activities are carried out in the specified person, method, and times.
- Step 3: The extent to which the planned objectives have been achieved is determined.
- Step 4: The reasons for the differences and deviations between the planned activities and the practices are investigated and activities aimed at eliminating them are initiated. It contains the PUKO cycle in itself.

Some questions need to be answered correctly before implementing the Deming cycle in the company. First of all, it is necessary to decide which change will be tried. This also shows the Plan stage of the cycle. There may be many ideas to choose from, but they need to understand that it is more important for company employees to learn about the process than to predict the right answer. Thus, the environment where employees can blame someone for wrong guesses is not created. Change can sometimes make things worse, but it can also help to achieve better. Evaluating the following questions before performing the change will be useful for the development of companies (Kerridge & Kerridge, 2000):

- Can the process be tested on a small scale?
- Are the effects reaching with a logical speed?
- Is it easy to measure?
- Do the tests require new measurements or are the resulting measurements satisfactory?
- Has the measurements been studied?
- Is it easy to perform this test?
- Will the tests take a long time?
- Do the tests cause disturbances in the existing process?

Due to human nature, we act for continuous improvement. As in human history, it is possible to see this in our daily life. For example, we make improvements through the PDCA cycle when cooking. We plan the food, cook it and then taste it if it's not what we want, we'll determine what we're going to do next. Thus, the cycle of improvement in each cooking is repeated until we get the food we want.

### 2.4 Lean Production Techniques

Lean manufacturing techniques cover the basic processes in the implementation of the TPS. Although it is not possible to limit these processes, the most fundamental techniques of lean production are mentioned in this study. The techniques of the lean manufacturing system are given in Figure 2.4.

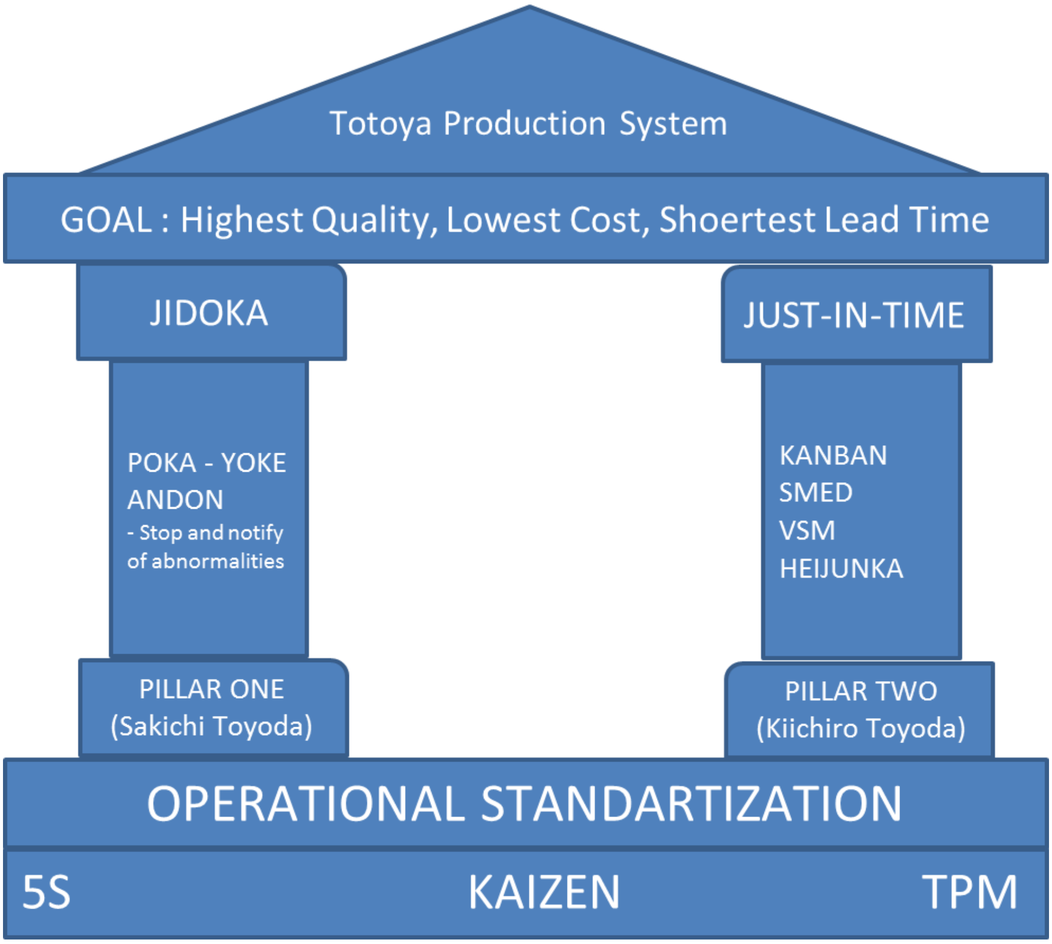



Figure 2.4 The lean manufacturing house

### *2.4.1 Continuous Improvement (Kaizen)*

Kaizen, consisting of the words “Kai” and “Zen”, means “Continuous Improvement” in Japanese. The main idea of Kaizen is to continuously find and implement small improvements in the areas around, as a team or individually. The Japanese have given themselves a significant competitive edge thanks to their Kaizen (continuous improvement) approach in production. They have maintained their industrial dominance in the world market for a long time by continuing to make more competitive products. The source of continuous improvement process is Kaizen philosophy (Apillioğlu, 2016). If we think of the Kaizen philosophy as an umbrella, it is possible to see the units in Figure 2.5 below this umbrella.

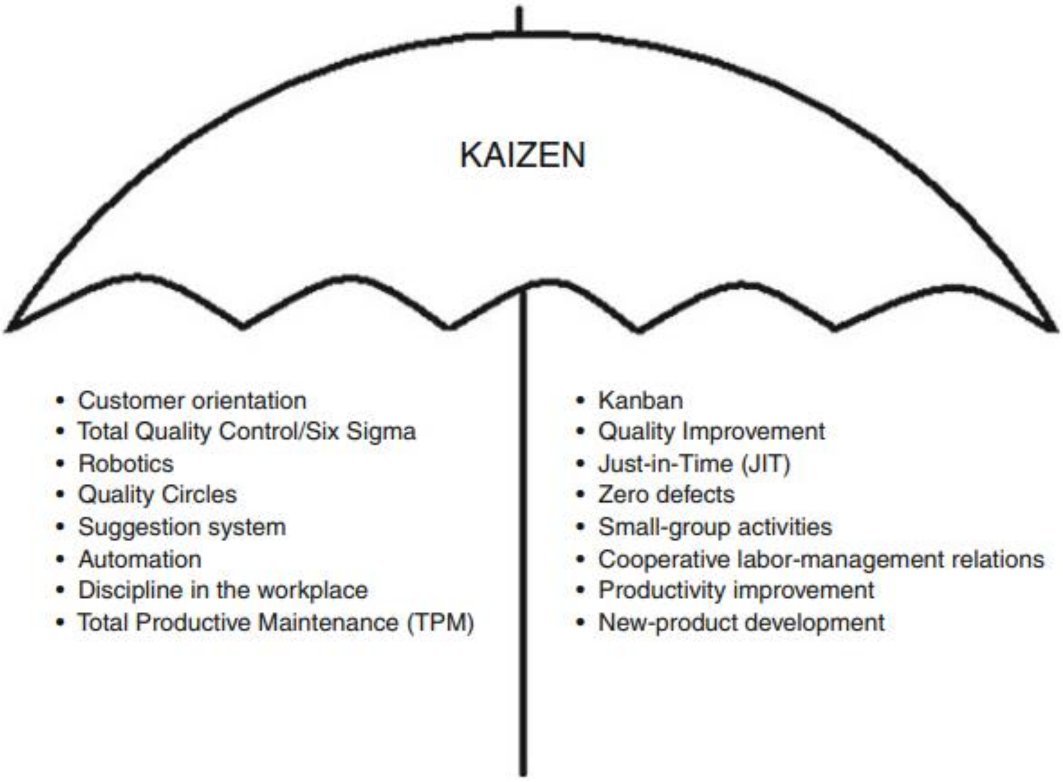



Figure 2.5 Kaizen umbrella (Imai, 2013)

For continuous improvement applications, the PDCA cycle is used as a general framework. In the process of continuous improvement, decisions are made according to the facts obtained from healthy data, not according to the beliefs, thoughts and assumptions of the individuals (Şirvancı, 1993). An enterprise in their “Continuous

Improvement" process increases its performance both in short and long term. The rapid increase in productivity and the increase in the market share provided by high competitive power increase the enterprise's income and create new investment opportunities. Additional financial advantage provided by increased capacity and production (reduction in unit costs) further increases competitiveness (Kavrakoğlu, 1994). The benefits of continuous improvement are summarized below (Şimşek, 2000);

1. Vitality occurs in all activities.
2. Unity of purpose and aim is ensured in the company.
3. The level of knowledge and skills of the employees develops continuously.
4. Employee motivation increases.
5. The common problems of the units in interaction are solved in the shortest way and permanently.
6. Production and other competitive elements show a faster development.

There are two opposing approaches to continuous improvement: the progressive progress approach (Kaizen) and the approach to progress in one major step (Innovation). Western companies prefer one major step approach, while Japanese companies generally prefer the progressive approach. "Innovation" emerges as the main changes following the technological breakthroughs or the application of the latest management concepts or production techniques. "Innovation" is impressive and a true focus of attention (Şimşek & Nursoy, 2002).

On the other hand, "Kaizen" is not striking at first glance, it shows its effect slowly, and its results are often not immediately noticeable. Innovation and Kaizen can be compared to the story of rabbit and turtle. Rabbit is a process of innovation with great steps. The turtle is Kaizen, but progressing in small steps. Both are required for the continuous improvement ecosystem to be created in the company. The Japanese have used Kaizen not as a substitute for the Western sense of Innovation, but as a complementary method (Şimşek & Nursoy, 2002). Figure 2.6 shows the effect of kaizen applications on innovation.

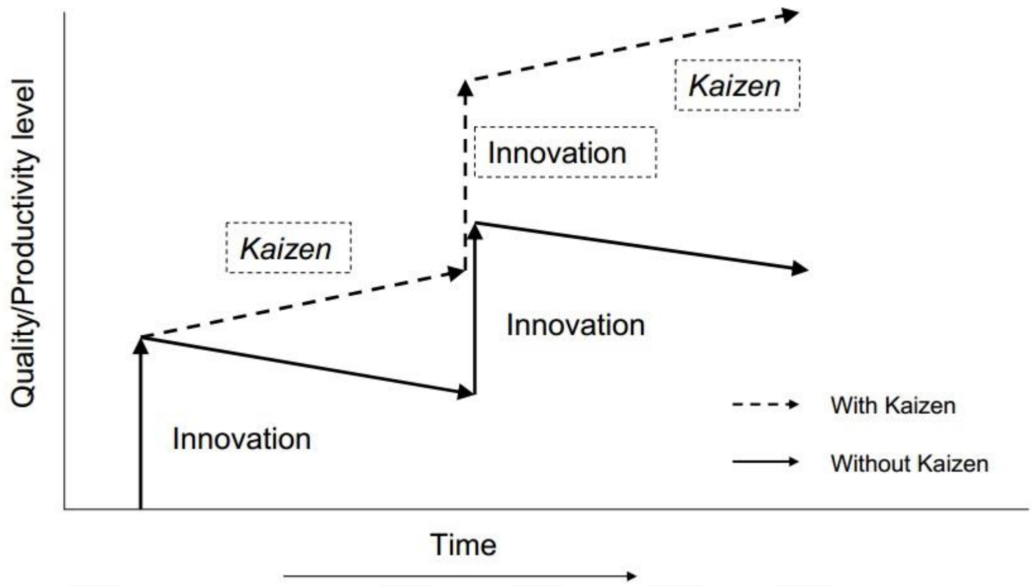



Figure 2.6 The effect of kaizen applications on innovation (Imai, 2013)

### *2.4.2 5S*

5S is a systematic approach that enables employees to participate in workplace cleanliness and order, creates a quality work environment in organizations and ensures its continuity. The 5S method forms the basis of all improvement techniques in the production or service industries. Especially because it is easily applicable and understandable method, participation of employees can be easy (Kılıç & Ayvaz, 2016). It consists of 5 Japanese words beginning with the letter "S". These words and their meanings are as follows:

1. SEIRI: Sort
2. SEITON: Straighten, Set
3. SEISO: Shine, Sweep
4. SEIKETSU: Standardize
5. SHITSUKE: Sustain

In Table 2.2, the meanings and explanations of the “S” which constitute the 5S system are given.

Table 2.2 The 5S methodology and objectives

| STEP | MEANING | OBJECTIVES |
|---|---|---|
| SEIRI<br>(Sort) | It is the stage where the necessary, unnecessary distinction is made and the working area is free of the materials and equipment that are not needed. | ➢ Determining the criteria. Adhere to these criteria to eliminate unnecessary.<br>➢ Determine priorities and frequency of use.<br>➢ To put kaizen and standardization on these foundations. |
| SEITON<br>(Straighten, Set) | According to the priorities of the materials needed to use, a layout plan is created. | ➢ Efficient planning and placement.<br>➢ Increase productivity by gaining the lost time that is lost searching for material. |
| SEISO<br>(Shine, Sweep) | For a cleaner working environment, the main purpose at this stage is to destroy garbage, dirt and impurities. | ➢ A level of cleanliness that meets the requirements, performing zero pollution.<br>➢ More efficient cleaning. |
| SEIKETSU<br>(Standardize) | These are the studies to ensure that classification, regulation and cleaning systematic to become a corporate culture and ensure its continuity. | ➢ Management standards to support 5S.<br>➢ Visual management that will reveal the negatives.<br>➢ Color coding. |
| SHITSUKE<br>(Sustain) | It is the regular control of the standards and regulations determined by the standardization step. | ➢ Create appropriate habits, complete participation and workshops following the rules.<br>➢ Creation of individual responsibility environment through trainings and audits. |

The success of the 5S system is the standardization and disciplinary stages. In the standardization phase, it is necessary to correctly define who will do the work in which period. At the disciplinary stage, 5S should be transformed into company culture through training and audits. At the same time, employees must establish order as a team in their common working areas. Teamwork is the key to success in the 5S system. Finally, as in all lean manufacturing applications, top management support is an indispensable element in the success of the 5S system.

### *2.4.3 TPM (Total Productive Maintenance)*

Manufacturers have recognized the need for continued improvement to ensure a successful competitive environment. In order to increase their business capacity, companies have started to invest in management approaches such as JIT, TQM. However, the benefits of these management approaches are often restricted due to the availability of reliable and inflexiable equipment. In order to eliminate this situation and to ensure continuous development, the efficiency of JIT and TQM applications has been increased and thus the need for a more effective application in the maintenance and repair of equipment has emerged. As a result, an entire company-wide equipment maintenance system "Total Productive Maintenance (TPM)" has started (Jostes & Helms, 1994).

