*International Journal of Computational and Experimental Science and ENgineering (IJCESEN)*

*Vol. 9-No.2 (2023) pp. 111-122*
*http://dergipark.org.tr/en/pub/ijcesen*

***ISSN: 2149-9144***



**Research Article**

# Process Improvement Study in a Tire Factory

**Seher ARSLANKAYA[1,*], Asude DEMİR[2]**

[1]Sakarya University, Engineering Faculty, Industrial Engineering Department, 54000, Sakarya-Turkey
* **Corresponding Author** : **Email:** aseher@sakarya.edu.tr - **ORCID:** 0000-0001-6023-2901

[2] Sakarya University, Engineering Faculty, Industrial Engineering Department, 54000, Sakarya-Turkey
**Email:** asude.demir1@ogr.sakarya.edu.tr - **ORCID:** 0000-0001-6488-0367

**Article Info:**

**DOI:** 10.22399/ijcesen.1289121
**Received :** 28 April 2023
**Accepted :** 07 June 2023

**Keywords**

Cycle time
SWOT analysis
Failure modes and effects analysis
Time analysis
Brainstorming
Process improvement

**Abstract:**

Today, motorsports are one of the sports branches with the world's largest audience and fan base. The production techniques of the tires used in these organizations are an indispensable factor in order to be the pioneer of the sector. In this study, SWOT Analysis and Failure Modes and Effects Analysis were performed for two different production lines, and the superiority of the lines against each other was evaluated. The process to be improved on the excellent line was determined as a result of brainstorming by an expert team. After the changed parameters, the effects on the final product and the process were evaluated. The study was concluded by determining that all the changes made do not constitute an obstacle to the continuity of the process and the quality of the final product. Time analysis was made by video recording the process whose cycle time changed. As a result of the calculations made after the time analysis, the annual tire gain was calculated as 7299. The production volume determined at the beginning of the period for 2022 is 71273 units, and while these tires were produced in 386,630.1 minutes with the old cycle time, they can be produced in 351.583.4 minutes with the new cycle times. Total time savings for 2022 production volume is 34,776.7 minutes, i.e., 24.15 days. With the new cycle times, the line's capacity has been increased by 10.24%. The company can produce 6,398 pieces of the tire with the highest cycle time and 8,105 pieces with the lowest cycle time in 34,776.7 minutes won.

## 1. Introduction

Process; It is a series of processes that produce outputs that will meet customer demands and expectations by processing resources such as humans, machines, materials, money, information, and time. Process management aims to monitor and improve processes continuously and regularly. The cycle includes the design and maintenance of processes, continuous evaluation, analysis, and improvements to meet customer needs better. Process improvement covers analysing a company's business processes, increasing efficiency, reducing errors, reducing costs, and increasing customer satisfaction.

The company, the sole tire supplier of prestigious races in motorsports, where interest is increasing daily, sends tires to racing organizations from many production facilities and warehouses. However, not all of the company's production facilities in different locations are within the motorsport organization. There is only one factory that produces motorsport tires entirely. This factory's capacity needs to be increased for producing certain groups of tires. In order to change the production capacity, it seemed normal at first to transport the A group tires, which were produced with the help of five-axis robotic arms on the lines called "BX", to the machines called "AX", which used more primitive methods in the production stages. However, due to the prestige of the A group and the deterioration in the tire quality due to the changing method, it was decided to carry out process improvement studies in the "BX" lines to increase production.

A systematic study of activities and flows will be provided for each process to be improved with process improvement work. Details will be revealed by understanding the processes to provide high quality at lower prices. Continuous reviews will seek ways to eliminate unnecessary operations, limit expensive materials and services, improve the environment, or make work safer. In addition, customer satisfaction will be ensured by preventing delays [1].