Enterprises that used automation in the production, more widely in time, realized that it was impossible to maintain their factories by using traditional maintenance workers. As a result, the most current concept, TPM, was developed. In 1969, a Japanese company, Nippondenso, decided to develop TPM. Seiichi Nakajima, director of the Japanese Institute of Plant Engineers (JIPE) and founder of JIPM (japan institute of plant maintenance), promoted TPM outside of Japan and started to be named as the father of TPM. Since 1980, the TPM Management Approach has improved considerably (Gibson and the others, 1995), (Swamidass, 2000), (McKone and the others, 2001), (McKone and the others, 1999).

The "Overall Equipment Effectiveness (OEE)" measurement method is used as the basic measurement parameter of the TPM system. "OEE" letters are used as the abbreviated letters of "Overall Equipment Effectiveness" which are mentioned in international literature for benchmarking studies and also by companies that practice TPM in our country (Yanmaz & Çayır, 2005). Figure 2.7 describes the OEE calculation.

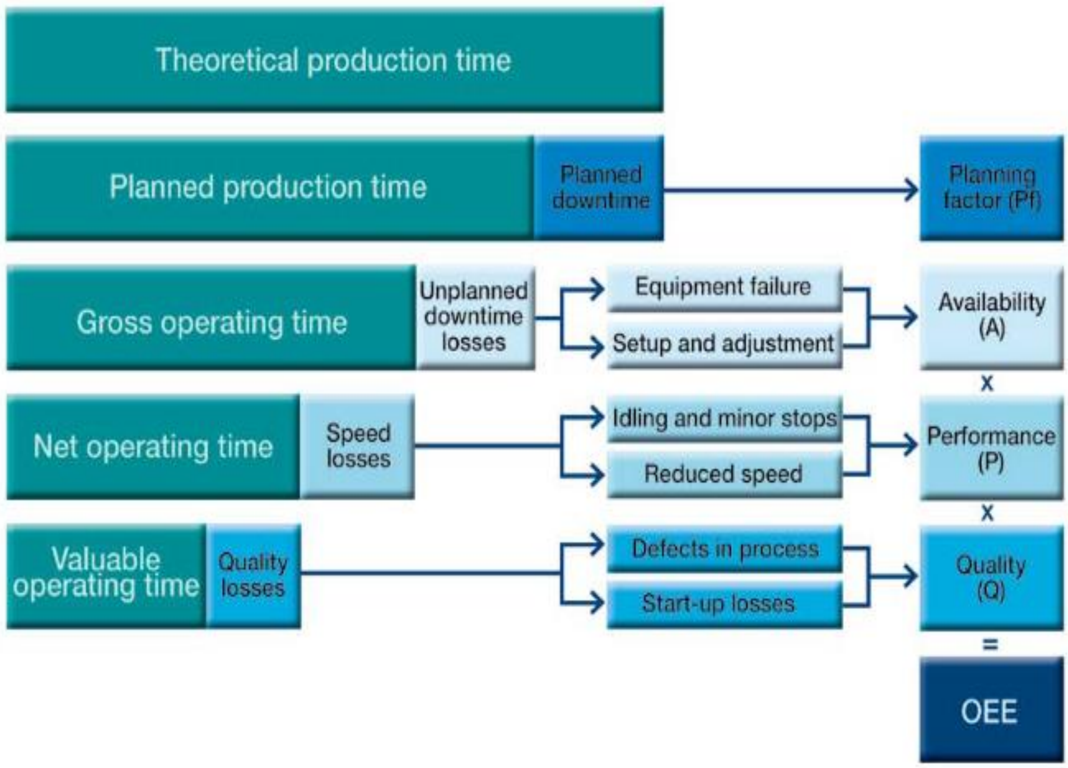



Figure 2.7 OEE (Güven, 2006)

The TPM Management Approach is focused on destroying 'six major losses'. In order to eliminate these six major losses that reduce the effectiveness of the equipment, the efficiency of equipment is maximized in the plant and the life cycle costs are minimized. These six losses are as follows (Chand & Shirvani, 2000), (Hipkin & Cock, 2000), (Swanson, 2001):

- Availability Loss:
  - Equipment Failure; It is the time that the equipment that breaks down loses during the period of non-production.

- Setup And Adjustments; If the manufacturing equipment produces more than one product, it is necessary to go for a model change. In order to change the model, it is necessary to change the mold, fixture, jig, equipment etc. on the machine. The time spent during this change is a loss of setup. Setup was not completed after the equipment is changed. It is necessary to adjust the equipment and adjust the fixture in order to produce high quality products. This is a loss of adjustment.

- Performance Loss:
  - Idling And Minor Stops; Some speed losses are immeasurably small and instantaneous, and it may take more time to record and analyze them than the time of loss. Examples are instant stops, such as tripping, momentary deceleration, speed fluctuations, material jamming, blockages, sensor blockages, sensor contamination, etc.
  - Reduced Speed; If the equipment is operated consciously or periodically slower than the ideal speed, or if it consciously tolerates production below its capacity, the equipment will lose speed. The loss of speed may be due to poor maintenance of the equipment, inefficient operator operation, equipment wear, installed or operating below its ideal capacity.

- Quality Loss:
  - Process Defects; Not all products produced by the equipment may be of good quality. Some products may be scraped and others may have to be re-processed. This loss is called scrap-re-processing loss because such products will in any case be stolen from the time of the equipment.
  - Reduced Yield; Some equipment, by their very nature, cannot produce good quality output, although they work until they are ready for production. This loss is frequently encountered in facilities such as ovens, paint shops, etc. Even if no setup is required, the equipment can produce scrap products before the production starts, or the plant is made

ready for production by deliberately entering scrap products into the equipment.

### *2.4.4 Poka – Yoke and Jidoka*

Poka-Yoke is a production planning and design technique that prevents the occurrence of errors that lead to customer dissatisfaction. For this reason, Poka-Yoke is customer-oriented, and prevents the possibility of errors from occurring. With Poka-Yoke, it is aimed to prevent or eliminate unwanted controller errors. This is the zero defect point targeted by Poka Yoke. Poka-Yoke is one of the important tools to reach zero error. "Pokayoke" is a Japanese concept which is composed of Poka (random error) and Yoke (avoidance, reduction) and is used together in terms of error avoidance. It is a method that was first introduced and developed by Dr. Shigeo Shingo in 1961. (Hinckley, 2007)

Poka-Yoke can take many forms, but the basic principles that apply to all of them are (Ulas, 2001):

- Each product should be checked.
- Errors should be detected as close to the source of the fault as possible.
- When an error is detected, the production line must be stopped immediately and necessary precautions should be taken to prevent the fault from occurring again.
- The process should be designed to prevent errors.

Autonomy (Jidoka), together with JIT, is one of the two main pillars of the Toyota Production System (TPS). Jidoka is the giving authority of stopping the production line to the worker and the machine. In short, it is to give the machine human intelligence and sensitivity. In other words, in the event of any abnormality during production, the designed system is activated and stops the machine or gives an audible or illuminated warning. With the participation of all of the employees, it is aimed to increase the efficiency of their equipment (Ohno, 2008).

In the Toyota system, when a faulty part is produced, the machine is stopped and the entire system shuts down. Following the removal of the defective part from the process, the process is continued again by the authorized persons. Corrective actions are implemented to eliminate the identified error and the error is completely eliminated. In short, when there is a problem in a machine or when a machine error occurs, the equipment, the whole production line and the workers are stopped. For the embodiment of the lean system; JIT and Jidoka are of special importance in TPS (Imai, 1986).

The most basic condition for lean production is quality in production. Whether or not a firm works according to lean production, the first item of many companies' agenda is often the subject of quality. However, there are such big differences between the firms that have adopted lean manufacturing and the conventional approach, in terms of the targets and the methods used; the concept of “quality” almost loses its meaning when it comes to most companies. Indeed, in many companies that continue to operate according to the conventional approach, the rate of excise between 1-5% is considered normal, while the minimum target for product quality in lean production is in the boundaries of ppm (parts per million). In other words, the rate of rejection is reduced to the level to be expressed by millions, not by tens, thousands or even thousands (there are faulty parts in every million parts, not in every hundred, thousand, or ten thousand). Even ppm is not enough, the ultimate goal is to reach the zero-defect point (Ulas, 2001).

Although the Poka-Yoke or Jidoka systems are extremely efficient, they are often considered an expensive investment. This situation causes most firms to avoid Poka-Yoke. Firms instead of Poka-Yoke are trying to put extra controls, which we call waste. Jidoka, on the contrary, does not always mean expensive investments. There are many applications done with simple hardware such as sensors.

### *2.4.5 Andon*

The elements that disrupt the production (material need, quality problem, failure etc.) cannot be delivered to the relevant units in time. Thus, the reaction times of the relevant units are prolonged. Since the records are not kept with proper tools, the desired information towards the past (production realization rate, reasons that hinder production, reasons that stop production, repetition rates, loss periods etc.) cannot be reached or can be reached very hard, or late. Employees cannot see their goals and actual performances in real time.

Andon is a system capable of signaling to machines and machine operators when any abnormal conditions such as equipment failure, lack of parts, or products produced other than specifications are generated. Andon means lantern or street lamp in Japanese. It can be in the form of an audible alarm, flashing lights, LCD monitors or cords that can be pulled by workers to call for help or, if necessary, to stop the production line (Krajewski, Ritzman & Malhotra, 2010).

Andon was first used in the form of light columns as seen in Figure 2.8. In later times, the lamp groups were transformed into lamp panels. With the development of technology, LED and digital panels became widespread. The growth of the size of the LCD monitors and TVs - with the price being reduced, not only the text, numbers, but also the graphical - pictorial warnings were included in the Andon system. This change can be seen in Figure 2.9.

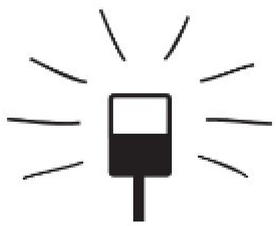


Figure 2.8 Basic andon (Marchwinski & Shook, 2006)

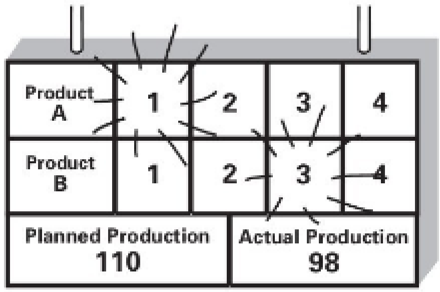



Figure 2.9 Complex andon (Marchwinski & Shook, 2006)

Andon is also a tool for revealing problems like Jidoka. However, unlike Jidoka, it serves to visualize the situation rather than a mission such as stopping the production. Andon is a subset of the Jidoka main column in the Lean Manufacturing House.

### *2.4.6 Heijunka*

The leveling of production with the use of the production volume and product type is called "Heijunka". "Heijunka" means "leveling" in Japanese (Liker, 2003). The balance of production (leveling-heijunka) is much more advantageous than the planned mass production system. Ohno stated that balanced production is fully confident in responding to the demand diversity that is more and more evident in the automobile market (Ohno, 2008).

As shown in Figure 2.10, a company produces A, B, C, and D models for leveled production with respect to part types. The weekly shirt request is five from the Model A, three from the Model B and two from each of the C and D Models. A mass producer who wishes to minimize model change between products produces these products on a weekly basis in the **AAAAABBBCCDD** scheme. A manufacturer of lean manufacturing has an idea about the negative impact of sending large and sparse batch orders to suppliers in previous processes. For this reason, by making improvements such as decreasing the setup times, performs repetitive production in the **AABCDAABCDAB** scheme. This series can be revised periodically according to changing customer orders or seasonality (Marchwinski & Shook, 2006).

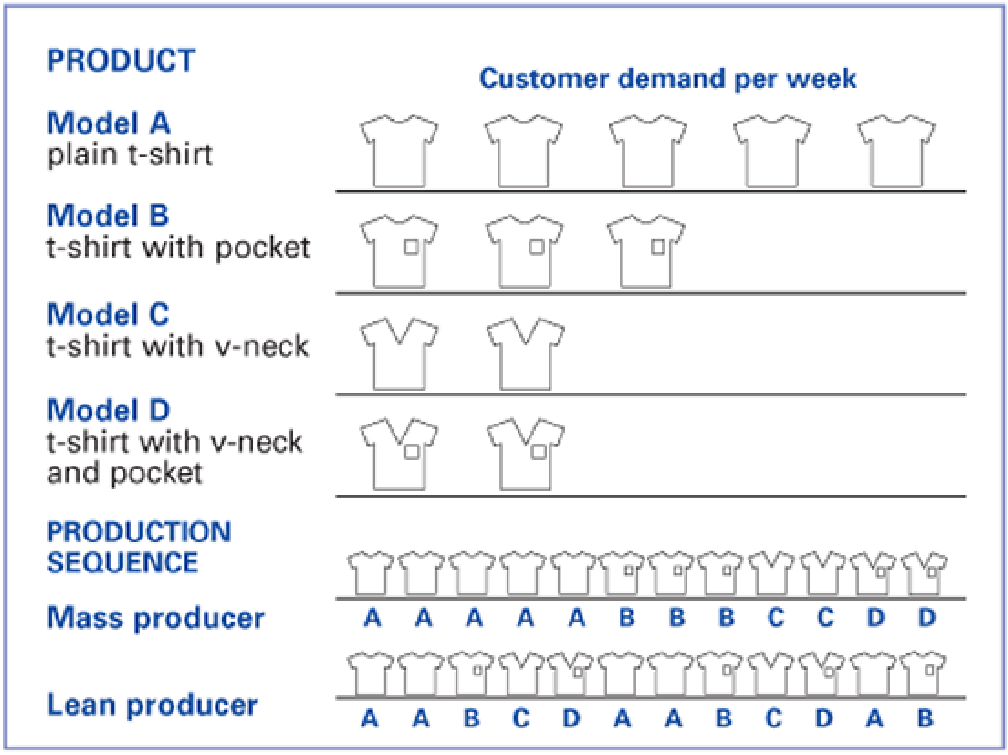



Figure 2.10 Heijunka by product type (Marchwinski & Shook, 2006)

Balanced production eliminates many problems caused by mass production. In his work named "Toyota Style", Jeffrey K. Liker summarized the benefits of Heijunka as follows;

- ✓ The main goal of Heijunka is to eliminate or minimize the negative effects of instant changes in customer demands on production (Liker, 2003).
- ✓ With Heijunka, the plant only manufactures up to the customer's order. Since the stock and storage are eliminated, there is no risk of goods that is not sold (Liker, 2003).
- ✓ The business calculates a part-based work requirement, determines a standardized work and levels the production. If there is a job that requires less effort after a work that requires extra effort, the workers can handle it. If the enterprise considers this and maintains a straight program, the balanced use of labor and machinery is ensured by Heijunka (Liker, 2003).

- ✓ If the company uses the JIT system in the processes of resource management and the suppliers deliver a few times a day, the suppliers will find a stable order patter. This will give them the opportunity to reduce their inventory and reflect some of their savings to the customer, so everyone will benefit from this leveling (Liker, 2003).

### *2.4.7 SMED*

Most of the firms that choose to work in stock are making this choice because of the long time of the model or mold change times and the adjustment times. According to this logic, as long as the model changing and adjustment times increase, the amount of stock needs to be increased so that the efficiency obtained from the machine is high, and the cost per unit piece is low. The tendency of the engineers who are reluctant to set up losses is to produce more parts (than the order amount) and keep them in stock (Ohno, 2008). SMED (Single Minute Exchange of Die), also known as fast die changing technique, is named after the initials of its name. Here, single minutes mean that reducing the model changeover time to a single digit time of less than ten minutes (Marchwinski & Shook, 2006).

In Formula 1 races, a tire change takes place that takes seconds, but determines that the race will be won and lost. Optimized F1 pit teams can change four tires in two seconds. An example is shown in Figure 2.11. Machine downtime is the equivalent of the F1 pit stop. It’s all based on the principles used for getting the car back racing as quickly as possible.

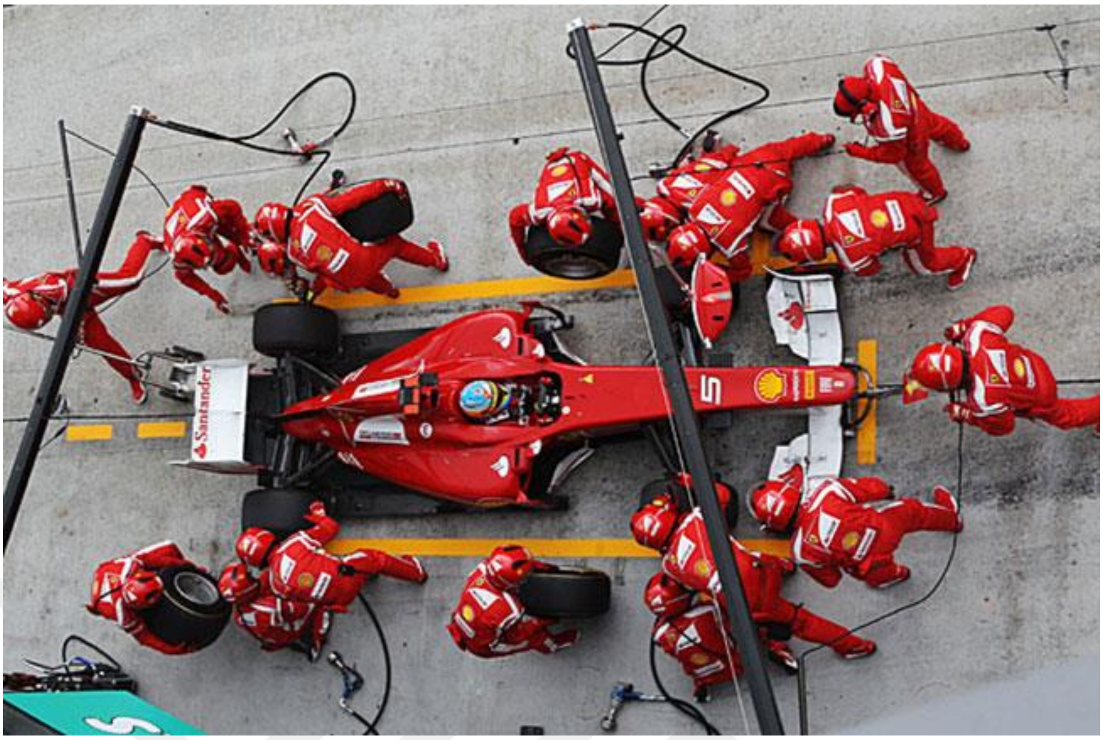


Figure 2.11 Pitstop and pit team (Pinterest, n.d)

The benefits of the SMED technique, which has the same logic as the pitstop logic, are the following (Tanık, 2010):

- ✓ Optimizes machine uptime.
- ✓ Makes small batch production possible.
- ✓ Reduces the time taken for manufacturing. This allows minimizing the amount of stock.
- ✓ Minimizes machine idle time.
- ✓ Thanks to the single machine adjusting and preparation process, it allows product transitions to be very serial.
- ✓ Leading the development of quality.
- ✓ It allows flexible production and delivery on time.
- ✓ Encourages design development.

The recommendation of Shingo (1988) with the SMED approach is to separate the internal adjustment operations that can only be carried out when the machine is off, from external adjustment operations that can be performed while the machine is running. The preparation time increases, as the operator is forced to operate on different parts of the machine and moves around, especially during the preparation of large machines. Therefore, the importance of parallel operations in such preparatory processes increases. SMED studies, mainly consisting of 3 stages, are shown in Figure 2.12.

Stage 1: Separation of Internal and External Set-Up
Stage 2: Converting the Internal to External Set-Up
Stage 3: Internal and External Adjustment Operations are Examined Separately from Each Angle

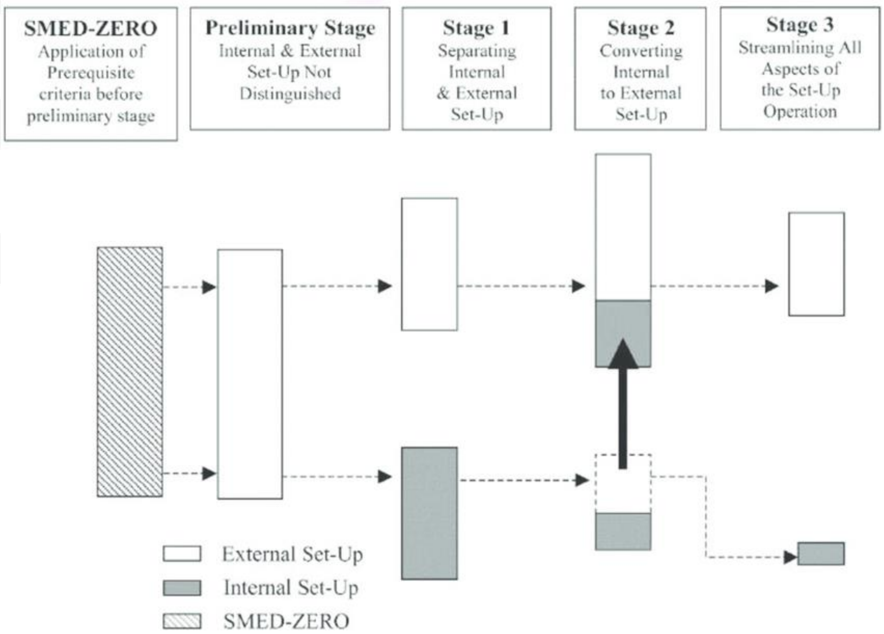


Figure 2.12 SMED stages (Shingo, 1988)

Internal Set-up activities are the activities that can be done or done during the standstill. In the course of external Set-up activities, the workbench works, that is to say, production (Marchwinski & Shook, 2006). For example, the next part of the workpiece to be worked on the workbench is brought to the workbench with the help of the crane by a process of preparation is a change in the process - while the machine is producing another part (workbench is working) - this process is called external Set-up. However, if the operator stops the workbench during the crane pick-up process, in order not to leave the machine unattended, the crane molding process becomes an Internal Set-Up operation.

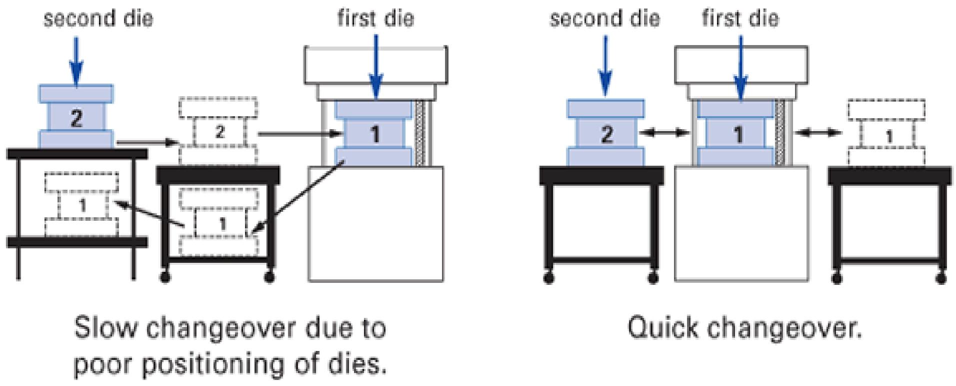



Figure 2.13 SMED example – Before and after (Marchwinski & Shook, 2006)

The SMED approach is generally an improvement that can be achieved by changing the way you look at the problem (not being able to change the model quickly) without requiring a significant investment. While no investment expenditure is required in steps 1 and 2, the purchase of some special equipment and tools in stage 3 may be on the agenda. In the SMED example in Figure 2.13, only the model change time improvement obtained by the method analysis study is seen. Finally, it is important to note that in order to say that we have obtained SMED, this should be available continually in practice, not in theory or supervision.

### *2.4.8 Kanban*

Managers in a business may prefer a push or pull system according to the flow of material in a process or supply chain. Kanban is a warning tool that gives authority and instruction to produce or transport materials in a pulling system. The term means "sign" or sign board in Japanese. Most firms using lean systems use the pull method, in which customer demand enables the production of a good or service. In contrast, in traditional systems, it often uses a push method that includes a production method without demand estimation and a customer order, which is contrary to the lean system (Marchwinski & Shook, 2006).

In the pulling system, the finished products are only offered to the market in the amount requested by the customer. In the push system, production is directed according to the future demand forecast. Changes in demand at a plant applying the pull system are transferred from the next process to the previous process. During the processes, if there are stock of finished and semi-finished products, this means, that plant implements the pushing system. In the pulling system, the information that will help us and enable us to decide comes to us as soon as we need it. Our information management systems work with the "pushing system" if we are getting the required standard information from other people, when necessary, by putting pressure on them (Emre, 1995).

In the Kanban system, supplier stations do not do anything before the demand for supply from the next station is reached. According to Krajewski et al. (1987), in the Kanban system, if the finished and continuing product is less than the desired number, the Work Centers are released to produce the order. Work Centers receive information from the signals such as a space or card. Kanban works according to the first in first out (FIFO) principle.

Kanban reduces circulating inventory and product. In this way, capital loss and wastage activities related to inventories are reduced. It prevents the set stocks in the inventory from being exceeded. Kanban increases flexibility in terms of changing customer needs and expectations. Greatly facilitates production management (Krajewski, King, Ritzman & Wong, 1987).

Kanban is named according to its place and purpose. The pull and production Kanbans are the basic Kanbans. Pull Kanban is the card used to determine the type and quantity of the piece that the next station wants to pull from the previous station. It moves between cells. The Production Kanban can determine the type and quantity of parts that the previous station should produce (Marchwinski & Shook, 2006). The Pull Kanban is used during different workstations starting from the last assembly line and as a final point during the "pulling" of the product or part between the factory and the supplier industries. On the other hand, the Production Kanban gives its workstations the start signal.

Kanban does not even need computer education systems. It is a system that the application is very simple, easy to understand, easily implemented, and does not incur additional costs. However, many problems are encountered in this practice. For example, a failed practice may be seen to have a negative effect on the outcome and causes resistance. All that is needed is cards, effective time planning and discipline.

### *2.4.9 VSM (Value Stream Mapping)*

One of the most effective methods for defining the value stream is the preparation of value stream maps. In Figure 2.14 below, the expected benefit from Value Stream Mapping is the ability to observe the activities that add value or do not add value while producing a product (Rother & Shook, 1998).

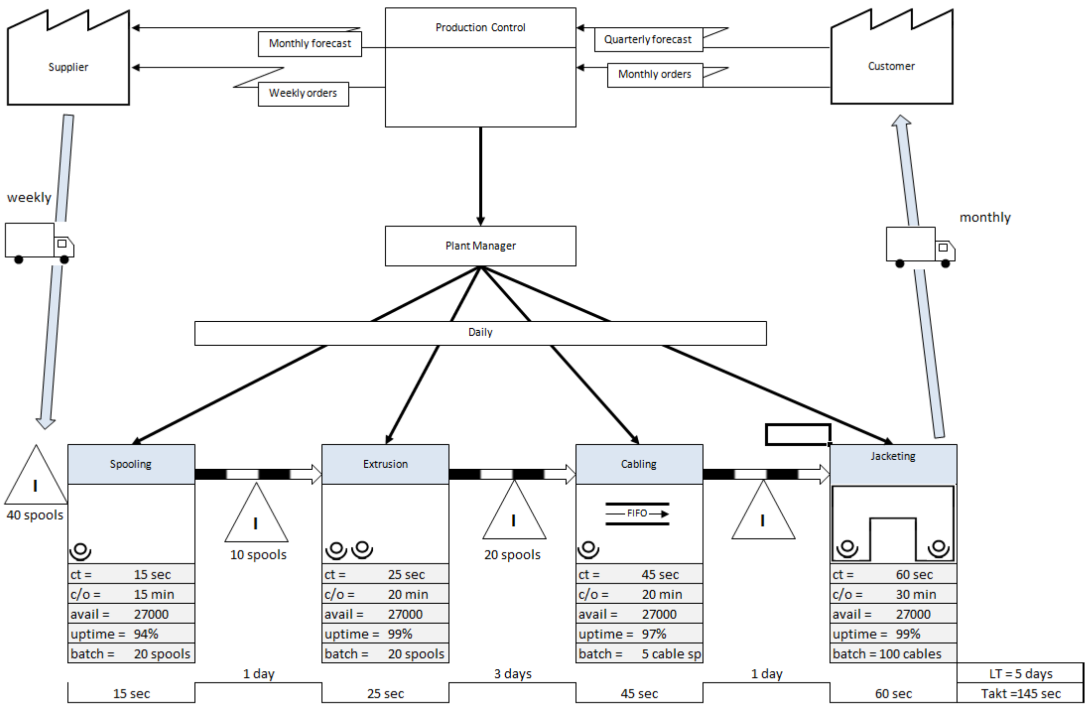



Figure 2.14 Example of value stream mapping – Current state (Rother & Shook, 1998)

Some questions are answered regarding the demand, material flow, information flow and supporting developments for the design of the future situation. An important value in these calculations is "takt time". Takt time is used to synchronize production speed with sales speed. The Takt time is calculated by dividing the working time that can be used in shifts by the amount of customer demand per shift (Rother & Shook, 1998).

In order to implement and drive a positive change in a given value flow, the necessary scientific and corporate culture components must come together. Leadership determines the organizational need in a broader perspective for a project. It also explains how the problem affects the organization and the scope of the project. In a typically three-day workshop, value-stream stakeholders draw a current state value stream map. They analyze the problems and propose countermeasures in the form of a future-state map. Typically, during the 30 to 120-day improvement phase, the team applies the changes to improve the performance of the value stream. They then check the results (Marchwinski & Shook, 2006). In the lean methodology, these changes are called "countermeasures" because they encourage continuous improvement of the process, unlike "solutions" which means a permanent correction (Worth, Shuker & Keyte, 2013).

# CHAPTER THREE
# A3 THINKING

## 3.1 A3 Thinking Process

Toyota emphasizes continuous improvement and problem solving. The A3 process is based on the principles of Edward Deming's PDCA(Plan-Do-Check-Act). The A3 report is so named because it is written on an A3 sized paper (metric equivalent of 11” x 17”). Toyota has developed several kinds of A3 reports for different applications (Marchwinski, Shook & Alexis, 2008).