In order to increase the production capacity of the “BX” line, the pressure values of the extruder pump and extruder screw were increased at the same rate. Changing values reduced the cycle time. Video recordings are taken for the new conversion and Avidemux 2.0. The new cycle times were calculated by analyzing the program. The time caused by the difference between the changing and old cycle times corresponds to a total of 7299 tires based on production. There are many studies on process improvement methods in the literature. This literature review includes studies that were accepted between 2014-2021. Kirkham, Garza-Reyes, Kumar, and Antony (2014) surveyed what improvement methods companies prefer to increase their competitiveness and which ones they achieve more success in. According to the results of the survey, it was determined that the most successful method was six sigma [2]. Patel, Chauhan, and Trivedi (2015) scanned the literature and revealed the gains obtained as a result of value stream mapping applications in the machining industry in 6 study examples [3]. Türkan and Görener (2017) carried out process improvement with Kaizen, Poka-Yoke, 8D application, and FMEA application in the manufacturing department of a steel production company. With these studies, gains such as cost savings, time savings, and faster and error-free work have been achieved[4]. Gupta, Singh, and Suri (2018) examined the service quality parameters of an Indian-origin logistics provider company, which took part in supporting the supply chain processes in a business they determined, using the SWOT analysis method in order to increase customer satisfaction with the strategies determined as appropriate for supply chain management [5]. Avunduk (2019) performed a process improvement on the pet blow molding machine using the Lean Six Sigma method. This work and financial gain contributed to the company's long-term environmental sustainability goal and the vision of a more livable world with less energy consumption [6]. Sevgili and Antmen (2019) aimed at lean production by using value stream mapping in a metal processing factory and minimized intermediate stocks due to process improvement, shortened the production flow time, and increased the daily production amount [7]. Apilioğulları (2020) conducted quality improvement studies with Lean Six Sigma and Industry 4.0 Integration for a process with high waste in the aluminum industry [8]. Sarı, Sergi, and Ozuduruk (2020) made a process analysis in the customer service department of a tire manufacturing company. A comprehensive SWOT analysis was used, and matrices were formed due to internal and external factors evaluation. Accordingly, a strategic plan has been determined to use the software resources of the enterprise more efficiently [9]. Berber and Deste (2021) improved various processes in an ice cream factory by using a scoreboard diagram, Poka-Yoke, and Kaizen together with brainstorming [10]. In the literature, the importance of process management and process improvement studies have applications in different sectors using different methods. At the same time, the effects of these concepts on business performance were also evaluated [11-17]. It is also clearly seen in the literature that the ANN or FL approaches have been used in different motivations, and satisfactory results have been obtained [18-33].

## 2. Material and Methods

### 2.1. SWOT Analysis

SWOT analysis can be defined as a strategic planning technique used to help a person or business identify strengths, weaknesses, opportunities, and threats related to business competition or project planning [9].

SWOT Analysis consists of 4 steps:

- Strengths: Strengths are used to maximize opportunities and minimize threats.
- Weaknesses: Weaknesses are minimized by taking advantage of opportunities and avoiding threats.
- Opportunities: Strengths are maximized, and weaknesses are minimized by using them.
- Threats: Strengths are used to minimize, and weaknesses are minimized by avoiding.

It is an analysis technique used to determine the positive and negative aspects of the internal structure of the system, as well as to determine the opportunities and threats in its external environment. Based on this statement, it is understood that SWOT Analysis is a current situation analysis. SWOT Analysis is also an analysis technique that helps to detect and predict the system's future state. According to this second meaning, SWOT Analysis is a future situation analysis [34].

### 2.2. Failure Modes and Effects Analysis

Failure modes and effects analysis (FMEA) is a widely used technique in many fields to increase process reliability and establish systems to prevent potential failures. FMEA; “What could have caused the error?”, “What could be the root causes of the error?”, “What could be the effects as a result of the error?” It is a method that seeks answers to such questions and analyzes and documents the answers it receives. It has proven to be a valuable and powerful tool in evaluating potential failures and preventing their occurrence [35].

FMEA implementation stages can be expressed as follows:

- Initial studies,
- Identification of hazard sources and hazards,
- Identification of possible fault effects, causes, and existing controls,
- Determination of probability, severity, detection, and ROS values,
- Sorting the errors according to RPN, determining the precautions to be taken,
- Recalculation of RPN values after the implementation of the foreseen measures.