While A3 basically follows the common path, the format and expression style is flexible. Many organizations change the design of A3 to suit their needs. A3 is similar to a resume that can be adapted to the layout, style, and features highlighted, depending on the type of job or the job seeker (Shook & Womack, 2010).

## 3.2 Steps of A3 Thinking

There is no “magic” in the steps through which the structured A3 Problem Solving template takes a team. These steps are basically (Shook & Womack, 2010; Bassuk & Washington, 2013):

- Identify the problem or need : A clear, focused, stand-alone statement that defines the problem (Bassuk & Washington, 2013).

- Understand the current situation/state: At this stage, it is explained what is already known about the problem and the topic (Shook & Womack, 2010).

- Develop the goal statement – develop the target state: the desired output is defined Shook and Womack, 2010). Targets need to be SMART (specific, measurable, attainable, relevant and timely) (Bassuk & Washington, 2013).

- Analysis (Perform root cause analysis): The reasons that make up the difference between the current situation and the target are analyzed in that section (Shook & Womack, 2010). The Root Cause Analysis section can accommodate either a Five Whys analysis or a Ishikawa (fishbone) diagram (Bassuk & Washington, 2013).

- Brainstorm/determine countermeasures: Countermeasures are suggested by the team to solve the problem or achieve the target (Shook & Womack, 2010).

- Create a countermeasures implementation plan: It specifies an action plan for who will do what, when, and when to reach the target (Shook & Womack, 2010).

- Check results – confirm the effect: A small pilot conducted over 1–2 weeks is recommended. Do the measured results match the predicted results (Bassuk & Washington, 2013) ?

- Follow up / Update standard work: This section contains a description of an audit plan, the results of the audit plan, and, if needed, recommendations for how the next A3 Reports will become standard work (Bassuk & Washington, 2013).

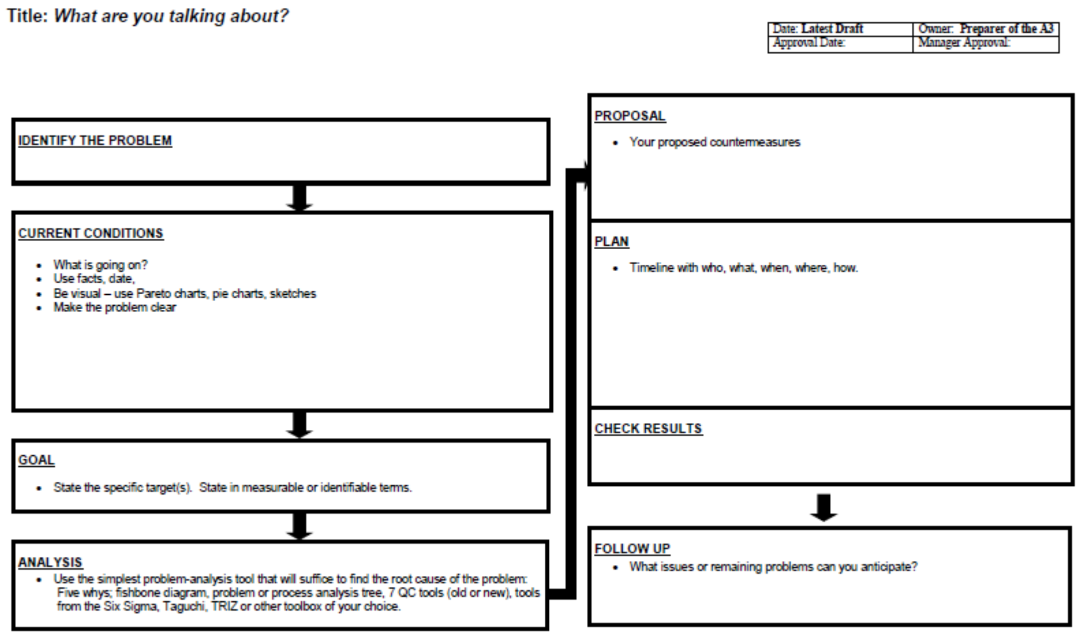



Figure 3.1 A3 thinking template (Shook & Womack, 2010)

There are many advantages to using the A3 approach as a standard technique. A3 report contributes to the problem solving process at company (Shook & Womack, 2010). Encourage people to identify problems and bring attention to them. It prevent to hiding problems, or pretending that there aren't any. Making problems visible is very important in lean philosophy. According to Taiichi Ohno, “Having no problems is the biggest problem of all.”

Many elements of the Toyota Production System were taken as keys to its tremendous success. However, the biggest success of the company instill an organizational culture of 'learning to learn' (Shook & Womack, 2010). In A3 problem solving, less is more. Complexity is not a mark of clear thinking.

In A3 reporting, the important thing is not the format itself, but the relevant process and thought structure. A3 reveals whether the problem has been solved or not by answering questions about the current situation, the nature of the issue (root causes), a set of possible countermeasures (solutions for root causes), the best countermeasure, and who will do what, and when to implement it. In the traditional management approach, superficial solutions are introduced to the encountered problems to save the day. Lean and A3 thinking system to move away from this approach, and get to the root of the problems. Preventing problems that may occur by taking precautions in advance, so that establishes systems with strong foundations.

## 3.3 Seven Elements of A3 Thinking

The mindset behind the A3 system can be divided into seven elements (Sobek & Smalley, 2008):

### *3.3.1 Logical Thinking Process*

Toyota first of all wants people to rationally think and act in problem-solving and decision-making processes. This is possible because the process involves cause and effect relations. The cause-and-effect relationships should be obtained with the help of PDCA cycle and scientific methods (Sobek & Smalley, 2008).

### *3.3.2 Objectivity*

Quantitative facts and data are used to define the problem. Facts and details are framed as objectively as possible (Sobek & Smalley, 2008).

### *3.3.3 Results and Process*

A3 thinking is a process that drives you results. Results without process lead to little long term value. Process without results fails to move to organization forward. It is important to balance between methodology and achieving results. This is related to how well the participants understand the problem and the effect of the solution on the big picture (Sobek & Smalley, 2008).

### *3.3.4 Synthesis, distillation, and visualization*

Brevity of reports forces synthesis of information to only the most vital points. A3 thinking encourages information through graphical representation to communicate the message clearly and efficiently. Graphical information, clearly and concisely stated, distills thinking to critical facts. It is a concise visual display of the information and data (Sobek & Smalley, 2008).

### *3.3.5 Alignment*

Inclusion of the problem, the analysis, the actions, and the follow-up plan gives all team members something concrete to agree or disagree with. A3 structure provides a vehicle for communication by having consensus of the problem causes and countermeasures at all levels (Sobek & Smalley, 2008).

### *3.3.6 Coherency*

A3 report structure establishes a logical flow that promotes coherency in the approach and thinking. Flow of the A3 promotes consistency across the organization, that speeds up communication and understanding (Sobek & Smalley, 2008).

### *3.3.7 Systems viewpoint*

The effect of countermeasures on the whole process should be understood. Countermeasures that can fix one problem to cause another should be avoided (Sobek & Smalley, 2008).

## 3.4 Benefits of A3 Thinking

Provides an easy-to-use approach to solve any problem type. Lets everyone know what it really means when everyone says "Let's do A3". Rather than seeking new ways to work together, it gives people the freedom to focus on the roots of problems

(Marchwinski, Shook & Alexis, 2008). The collaborative method helps to improve the communication and teamwork within the organization.

It also encourages people to identify problems. Unlike hiding problems or pretending to be nonexistent, it causes people to pay attention to them (Marchwinski, Shook & Alexis, 2008). In this way it contributes to the problem solving process.

Eliminates the habit of jumping to solutions before root causes are identified (Marchwinski, Shook & Alexis, 2008). Provides effective measures based on information and data and provides solutions. The goal is not to find fire-fighting solutions, but to prevent the fire from occurring. It clarifies the relationship between real problems and the measures to be taken.

It contributes to the training of new leaders. This is because the method shows the employee how to handle his/her job and his/her responsibilities (Marchwinski, Shook & Alexis, 2008). Encourages employees to take initiative and clarifies their responsibilities. The basis of this benefit is the mentoring environment created by A3 reporting.

It provides a systematic logical thinking process. It teaches people to see, understand and synthesize cause-effect relationships in visual, concise forms that everyone can understand at a glance (Marchwinski, Shook & Alexis, 2008). Contents can be made publicly visible and accessible.

Creating an organizational "learning to learn" culture is the most prominent benefit of A3 Reporting. Unlike doing just what is being said, it involves the use of more effective ways of thinking, working and learning together (Marchwinski, Shook & Alexis, 2008).

It contributes greatly to the continuous improvement process.

### 3.5 Basics of A3 Thinking

A3 reporting method is easy, but it will benefit to carry out the process based on some foundations.

The question of whether to use a pen, pencil or computer tools during the report preparation raises a discussion. Most experienced A3 practitioners prefer to write the A3 manually. However, today is the age of the computer, and an A3 created on the computer can be shared independently from the location (Shook & Womack, 2010). It can be said that the pen is the latest method of A3 reporting.

It is not correct to rely on the official elements when preparing A3 reports. The author will need to decide on a separate format in each case while the process is working. For these reasons, in some cases the A3 can have seven boxes, while the others may have four or eight boxes (Shook & Womack, 2010).

The best A3s are those that are carried with, marked if necerssary, and revised in gemba. The more an A3 creates healthy discussion environment, the more it will do its job. It is not important for everyone to speak the A3 language to begin the solution of a case. Only one should start using the A3 reporting. The different language can cause confusion and conflict. At the same time the A3 process can also be irregular, but it works (Shook & Womack, 2010). The controversial discussion proves that something is done right. As a result of the process, a scattered A3 report can be obtained, but the culture of "learning to learn" becomes widespread.

When participants say that they agree, send a copy of the agreed A3 report to the relevant units. Keep your agreed A3 report at your next meetings. Of course, participants have the freedom to change ideas. But one should not forget that if a participant wants to make a change in his/her position, this should be in the light of the decisions made before.

A large amount of data is stored through databases in the computer environment. However, the computer environment may be at risk of hosting data that people do not know how to translate into information. It should be noted that A3 reports serve not as data, but as a practical information sharing mechanism because they tell a story that has a flow.

### 3.6 Literature Review on A3 Thinking

In the literature, there are examples in various fields of study, such as education and service where A3 reporting is used. Loyd et al. (2010) conducted a study on the benefits of the A3 reporting method for academic use. This paper discusses the use of A3 reporting as a standard communication tool to reduce losses in teaching, learning and reporting processes. This is a study showing the benefits of the use of A3 reporting in education. Anderson et al. (2011) investigated the effects of A3 reporting method on learning process in their study. His studies included case studies conducted with an MBA class. At the end of the semester, the students in the classroom created several A3 reports on case analysis studies. It was seen that this reporting method improved students' communication and contributed positively for the teachers to review the cases easily. Bassuk and Washington (2013) designed the A3 report format in their practice at the Seattle Children's Hospital (Research Institute, Foundation) to perform measurable improvements of the problems identified by the author, sponsor and coach of the report. As a result of the study, it has been observed that A3 Thinking is a way to solve problems consistently as well as disciplined reporting. In their study, Ta and Xu (2017) discusses the difficulties encountered in conducting A3 reporting. It has been seen that problems such as not having sufficient root cause analysis and assigning more time than necessary to the action make the process cumbersome. Mobile application was proposed as an improved A3 reporting tool and 90% improvement was foreseen in this way.

There are also studies in the field of loss elimination in the literature. Zeng and Zhang (2014) aimed to eliminate losses with A3 report in order to act agile against customer demands. They have integrated ITIL (The Information Technology

Infrastructure Library) and A3 reporting and achieved promising results in terms of customer satisfaction. The study by Zeng and Zhang (2014) is seen as a loss elimination study in the service sector compared to this study.

Tortorella and Fries (2015) aims to use A3 reporting as a complementary method to facilitate problem solving in the general framework. In this study, A3 reporting was used together with LAMDA (Look-Ask-Model-Discuss-Act) method.

The only study on A3 reporting in Turkey is Çelepçıkay (2014) master thesis. The subject of the study is to detect and eliminate losses in the cross shipping unit. As a result of the A3 study, it is predicted that the average stock process will be reduced by 20%. In addition, employee overtime costs and product acceptance processes have been improved.

Svendsen and Haskins (2016) used A3 reporting as an integrated tool with root cause analysis. As a result of the study, A3 reporting was found to be a reliable tool as a problem solving technique. This is the only study in the literature that used A3 reporting for error elimination.

It is seen that A3 reporting technique has applications in many areas such as education and service. Its main objective is to improve the processes in which it is implemented. Some studies in the literature have aimed to improve the processes by loss elimination. However, there is no example in the literature regarding its use as integrated with TQM. It is a philosophy that ensures continuous improvement in efficiency and processes through learning. One of the main objectives of TQM is to make teamwork by ensuring that all employees participate in development activities. The goal is to combine both “thinking” and “practice için for employees at all levels. Therefore, it would be beneficial to use A3 reporting management, which is known as the lean instrument which forms the basis of total quality management and learning culture, in order to reduce error losses.

# CHAPTER FOUR
# EXPERIMENTAL DESIGN

## 4.1 History Of Experimental Design

It is possible to divide the history of the studies on experimental design into 5 periods. These periods:

- First period - before 1940,
- Second period - 1941 - 1950,
- Third period - 1951 - 1970,
- Fourth period - 1971 - 1990,
- Fifth period - 1990 and later.

The initial period of experimental design was found and developed by the British statistician Sir Ronald Fisher in the 1920s in order to improve the production efficiency in the agricultural field. In a short period of time, the method has been applied to improve production in the agricultural sector in the US and has made a major contribution to America becoming a leader in this field. Fisher also developed the "variance analysis" (ANOVA) method, which is now considered the main method for the analysis of experimental data (Şirvancı, 1997).

Fisher was followed by Yates in the following years. Fisher was followed by Yates in the following years. Yates made method analyzes on factorial experiments. "Yates Ranking", used under its own name, forms the basis of the experimental design (Tamhane, 2009).

The second period in experimental design includes the World War II. During World War II, a considerable amount of ammunition was used. Large quantities of bullets and bombs were required to produce in the factories to meet the need. However, there were serious accidents due to the explosion of these bullets and bombs during the production. Another consequence of these accidents, which cannot be ignored, is their effect on the change of balances in the war. In these years, in the science of statistics, studies on sequential analysis and distributions for the weapons industry were conducted (Cabuk, 2013).

In the third period (1951-1970), the idea of using statistical methods, especially the experimental design to improve quality in industrial products was firstly noticed by the US and then by other countries. This is largely due to the fact that, in general, statistical methods increase the quality of Japanese production (Köksoy, 2001). In the 1950s, the use of experimental design methods in the chemical industry was supported by the Box and colleagues' intense studies on reaction surface designs (Box & Draper, 1987).

Experimental design has been applied intensively in chemical and pharmaceutical sectors. However, there has been a very limited use in the manufacturing sector until the 1970s (Şirvancı, 1997).In the fourth period, after the conferences of W. Edwards Deming in Japan, on the philosophy and methods of improving quality and efficiency in the 1970s, these techniques were used by Japanese statisticians in the Japanese industry. With the use of experimental design techniques in the industry, it has been possible to develop high quality products at low cost (Köksoy, 2001).

In the United States, the manufacturing sector rediscovered experimental design in the early 1980s to investigate the causes of Japanese quality. The experimental design was conducted in Japan at that time under the leadership of Genichi Taguchi. Taguchi did not introduce theoretical innovations to the experimental design. However, he has made innovations in the applications in production and has ensured the acceptance of the method in the manufacturing sector with successful applications (Şirvancı, 1997).

Experimental design techniques have been used in the USA and Europe since the 1980s to provide quality at the design stage. Today, experimental design method is used for optimization and decision making in different areas (Hamzacebi & Kubay, 2003).

After 1990, modern age of experimental design has been begun. The further acceleration of economic developments has led to the development of competition and hence statistical methods. When the aim is to investigate and increase the efficiency and effectiveness in industry, agriculture, and all other branches of science, empirical studies have to be done.

Detailed information on product quality improvement will be given in section 4.5.

## 4.2 Description Of Experimental Design

In theory, a number of factors have the same effect on a process at the same time. However, the application of the experimental design is the most effective way to identify and optimize important factors and achieve a competent result with several experimental trials. The general model of a process or system is shown in Figure 4.1 While process variables $X_1$, $X_2$, ..., $X_p$ are controllable variables, $Z_1$, $Z_2$, .., $Z_q$ can be assumed as uncontrollable variables (Lunani, Nair & Wasserman, 1997).

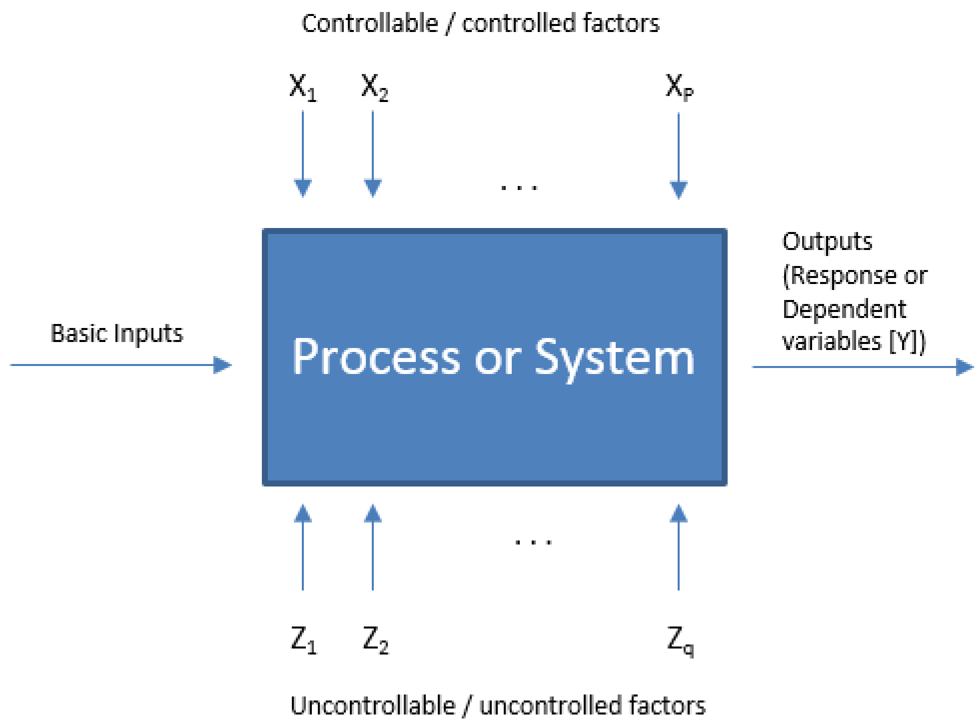



Figure 4.1 General representation of a system or process (Lunani, Nair & Wasserman, 1997)

The experimental design process consists of the following 4 steps (Montgomery, 1991):

1. Actual differences between the effects of factors that are supposed to be investigated, and the levels of these factors need to be determined.
2. In the experiment, it is decided how many repeats will be made for each factor.
3. The technique to be used in data analysis is determined.
4. The experimental data obtained with the determined experimental design are interpreted.

In the experimental design studies, full factorial design and Taguchi method are widely used. Increasing process productivity and reducing scrap and reprocessing rates are the forefront of efforts for product and process improvement. In order to improve the performance of existing products and processes, using experimental design method to examine output and input together gives effective results.

## 4.3 Basic Principles Of Experimental Design

In experimental design, the designer tries to evaluate the variability of the outputs, by changing the factors in a systematic way that affect the process. The success of the statistical experimental design depends on the accuracy of the collected data. For this reason, decisions such as how the data will be collected, and how many observations are to be made for each trial should be determined before the data is collected, at the design stage. The collected data must be independent of each other and sufficient to make a statistical interpretation. In statistical experimental design, there are three basic principles used to achieve these two conditions: replication, randomization and local control. (Özkurt, 1999).

### *4.3.1 Randomization*

It is environmental developments that occur randomly without being bound by a certain rule and order. Randomness assumes that every possible share of the experimenter has the same probability. If the tests are assigned to multiple levels of arguments, the order of assignment should be randomly selected. Randomization should also be applied during the collection of experimental data. Randomization is also necessary for statistical methods to be used to analyze the results of the experiment and helps to eliminate bias. Randomization is usually achieved by a game of chance. For example; withdrawing numbered cards from a card package, or drawing numbered balls from a container (Easton & McColl, 1997).

### *4.3.2 Replication*

It means performing more than one experiment. Replication is necessary to ensure the measurement of the test error. The error is caused by coincidences and other factors contributing to variability. These factors are not included in the experiment but also uncontrollable. When two or more test pieces are subjected to the same test, that test is repeated. Replication is necessary to recognize the effect of possible external factors on error results (Easton & McColl, 1997).

If it is desired to increase the precision of the statistical significance test performed at a certain level of significance, the number of repetitions in the experiment should be increased. It is important to have an appropriate degree of precision of an experimental research. It is unnecessary to perform more than the number of repetitions, which makes the difference between the two experiments statistically significant, which will increase the cost. On the other hand, it is wrong to do experiments that do not provide statistical significance. It is therefore essential to find the optimal number of replications (Easton & McColl, 1997).

### *4.3.3 Local Control*

Blocking is a design method used to compare the relationship between related factors. It is used to reduce or eliminate variability that may pass through "irrelevant factors", which the observer is not directly interested in but may be effective in experimental responses. The aim of blocking is to make experiments with more homogeneous groups. Thus, the experimental error is reduced (Easton & McColl, 1997).

Each piece of data collected in an experiment that is homogeneously classified, called as a block. Blocking is a method used to increase the accuracy of an experiment. The experiments carried out in each block in the blocking method are evaluated within themselves. Thus, the effect of unrevelant factors affecting the process is eliminated, and only the effects of the relevant factors on the process are determined. Blocking generally uses variables that influence the process, such as material and operator. For example, in an experiment in which the performance of three different machines were examined by statistical experimental design, in the case of a difference between the operators using these machines; if operators are considered as a blocking variable when designing the experiment, the differences between the operators will have reduced effect on the experiment (Özkurt, 1999).

### 4.4 Classification Of Experimental Design

#### *4.4.1 Full Factorial Experimental Design*

R. A. Fisher's full-factorial experimental design (multi-factor experiments, exact-matched experiment / factorial design) is one of the experimental design methods used when the factors interact with each other (Savaş, 2001). Factorial designs produce more valid results, since the effect of a factor can be measured at different levels of other factors. In addition, factorial designs are more effective than experiments in which one factor is examined at a time. Also, if there is interaction in the experiment, it is necessary to use factorial design to prevent false results (Baray & Sarı, 2006).

In these designs, full testing and repetition of all possible combinations of factors and levels is made. Thus, all of the possible a x b combinations of the B factor with "b" number of levels A facfor with "a" number of levels are studied (Miller, Freund & Johnson, 1990) The number of experiments required to see the effects of factors, both separately and in combination, on the product / process performance in the full-factorial experimental design; calculated by the formula n = ak. Here, the "a" symbol refers to the number of levels of the factor, while the "k" symbol is the number of factors of interest (Baray & Sarı, 2006).

A disadvantage in the implementation of factorial experiments is that the number in the combination of processes increases rapidly with the increase in the number of factors or levels.

### *4.4.2 Fractional Factorial Experimental Design*

Such designs find a wide range of applications in both business and engineering areas. Fractional factorial experimental design is an experimental design method used to reduce the time and cost loss in full factorial design. In this method, the aim is to reduce the number of experiments. In such designs, orthogonal indexes are used (Antony, 2003).

In doing so, the number of experiments can be reduced by reducing the number of interactions between factors. The use of classical experimental design methods is not efficient under industrial conditions. As the number of factors affecting the system increases, the number of experiments required increases rapidly, the costs rise and the applications become more difficult. In such cases, the implementation of the fractional factorial design, Taguchi Method, will be more efficient and easier. Taguchi method can be applied successfully in many cases which require decision making. Genichi Taguchi has developed a solution to increase efficiency in the implementation and evaluation of experiments (Ross, 1996).

Taguchi method is a powerful method developed as an alternative to full factorial experimental design in order to reduce cost in optimization and parametric analysis studies, to reach the results in a short time and to determine the effects of the parameters on the target result (Taguchi, Elsayed & Hsiang, 1989).

In quality engineering, robust design is based on 3 basic processes. These are; orthogonal arrays, signal-to-noise ratio (S / N ratio) and loss function. Taguchi design is based on three basic concepts; system design (concept creation), parameter design (target for product and process) and tolerance design (additional work done when the result is not reached to the desired goal) (Gökçe & Taşgetiren, 2009). Accordingly, S / N ratios are calculated by using the following equations according to whether the objective is "the smallest best", "the greatest best" and "the nominal best“ (Gökçe and Taşgetiren, 2009) (Kumar, Satsangi & Prajapati, 2011).

- Smallest – Best

In such problems, the target value of the quality variable Y is zero. In this case the signal to noise ratio is defined as:

$$\text{S / N Ratio} = -10.\log(\textstyle\sum_{i=1}^{n} \frac{y_i^2}{n}) \quad (4.1)$$

- Greatest – Best

In this case the target value of Y is infinite and the signal-to-noise ratio is defined as follows:

$$\text{S / N Ratio} = -10.\log(\textstyle\sum_{i=1}^{n} \frac{\frac{1}{y_i^2}}{n}) \quad (4.2)$$

- Nominal – Best

For such problems, a specific target value (eg, product dimensions) is given for Y. In this case,

$$\text{S/G Oranı} = 10.\log(\textstyle\sum \frac{\bar{y}^2}{S^2}) \quad (4.3)$$

$$\bar{y} = \frac{1}{n}\textstyle\sum_{i=1}^{n} y_i \quad (4.4)$$

$$\bar{S} = \frac{1}{n-1}\textstyle\sum_{i=1}^{n}(y_i - \bar{y})^2 \quad (4.5)$$

In equations yi : i. observation value of performance response, n : the number of tests in an experiment, $\bar{y}$: the mean of observation values, S2 : the variance of the observation values. In all three problems, the goal is to maximize the S / N ratio.

### 4.5 Purpose of Experimental Design

The objectives of the experiment that will be used to improve the performance of an existing process are as follows (Montgomery, 2001a);

1. Determining which variables are most effective in Y output,
2. To determine the level of effective x variables in order to keep Y output at the desired optimum level,
3. To determine the level of effective x variables to keep the change of Y output to a minimum,
4. In order to minimize the effect of uncontrollable variables such as $Z_1$, $Z_2$, ...., $Z_q$ determine the levels at which effective x variables should be kept (Montgomery, 2001a).

### 4.6 Use Of Experimental Design In Reducing Error And Rework Waste (Literature Review)

Taguchi divides the work done to improve quality into two; off-line quality control and on-line quality control activities. Off-line quality control activities include quality activities carried out in the market research and product and process development stages. Experimental design is included in off-line quality control in quality system. To ensure both product and process quality, 3 quality stages defined by Taguchi are listed below (Şirvancı, 1997).

1. System design,
2. Parameter design,
3. Tolerance design.

According to Taguchi, the most decisive quality studies for both product and process design are the stages of parameter design (Şirvancı, 1997).

Experimental design is a critical quality improvement technique used to improve the performance of manufacturing processes in engineering. The following contributions are obtained by using experimental design techniques in process development (Montgomery, 1991):

1. Output amount is increased,
2. Variability in the process is reduced,
3. Process development time is reduced,
4. Costs are reduced.

Technology and statistical methods are used together to produce low cost and high quality products. There are many quality improvement techniques developed for this purpose and have been successfully implemented so far. Experimental Design is one of these techniques. Utilizing experimental design to solve scrap and reprocessing problems will provide a high value for companies.

In the literature, it can be considered as an example of the experimental design that a metallurgical engineer examines the effects of two different curing processes (oil cooling and cooling with water) of an aluminum alloy (Montgomery, 1996). The purpose of the experiment is to determine which cooling process provides maximum hardening on the alloy. Within the scope of the experimental design, the engineer decides to process a certain number of alloy samples for each Cooling Process and then measure the average hardness. The average hardness of the samples used for each cooling process is used to decide which process is better. In a study conducted by Yang and Tarng (1998), Taguchi method was used to determine the best levels of cutting tool parameters during turning of S45C steel bars. The L9 orthogonal array was applied to see the effects of three basic factors, with each having three levels, on turning. In another study, Ke et al. using the force and smoothness of the magnetic field as an indicator, they proposed the best magnetic design for the thin type CD / DVD drive by applying the Taguchi Method.

In various studies in Turkey, Experimental Design method is used. For example, Savaşkan et al. (2004), in order to reach the targeted optimum point by taking into account the performance optimization of fine hard ceramic coated (TiAlN and TiN) drill bits, they examined the effects of coating type, cutting speed and feed speed which are the most important factors in the industrial environment with the help of Taguchi Experimental Design technique. As a result of the application of the Taguchi method, a 40% increase in the resistance of the drill bits to the corrosion has been achieved despite an increase of 25% in the coating costs. Baynal and Terzi (2005) have used Taguchi Technique and Goal Programming Method in order to optimize the quality characteristics of an industrial production process with multi-level variables and multiple quality objectives. Kırış et al. (2009), in their study, they realized the quality characteristics of a motor as a result of the high number of air gap error and its share in the total production volume and realized the improvement works with Taguchi method. Meral et al. (2011) investigated the performances of the coated and uncoated drills according to the cutting parameters and determined the optimum processing conditions in hole drilling operations according to Taguchi L9 orthogonal plane. Şirin et al. (2015) in the study of the surface roughness milling of cold work tool steel has determined the optimum machining conditions with the experimental design. The experiments were conducted according to the Taguchi L9 vertical sequence and signal to noise (S / N) ratios were used in the evaluation of the experimental results. Basmacı et al. (2018) examined the effects of cutting parameters (cutting depth, cutting speed, radius, feed speed, flow rate, chip angle, approach angle) on surface roughness and temperature after turning. 93.85% accuracy value was obtained for the surface roughness and temperature estimation of the developed models. As can be seen, Experimental Design is a widely applied method for increasing the quality ratio. It is also a common method of reducing errors and rework losses.