At the method's core is determining risk priority numbers (RPN). The probability, severity, and detectability of the error calculate these numbers:

Risk Priority Number (RPN) = Probability of Occurrence x Severity x Detectability (1)

In this equation, "Probability of Occurrence" is the frequency level of the error; "Severe" means the severity of the error; "Detection of Errors" or "Detection" refers to the level of detecting the error before it reaches the user [4]. In this study, scoring was done based on expert opinions. If the RPN value is less than 40, there is no need to take precautions, if it is between 40 and 100, it means that precautions can be taken, and if it is greater than 100, it means that precautions should be taken.

### 2.3. Brainstorming

It is a group activity when it is desired to collect ideas, solutions, and root causes on any subject. The number of participants in the group should be at least 5-6 people and not more than 19-20 people. In addition to the experts on the subject, there should be those not directly involved. In this way, it will be possible to look at the current problem from different angles without conditioning what is known [36].

### 2.4. Root Cause Analysis

Root causes analysis covers the studies to determine the main reason for the origin of the errors and the measures to be taken to prevent the errors from recurring [37]. Analysis, “What would not be what if it was not?” It is carried out in 5 steps by looking for an answer. The materials and also used methods should be detailed in this section.

## 3. Application

A tire company produces tires for motorsport organizations in its production facility. There are two types of production lines depending on the prestige and conditions of the organizations where the tires will be used. The lines are locally named “BX” and “AX”. The “BX” line includes a more technological, innovative, and high-quality production process than the “AX” line. However, since the number of BX lines is less than that of AX lines, the production capacity is insufficient for tire groups produced only in BX lines. This leads to the production of tires with insufficient capacity in different locations; therefore, it causes an extra cost of production, logistics, and quality.

This scope of work; A SWOT analysis was conducted for the BX and AX lines, and an answer was sought to the question, "Can a production line change be made for a particular tire group?" Defect Modes and Effects Analysis (FMEA) was applied for tires produced in different lines. After determining a process by brainstorming method for the BX line, which has insufficient capacity, and arranging the cycle time, root cause analysis was performed for tires produced with two different cycles. As a result, the production capacity gained in a working year in the accelerating cycle is expressed numerically.

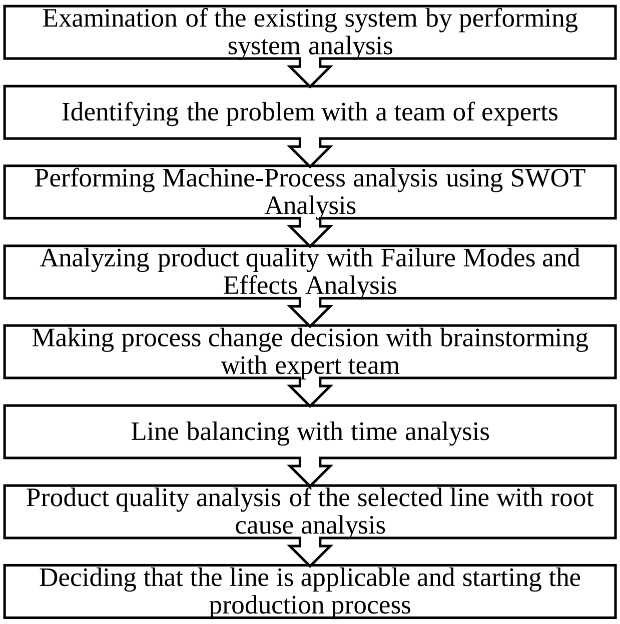


***Figure 1.*** *Application Steps*

### 3.1. Examination of the Existing System

The final product is first visually checked. Then, X-Ray images are taken, and it is checked whether there is foreign matter in the tire paste. Finally, the tire is attached to a rim and moved. In this process, the mass values of the tire are checked. All completed and approved tires are labeled and stored. The business supplies tires to more than one race organization. Similar or different tire groups can be produced in two different production lines. However, only BX production lines are preferred for certain groups of tires. Since quality errors are less in BX lines, this line is preferred for producing tires of high organizations. In addition, since the production in these lines is almost entirely automated, personnel errors may occur at a minimum level.