## CHAPTER FIVE
## CASE STUDY

### 5.1 Information about the Company

Ege Fren Incorporation was established on 23 January 1987. 51% of the company is owned by Ege Endüstri ve Ticaret A.Ş. and 49% of the company is owned by Meritor. There are two factories in Pınarbaşı and Gaziemir in Aegean Free Zone and a Spare Parts Logistics Center in Pınarbaşı. Its main factory is located in Pınarbaşı – İzmir and it is 27,158 $m^2$ with 8,307 $m^2$ closed area. The second factory for export production has a closed area of 6,260 $m^2$ and is located in Gaziemir – İzmir, Aegean Free Zone. As of the end of 2005, the paid-in capital is TL 8,000,000.

Bayraktar Group, which is contributing to Turkey's economy with industrialist identity, performs production of spare parts of international standards with a total of four factories in Izmir. Ege Endüstri and Ege Fren, which are the OEMs of international brands, are exporting to a large extent.

Ege Fren factory, which produces brakes and brake parts in partnership with the world's number one truck axle manufacturer Meritor, is the main supplier and licensed manufacturer of many global brands including MAN truck manufacturer, thanks to its superior quality standards. Ege Fren is steadily strengthening its position in the sector with its successful R&D investments, high production capacity and stable growth.

### 5.2 Business Products

Automotive sector is an industry whose business volume has increased year by year. Accordingly, production increased continuously. New customers and demands are the main reasons for the increase in production. In addition, new projects and R&D activities require additional batch production and increase the amount of production. Ege Fren increased its annual production volume from 1,975,945 in 2016 to 2,370,964 at the end of 2018.

Following are the products manufactured in Ege Fren Inc.; complete brake (S-Cam, Z-Cam, Wedge…), torque plate, disc brake caliper, flywheel housing, engine support bracket, axle sleeve, brake plate, drum, hub, brake shoes, brake discs, disc brake body. Figure 5.1 shows the complete brake assemblies.

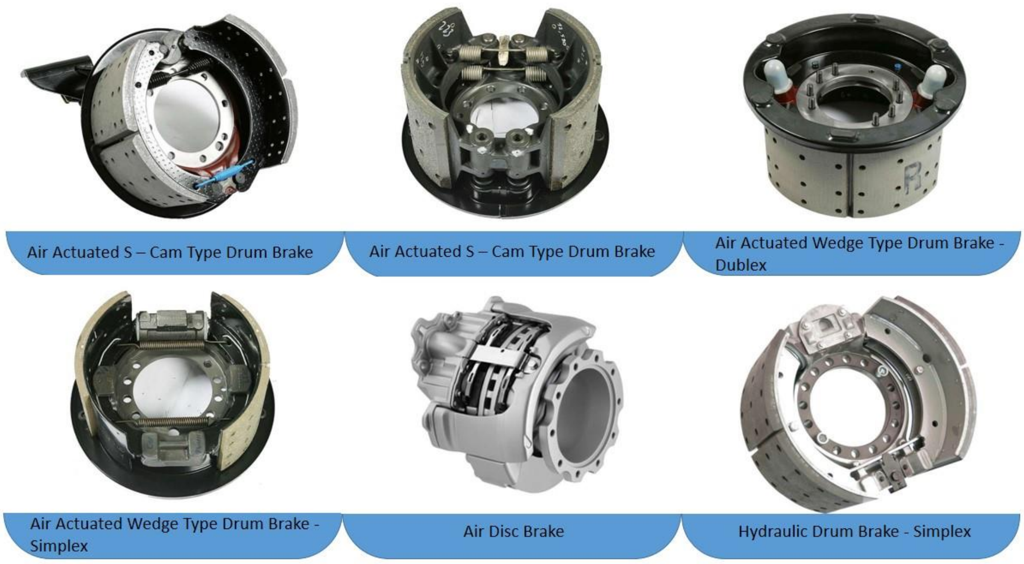



Figure 5.1 Complete brake groups (Egefren, n.d.)

Ege Fren manufactures complete brake as well as brake sub-parts. During the study, the surface roughness problem encountered in the brake plate product group will be examined. It is important that the surface roughness is at the desired level. Because the gap between the moving parts greatly affects the fatigue strength, corrosion resistance, and coefficient of friction.

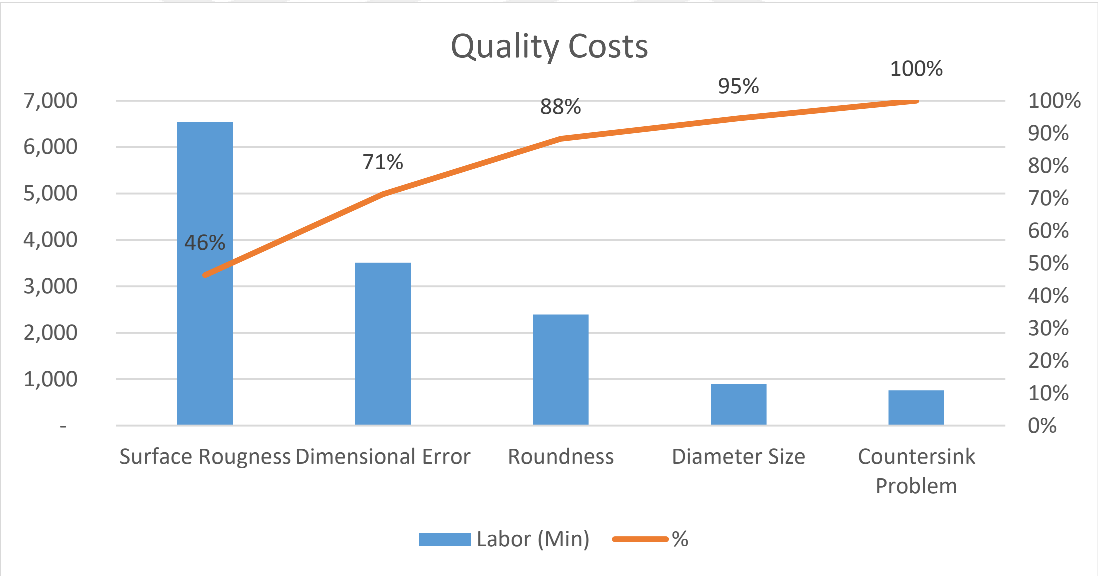
### 5.3 Explanation of the Problem

Quality costs are crucial for living in an intensely competitive environment with ever-changing consumer understanding and increasing globalization. Likewise, the impact on organizations' profits is what many executives know, but in order to adopt a quality-oriented approach, "increasing quality problems" need to increase costs. The “preventive” approach requires investment and expenditure on the right ones.

In the pareto analysis conducted within the company, reprocessing losses come first in quality costs with 6,541 minutes and 46%. When we examine the rework losses, the surface roughness problem as seen in Table 5.1 takes the first place for the company. This indicates that we should first focus on surface roughness in order to investigate the quality losses.

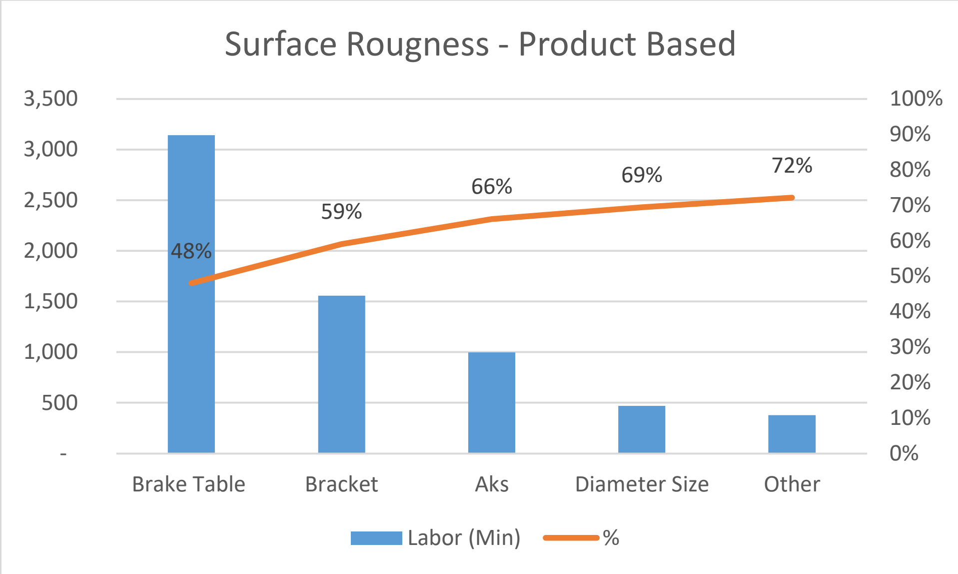
During forming by removing sawdust; Depending on the method chosen, the type of cutter and the machining conditions, physical, chemical, thermal factors and mechanical movements between the cutter and the work piece result in traces of machining on the treated surfaces, although this is undesirable. This condition which causes irregular deviations below and above the nominal surface line is called surface roughness (İşbilir 2006).

Table 5.1 Pareto analysis of quality costs




In 2018, it is seen that 48% of the rework workmanship related to surface roughness belongs to the brake table product group with 3,140 minutes. Table 5.2 shows pareto analysis of surface roughness according to product based.

Table 5.2 Pareto analysis of surface roughness – Product based (2018)




As a result of this data, the team wonders the answer of this; “Can rework costs be reduced 40 percent by improving the brake pad product range?” To solve this problem, the steps of A3 technique are applied step by step.

## 5.4 Current Situation Analysis

In the first stage of the current situation analysis, a value stream map was drawn for the Scania Brake Shoe product group. In this map, it is seen that the amount of loss during machining is the highest loss operation with 33%.

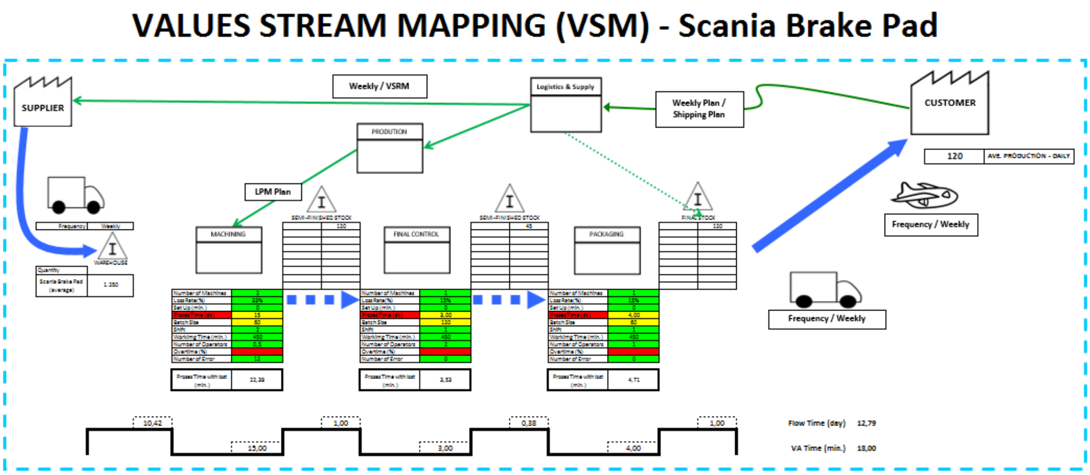



Figure 5.2 Value Stream Mapping (VSM) – Scania Brake Pad

Fishbone diagram was used in the current situation analysis. Fishbone diagram is one of the first outputs of problem solving processes. This diagram presents all the factors that affect the process design. It allows the team to prioritize among these factors and decide in which order to investigate the problem. Bringing together all the factors by using brainstorming is of great importance in order to see the whole picture.

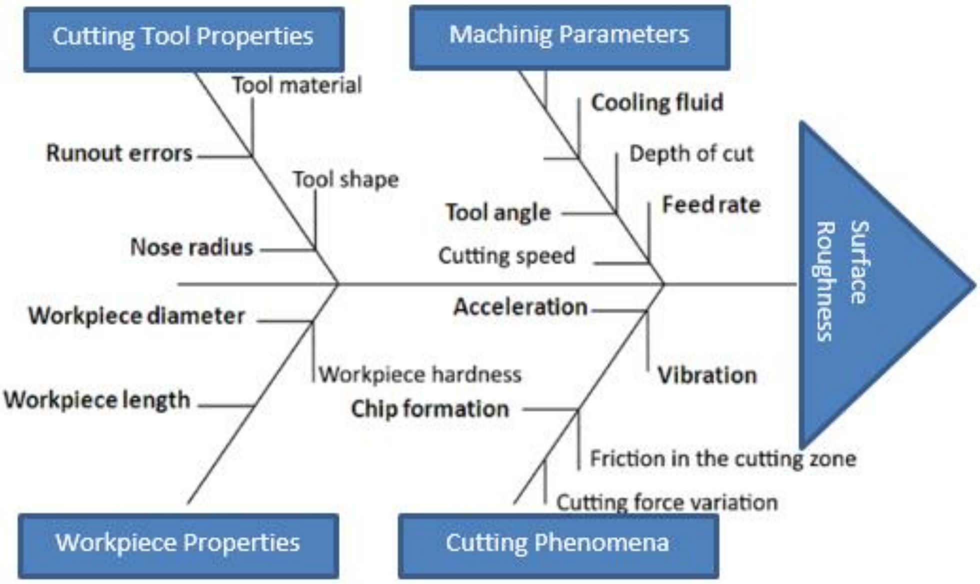



Figure 5.3 The fishbone diagram

Based on the fishbone diagram, the factors to be taken as variables during the experiments and the factors to be fixed will be decided. The parameters and levels to be included in the experiment were decided in a workshop with the participation of the team. The probability effect matrix, shows in the Table 5.3, was made during the workshop.

Table 5.3 Probability and impact analysis

| ***Category*** | **Root Cause** | **Probability (1-5)** | **Impact (1-5)** | **Importance** |
|---|---|---|---|---|
| ***Cutting Tool Properties*** | Tool Material | 2 | 5 | 10 |
| | Runout Errors | 4 | 3 | 12 |
| | Tool Shape | 4 | 4 | 16 |
| | Nose Radius | 4 | 1 | 4 |
| ***Machinig Parameters*** | Cooling Fluid | 4 | 4 | 16 |
| | Depth of Cut | 4 | 4 | 16 |
| | ***Tool Angle*** | ***4*** | ***5*** | ***20*** |
| | ***Feed Rate*** | ***4*** | ***5*** | ***20*** |
| | ***Cutting Speed*** | ***5*** | ***5*** | ***25*** |
| ***Workpiece Properties*** | Workpiece Diameter | 3 | 2 | 6 |
| | Workpiece Length | 3 | 3 | 9 |
| | Workpiece Hardness | 5 | 3 | 15 |
| ***Cutting Phenomena*** | Acceleration | 3 | 2 | 6 |
| | Vibration | 3 | 5 | 15 |
| | Chip Formation | 3 | 5 | 15 |
| | Friction in the Cutting Zone | 2 | 4 | 8 |
| | Cutting Force Variation | 4 | 2 | 8 |

### 5.5 The Analysis (Full Factorial Experiment Design)

In this study, it is aimed to analyze the effect of tool geometry on surface roughness value. Important processing factors affecting the process under machining conditions are cutting and feed rates. The time advantage of higher cutting and feed rates increases productivity. This situation is desired to be evaluated by all companies engaged in machining. Therefore, to find the point where the tool geometry will give optimum surface roughness performance together with these two factors is the main purpose of the experiments.

### *5.5.1 Experiment Parameters and Level Selection*

Effective machining depends on cutting speed and feed rate. Much time can be lost if the appropriate cutting speed and proper feed rate are not chosen. Machining costs may increase and surface quality may deteriorate. The speed of the workpiece must therefore be calculated. For roughing and finishing, it is necessary to determine the appropriate feed amount and calculate the machining time of the part.

The cutting speed is the speed at which the tool cuts the workpiece in the direction of cutting to produce chips. Cutting speed V is given in meters per minute [m / min]. The amount of feed is the distance that the insert travels on the workpiece per minute during cutting. The unit for this is mm / min. The cutting tool used in machining, the cutting speed of the insert, and the feed rate are the main factors affecting the surface roughness.

Although the cutting edges of the tools used in the machining of metals and metal alloys are sufficiently sharp, they are very difficult to withstand stresses during chip removal. For this reason, it is important to provide the ideal angles (ideal tool geometry) to facilitate the cutting and cutting of the appropriate value that the tool can withstand. Tool geometry is another important parameter that affects the surface roughness.

The three different factors were determined as 2 levels with the minimum (-1) and maximum (+1) values for cutting speed and feed. There are two tool geometries of the examined product, this factor is taken as two levels. The factors and levels that are considered to be examined in the experiments to be conducted are predicted as in Table 5.4. For tool geometry, the level 1 tool code, called triangle, is WNMU080608EN-GM, the square is called level 2 tool code SNMU130508EN-GM/PR1510.

Table 5.4 The factors and levels

| *Parameters* | *Unit* | *Level 1* | *Level 2* |
|---|---|---|---|
| *Tool Geometry (A)* | | Triangle | Square |
| *Cutting Speed (B)* | m/min | 800 | 1200 |
| *Depth of Cut (C)* | mm/rev | 760 | 1140 |

### *5.5.2 Experimental Design*

After determining the factors and levels, the next step is to determine the experiments. According to full factorial experiment design, 8 experiments were repeated 4 times. The reliability of the results was obtained statistically by means of these averages. In Table 5.5, you can see the surface roughness value of each experiment.

Table 5.5 The test results

| *Experiment* | *Tool Geometry (A)* | *Cutting Speed (B)* | *Depth of Cut (C)* | ***Surface Roughness (RA)*** |
|---|---|---|---|---|
| *1* | WNMU080608EN-GM | 800 | 760 | 1,713 |
| *2* | SNMU130508EN-GM/PR1510 | 800 | 760 | 2,304 |
| *3* | WNMU080608EN-GM | 1200 | 760 | 2,103 |
| *4* | SNMU130508EN-GM/PR1510 | 1200 | 760 | 2,12 |
| *5* | WNMU080608EN-GM | 800 | 1140 | 1,59 |
| *6* | SNMU130508EN-GM/PR1510 | 800 | 1140 | 2,176 |
| *7* | WNMU080608EN-GM | 1200 | 1140 | 2,254 |
| *8* | SNMU130508EN-GM/PR1510 | 1200 | 1140 | 2,28 |

For the selected factors and experimental results, firstly, the effects of all parameters, binary interactions were analyzed by analysis of variance in Minitab and the results shows in Figure 5.4. The reason why the triple interaction is not included in the analysis is that there is not enough Degrees of Freedom value due to the summarize column analysis.

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 6 | 5,6417 | 0,9403 | 1,44 | 0,564 |
| Linear | 3 | 3,5190 | 1,1730 | 1,79 | 0,491 |
| Tool Geometry (A) | 1 | 0,9207 | 0,9207 | 1,41 | 0,446 |
| Cutting Speed (B) | 1 | 2,1012 | 2,1012 | 3,21 | 0,324 |
| Depth of Cut (C) | 1 | 0,4970 | 0,4970 | 0,76 | 0,544 |
| 2-Way Interactions | 3 | 2,1227 | 0,7076 | 1,08 | 0,593 |
| Tool Geometry (A)*Cutting Speed (B) | 1 | 1,0805 | 1,0805 | 1,65 | 0,421 |
| Tool Geometry (A)*Depth of Cut (C) | 1 | 0,3741 | 0,3741 | 0,57 | 0,588 |
| Cutting Speed (B)*Depth of Cut (C) | 1 | 0,6682 | 0,6682 | 1,02 | 0,497 |
| Error | 1 | 0,6544 | 0,6544 | | |
| Total | 7 | 6,2961 | | | |

Figure 5.4 Analysis of variance – V1

When P-value values were analyzed, it was observed that a factor and an interaction, Depth of Cut (C) and Tool Geometry (A) * Depth of Cut (C), had no effect on the model. The full factorial design model has been reduced by subtracting these two minor factors and interaction from the model. The results are shown in Figure 5.5.

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 4 | 0,504859 | 0,126215 | 794,64 | 0,000 |
| Linear | 2 | 0,304635 | 0,152317 | 958,98 | 0,000 |
| Tool Geometry (A) | 1 | 0,186050 | 0,186050 | 1171,35 | 0,000 |
| Cutting Speed (B) | 1 | 0,118585 | 0,118585 | 746,60 | 0,000 |
| 2-Way Interactions | 2 | 0,200225 | 0,100112 | 630,30 | 0,000 |
| Tool Geometry (A)*Cutting Speed (B) | 1 | 0,160744 | 0,160744 | 1012,03 | 0,000 |
| Cutting Speed (B)*Depth of Cut (C) | 1 | 0,039480 | 0,039480 | 248,57 | 0,001 |
| Error | 3 | 0,000476 | 0,000159 | | |
| Total | 7 | 0,505336 | | | |

Figure 5.5 Analysis of variance – V2

In the new model obtained, there is no meaningless source type for surface roughness. This can be seen from the fact that all source values are below 0.05. When the R-square value is examined, it is seen that the obtained model has a significance level of 99.78%.

When the response graphs of the main factors in Figure 5.6 are examined, it is seen that the first level values should be selected for Tool Geometry and Cutting Speed. Depth of Cut factor was excluded from the model because it was not significant.

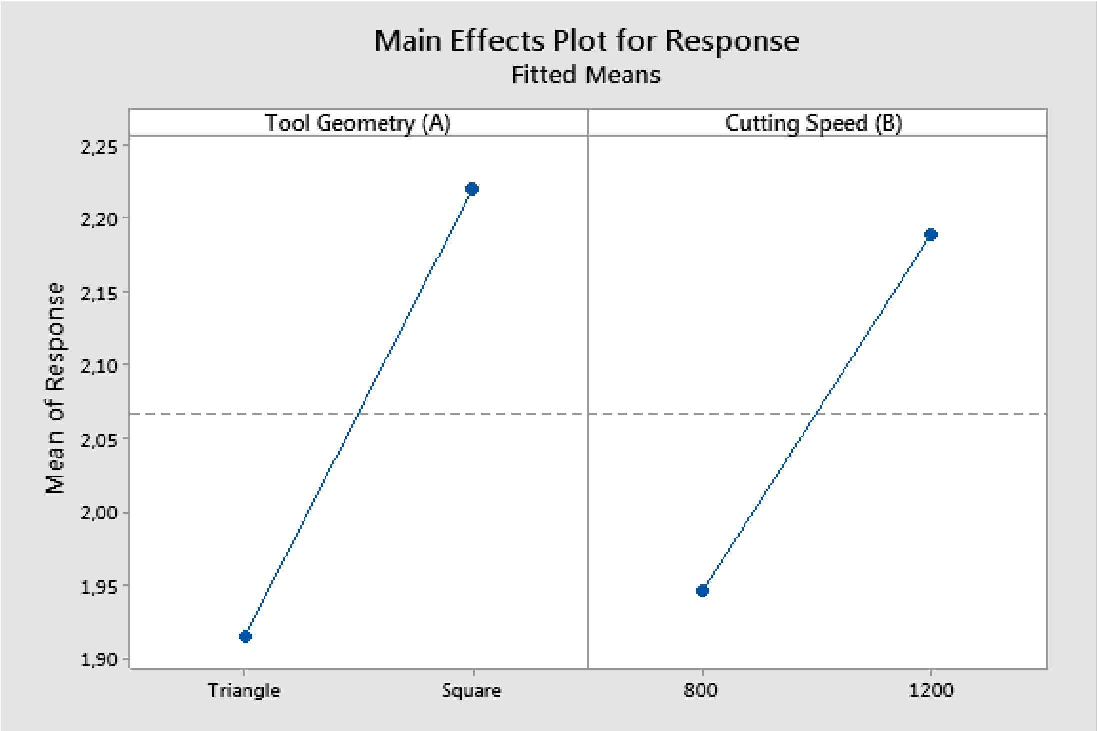



Figure 5.6 Main effects plot for response

When the interaction graphs in Figure 5.7 are examined, it is seen that there is an interaction between Tool Geometry and Cutting Speed. When the first level is selected for both factors, minimum surface roughness will be obtained. Interaction is available between Cutting speed and Depth of Cut. Although the Depth of Cut is not considered in the main factors, attention must be paid to which level should be used due to interaction. In the main factors, the first level was selected for cutting speed. When the interaction graph is examined, it is seen that first level cutting speed and second level depth of cut value are minimum.

Factor levels for optimum results are the first level for Tool Geometry and Cutting Speed. For Depth of Cut, it is the second level. Within the company, the selected optimum parameter values have started to be used.

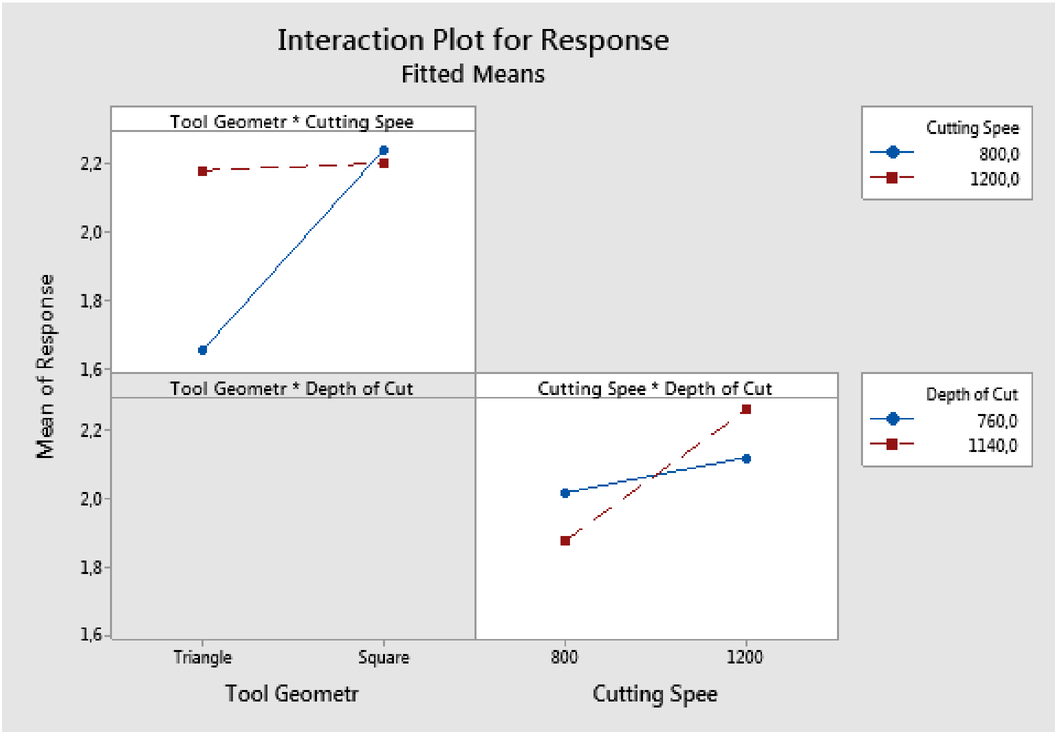
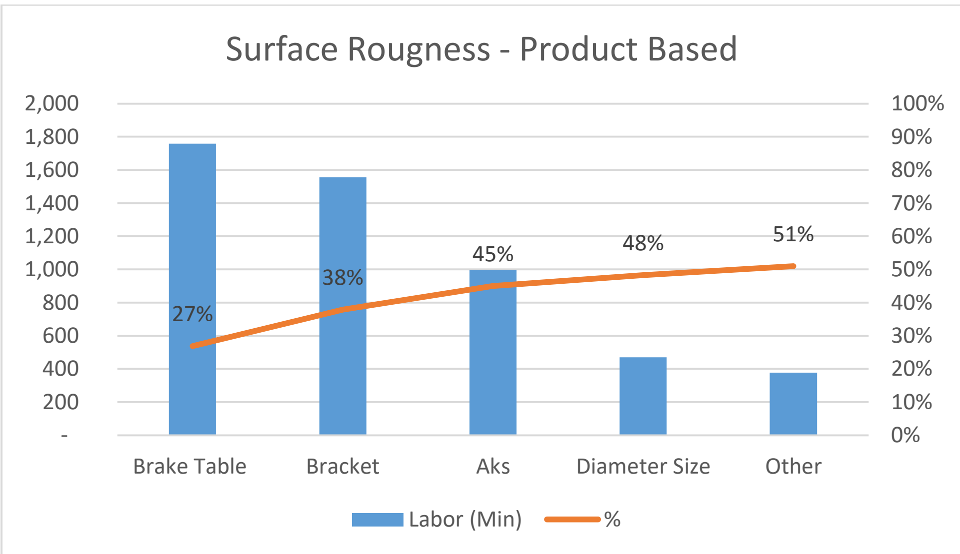



Figure 5.7 Interaction plot for response

For the first 6 months of 2019 in the brake plate group, the reprocessing labor related to surface roughness is 884 minutes. The annual reprocessing loss will be 1,768 minutes, if it is predicted to be twice that amount. Compared to 2018 reprocessing data, 44% improvement was achieved.  Table 5.6 shows Pareto analysis of new situation according to product based.

Table 5.6 Pareto analysis of surface roughness – Product based (2019)



# CHAPTER SIX
# CONCLUSION

In this study, it is examined the losses experienced in the production process of Turkey's largest commercial vehicle brakes and brake systems manufacturer. The problem of surface roughness causing loss of reprocessing is discussed. It is seen in the literature that the main parameters affecting the surface roughness value encountered in machining are cutting speed, feed rate and tool geometry. In other words, changes made on these three parameters affect the surface roughness value. In this case, unlike literature, the effect of casting on surface roughness was investigated using a lean method. In the solution of these problems determined by developing A3 methodology, optimum cutting parameters for ductile casting were determined.

It was found that Tool Geometry and Cutting Speed parameters had significant effects on surface roughness. Depth of Cut parameter has no significant effect on the model. However, the Cutting speed and Depth of Cut interaction has a significant effect on the model. Therefore, the Depth of Cut parameter level is also an important factor for surface roughness.

For optimum results, factor levels of Tool Geometry and Cutting Speed are the first level. Unlike, it is the second level for Depth of Cut. Within the company, the selected optimum parameter values have started to be used.

Reducing the processing time by increasing the cutting speed and depth of cut for the company is often among the cost improvement projects. During the commissioning of these projects, surface roughness control was started to be ensured. In this way, the project made for the brake plate is standardized and it is aimed to prevent losses in all projects.

For the first 6 months of 2019 in the brake plate group, the reprocessing labor related to surface roughness is 884 minutes. The annual reprocessing loss will be 1,768 minutes, if it is predicted to be twice that amount. Compared to 2018 reprocessing data, 44% improvement was achieved.

As a result, it is seen that improvement can be done by using A3 Reporting Method and Full Factorial Experimental Design. In the following works, the number of parameters can be increased and the working area can be expanded, for example machine load values can be considered. In addition, more successful results can be obtained by using machine learning algorithms which are artificial intelligence techniques. By establishing a system that is monitored with live data, a problem can be detected before it occurs. In this way, an active predictive quality system can be established.

## REFERENCES


Anderson, J. S., Morgan, J. N., & Williams, S. K. (2011). Using Toyotas A3 thinking for analyzing MBA business cases. *Decision Sciences Journal of Innovative Education, 9*(2), 275-285.

Antony, J. (2003). *Design of experiments for engineers and scientists.* Oxford: Elsevier.

Apillioğlu, L. (2016). *Verimliliğin şifresi*. İstanbul: Aura Yayınevi.

Baray, A., & Sarı, T. (2006). Kalite geliştirmede deney tasarımı yöntemi ve otomotiv sektöründe bir uygulama. *İstanbul Üniversitesi İşletme Fakültesi Dergisi, 35*(2), 37–62.

Bassuk , J.A. & Washington, I.M. (2013). The A3 problem solving report: A 10-step scientific method to execute performance ımprovements in an academic research vivarium. *Plos One, 8*(10). Retrieved October 29, 2013, from https://doi.org/10.1371/journal.pone.0076833.

Baynal, K., & Terzi Ü. (2005). Çoklu kalite başarım özelliklerinin hedef programlama ve Taguchi yöntemi kullanılarak eniyilenmesi. *V. ulusal üretim arastırmaları sempozyumu*, 573-578.

Box, G. E., & Draper, N. R. (1987). *Empirical model-building and response surfaces.* New York: John Wiley & Sons.

Chand, G. & Shirvani, B. (2000). Implementation of TPM in cellular manufacture. *Journal of Materials Processing Technology, 103*(2000),149-154.

Cowley, M., & Domb, E. (1997). *Beyond strategic vison: effective corporate action with hoshin planning*. Boston: Butterworth-Heinemann.

Çelepçıkay, Ö. (2014). *A3 düşünme yolu ile çapraz sevkiyat tesisinin geliştirilmesi.* Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, İstanbul.

Duggan, K. J. (2002). *Creating mixed model in value streams.* New York: Productivity Press.

Emre, A. (1995). T*am zamanında üretim sisteminin ülkemizdeki uygulamaları ve sorunları.* Ankara: M.P.M. Yayınları.

Gibson, T., Greenhalgh, G. & Kerr, R. (1995). *Manufacturing management principles and concept.* Petersfield: Chapman & Hall, Inc.

Gökçe G., & Taşgetiren S. (2009). Kalite için deney tasarımı. *Makine Teknolojileri Elektronik Dergisi. 6*(1), 71-83.

Güven, K. (2006). *Periyodik Bakım Yapan Bir Tekstil İşletmesinde Bilgisayar Destekli Toplam Verimli Bakıma Geçiş ve Kaliteye Etkisi.* Yüksek Lisans Tezi, Erciyes Üniversitesi, Kayseri.

Hamzaçebi C., & Kutay F. (2003). Taguchi metodu: bir uygulama. *Teknoloji Dergisi*, *6*(3-4), 7-17.

Hinckley, C. M. (2007). Combining mistake-proofing and Jidoka to achieve worldclass quality in clinical chemistry. *Accreditation and Quality Assurance, 2007*(12), 223–30.

Hipkin, I.B. & Cock, C.D. (2000). TQM and BPR: lessons for maintenance management. *The International Journal of Management Science. 3*(28), 277-292.

Imai, M. (1986). *Kaizen*. İstanbul: Kalder Kalite Derneği.

Imai, M. (2013). *Gemba Kaizen: A commonsense approach to a continuous improvement strategy.* New York: McGraw Hill Professional.

Irvin, M., Freund, J. E., & Johnson, R. A. (1990). *Probability and statistics for engineering*. New Jersey : Prentice Hall.

İşbilir F., (2006), *Takım ömrünün sebep-sonuç diyagramları ile açıklanması, yüzey pürüzlülüğü ve takım ömrüne etkili faktörlerin analizi*. Yüksek Lisans Tezi, Gazi Üniversitesi, Ankara.

İpbüken, Y (2018). *Kitlesel ve yalın üretim sistemleri srasında bir karşılaştırma.* Retrieved May 27, 2018, from https://lean.org.tr/kitlesel-ve-yalin-uretim-sistemleri-arasinda-bir-karsilastirma/.

İzgiz, S. (2001). *Deney tasarımı ve taguchi metodu ürün ve proseslerin optimizasyonu*. İstanbul: Federal Mogul.

Jackson, T.L. & Jones, K.R (1996). *Implementing a lean management system.* Portland: Productivity Press.

Jostes, R.S. & Helms, M.M. (1994). *Total productive maintenance and its link to total quality management.* Bingley: MCB UP Inc.

Kavrakoğlu, I. (1994). *Toplam kalite yönetimi.* İstanbul: KalDer Yayınları.

Kerridge, D., & Kerridge, S. (2000). *Principles not rules: making sense of deming philosophy*. Retrieved , from http://www.deming.eng.clemson.edu/pub/files/prinrule.txt

Kılıç, A., & Ayvaz, B. (2016). Türkiye Otomotiv Sanayinde Yalın Üretim Uygulaması. *İstanbul Ticaret Üniversitesi Fen Bilimleri Dergisi*, *15*(29), 29-60.

Kırıs, S., Anagün, A.S., & Yüzügüllü, N. (2009). *Bir kalite karakteristiğinin deney tasarımı ile iyileştirilmesi*. Retrieved, January 20, 2019, from https://docplayer.biz.tr/9213544-Bir-kalite-karakteristiginin-deney-tasarimi-ile-iyilestirilmesi.html.

Kittredge, J. (2003). Strategic renewal: management 101 meets performance architecture. *Journal of Cost Management*, *17*(3), 15-23.

Köksoy, O. (2001). *Taguchi ve cevap yüzeyi felsefelerinin birleştirilmesi: problem ve çözüm teknikleri*. Doktora Tezi, Hacettepe Üniversitesi, Ankara.

Krajewski, L., J., King, B., E., Ritzman, L., P.,Wong, D., S. (1987). Kanban, MRP and shaping the manufacturing environment, *Management Science. 13*(1), 42.

Krajewski, L.J., Ritzman, L.P. & Malhotra, M.K. (2010). *Operation management: processand supply chains.* Harlow: Pearson Education Inc.

Kumar, S., Satsangi, P.S., & Prajapati D.R. (2011). Optimization of green sand casting process parameters of a foundry by using Taguchi's method. *International Journal of Advanced Manufacturing Technology, 55*(1), 23-34.

Liker, J.K. (2003). *The Toyota way: 14 management principles from the world's greatest manufacturer.* New York: McGraw Hill Professional.

Loyd, N , Harris G. A. & Lisa Blanchard (2010). Integration of A3 thinking as an academic communication standard. *Proceedings of the 2010 Industrial Engineering Research Conference.*

Lunani, M., Nair, V.N., & Wasserman, G.S. (1997). Graphical metods for robust design with dynamic characteristics. *Journal of Quality Technology, 3*(29), 327-338.

Marchwinski, C., Shook, J., & Alexis, S. (2008). *Lean lexicon lexique lean: a graphical glossary for lean thinkers*. Cambridge: Lean Enterprise Institute.

Marchwinski, C., & Shook, J. (2006). *Lean lexicon.* Cambridge: Lean Enterprise Institute.

McBride, D. (2003). *The 7 wastes in manufacturing*. Retrieved May 27, 2018, from https://www.emsstrategies.com/dm090203article2.html.

McKone, K.E., Schroeder, R.G., Cua, K.O. (1999). Total productive maintenance: a contextual view. *Journal of Operations Management, 17*(1999), 123-144.

McKone, K.E., Schroeder, R.G. & Cua, K.O. (2001). The impact of total productive maintenance practices on manufacturing performance. *Journal of Operations Management. 1*(19), 39-58.

Monden, Y. (1983). *Toyota production system: practical approach to production management.* Norcross: Industrial Engineering and Management Press.

Montgomery, D. C. (1991). *Design and analysis of experiments (3rd Ed.).* New York: John Wiley&Sons.

Montgomery, D. C. (2001a). *Design and Analysis of Experiment.* New York: John Wiley&Sons.

Murat, N. (2016). *Pazarlamanın evrimi ve henry ford etkisi.* Retrieved May 27, 2018, from http://www.pazarlamasyon.com/pazarlama/pazarlamanin-evrimi-ve-henry-ford-etkisi/.

Ohno, T. (2008). *Toyota ruhu.* İstanbul: Scala Yayıncılık.

Okur, A. S. (1997). *Yalın üretim - 2000'li yıllara doğru türkiye sanayii için yapılanma modeli.* İstanbul: Söz Yayınları.

Özkurt, Ö. (1999). *Deney tasarımları ve istatistiksel veri analizi.* Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, İstanbul.

Sobek, D. K., & Smalley, A. (2008). *Understanding A3 thinking: A critical component of Toyotas PDCA management system.* Boca Raton: CRC Press.

Ross, P.J. (1996). *Taguchi tecniques for quality engineering*. Newyork: Mcgrow – Hill International Book Company.

Rother, M., & Shook, J. (1998). *Learning to see.* Brookline: Lean Enterprise.

Savaşkan, M., Taptık, Y., & Ürgen, M. (2004). Deney tasarımı yöntemi ile matkap uçlarında performans optimizasyonu. *İTÜ Dergisi*, *3*(6), 117-118.

Shook, J., & Womack, J. P. (2010). *Managing to learn: Using the A3 management process to solve problems, gain agreement, mentor and lead.* Cambridge: Lean Enterprise Institute.

Shingo, S. (1988). *A revolution in manufacturing the SMED system.* Cambridge: Productivity Press.

Easton, V. J., & McColl, J. H. (1997). *Statistics glossary.* Retrieved May 02, 2019, from http://www.stats.gla.ac.uk/steps/glossary/.

Suzaki, K. (2005). *İmalatta mükemmellik yolu sürekli iyileştirme teknikleri*. İstanbul: Otoyol Sanayi Yayınları.

Svendsen, A., & Haskins, C. (2016). Applying A3 problem resolution to new system design to improve performance and reduce rework. *INCOSE International Symposium, 26*(1), 1161-1175.

Swanson, L. (2001). Linking maintenance strategies to performance. *International Journal of Production Economics, 3*(70), 237-244.

Swamidass, P.M. (2000). *Innovations in competitive manufacturing.* London: Kluwer Academic Publishers.

Şimşek, M. (2000). *Sorularla toplam kalite yönetimi ve kalite güvence sistemleri*. İstanbul: ALFA.

Şimşek, M. & Nursoy, M. (2002). *toplam kalite yönetiminde performans ölçme*. İstanbul: Hayat Yayıncılık.

Şirvancı, M. (1993). Toplam kalite yönetiminin temel öğeleri. *Önce Kalite Dergisi, 5*, 12.

Şirvancı, M. (1997). *Kalite için deney tasarımı "Taguçi yaklaşımı.* İstanbul: Literatür Yayınları.

Ta, S., & Xu, X. X. (2017). Analysis of the A3 report template and suggestions for improvement. *2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM).* Retrieved February 12, 2018, from https://ieeexplore.ieee.org/document/8290302.

Taguchi, G., & Elsayed, E., & Hsiang, T. (1989). *Quality engineering in production systems.* Newyork: McGraw-Hill Books.

Tamhane, A. C. (2009). *Statistical analysis of designed experiments.* Newyork: John Wiley & Sons.

Tanık, M. (2010). Kalıp ayar sürelerinin SMED metodolojisi ile iyileştirilmesi: Bir yalın altı sigma uygulaması. *Muğla Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 25*(2010), 117-140.

Taşçı D., & Çabuk S. N. (2013). *Kalite yönetim sistemlerinde temel kavramlar: Kalite kontrol, kalite güvence ve kalite iyileştirme*. Eskişehir: Anadolu Üniversitesi Yayınları.

Tortorella, G. L., & Fries, C.E. (2015). Application of focus groups and learning cycles on the A3 thinking methodology: the case of increasing machinery capacity at a steel plant. *Proceedings of the 2015 ınternational conference on operations excellence and service engineering.*

Toyota Motor Corporation (2006). *Toyota üretim sistemi (standart işler ve kaizen) kitabı.* Toyota Otomotiv Sanayi Türkiye A.Ş. İnsan Kaynakları Geliştirme Bölümü. Saarya: Toyota Motor Company.

Utas, T. (2001). *Yalın üretim ve yalın üretimde kullanılan stratejiler*. Yüksek Lisans Tezi, İstanbul Üniversitesi, İstanbul.

Walton M. (1986). *The DEMING Management Method*. Newyork: Berkley Publishing.

Womack, J., Jones, D., & Roos, D. (1990). *The machine that change the world: the story of lean production.* Newyork: Rawson Associates.

Womack, J., & Jones, D. (1998). *Yalın düşünce.* İstanbul: Sistem Publishing.

Worth, J., Shuker, T., & Keyte, B. (2013). *Perfecting patient journeys.* Cambridge: Lean Enterprise Institute.

Yanmaz M. & Çayır E. (2005). İşletme etkinliğinin (OEE) ölçülmesi. *II. Bakım Teknolojileri Kongresi ve Sergisi*, 61-74.

Yang, W.H., & Tarng, Y.S. (1998). Design optimization of cutting parameters for turning based on Taguchi method. *Journal of Materials Processing Technology, 1-3*(84),122-129.

Yingling, Jon C., Detty, Richard B., & Sottile, Joseph J. (2000). Lean manufacturing principles and their applicability to the mining ındustry. *Mineral Resources Engineering, 9*(2), 215-238.

Zeng, J. & Zhang  J. (2014). Instill lean A3 thinking into healthcare IT services. *International Journal of Business and Social Research (IJBSR), 8*(4), 1-7.

## APPENDICES

### Appendix-1: ABBREVIATIONS

**PUKÖ Döngüsü :** Planla – Uygula – Kontrol Et – Önlem Al

**SMED :** Single Minute Exchange of Dies

**TPM :** Total Productive Maintenance

**VSM :** Value Stream Mapping

**OEE :** Overall Equipment Effectiveness

**PDCA Cycle :** Plan–Do–Check–Act

**TPS :** Toyota Production System

**TQM :** Total Quality Management

**JIT :** Just in Time

**JIPE :** Japan Institute of Plant Engineers

**JIPM :** Japan Institute of Plant Maintenance

**S / N Ratio :** Signal and Noise Ratio

**VA / NVA :** Value Added / Non-Value Added