### 3.2. Identifying the Problem

The production capacity of BX lines remains below the demanded number. Since the open AX lines in demand cannot be closed by production, it is necessary to increase the capacity through process improvement studies in BX lines.

### 3.3. Machine – Process Analysis

For the BX and AX lines, the SWOT Analysis based on the tire group produced in both lines, quality results, and general conditions is as in Tables 1 and 2. As a result of the SWOT analysis, it was determined that the BX line is more advantageous than the AX line.

### 3.4. Product Quality Analysis – Failure Modes and Effects Analysis

Fault Types and Effects Analysis (FMEA) for tires with similar characteristics and belonging to the same group produced in different lines are given in Table 3 and Table 4. The severity, probability, and detectability values for FMEA were determined based on the opinions of the company's quality management system specialist.

***Table 1.*** *BX Line SWOT Analysis*

| Strengths | Weaknesses | Threats | Opportunities |
|---|---|---|---|
| • There is no joint on the tread of the produced tire<br>• Use of high-end technology<br>• Standardization of the manufactured product<br>• Does not need a separate machine, operator and process for the production of the tread of the tire<br>• High level of traceability | • Few lines<br>• Insufficient capacity<br>• Insufficient number of technician personnel to work on the lines<br>• High installation and maintenance cost<br>• High energy consumption<br>• High equipment cost | • Reducing the product range due to the low capacity of the line<br>• Possibility of change with AX lines due to the large area coverage in the layout | • Using a completely different production methodology than competitors<br>• Industry support for automation and high technology<br>• Modification capability |

***Table 2.*** *AX Line SWOT Analysis*

| Strengths | Weaknesses | Threats | Opportunities |
|---|---|---|---|
| • Too many lines<br>• Does not take up much space in the layout<br>• Number of authorized personnel for use | • Having a joint on the tread of the produced tire<br>• Use of low-level technology<br>• Occupational safety risks<br>• Low traceability level | • Risk of being discontinued due to low level technology use<br>• Risk of being out of use for space purposes for BX in layout | • Insufficient BX production capacities<br>• Possibility of replacement with BX lines as it takes up less space in the layout |

***Table 3.*** *BX Line Failure Types and Effects Analysis*

| Fault Type No | Fault Types | Possible Effects of Fault | Severity | Fault Causes | Probability | Control | Detection | RPN |
|---|---|---|---|---|---|---|---|---|
| 1 | The appearance of the bandina on the outside, which provides durability to the tire | Non-durable tire production<br><br>Discarding the carcass | 7 | Faulty semi-finished product production<br>Rig issues<br>Electronic malfunctions | 3 | Equipment control planned<br>Paintenance<br>Semi-finished quality control | 2 | 42 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2 | 2nd phase transfer error | Formed tire production<br><br>Discarding the carcass or tire | 9 | Incorrect positioning of the 1st phase in the clichés Electronic malfunctions Incorrect machine setting | 4 | Machine recipe control 100% control of 1st phase placement | 6 | 216 |
| 3 | Carcass weight is out of limits | Heavier or lighter tire production Discarding the carcass or tire Machine posture | 10 | Incorrect machine setting Incorrect use of semi-finished products Incorrect cycle time | 4 | Control of semi-finished product cards Checking the machine weight setting | 3 | 120 |
| 4 | Parallel generation application | Positioning the belts in the same direction and direction | 10 | Operator error | 2 | Belt direction control Belt material - process conformity check | 7 | 140 |

***Table 4.*** *AX Line Failure Types and Effects Analysis*

| **Fault Type No** | **Fault Types** | **Possible Effects of Fault** | **Severity** | **Fault Causes** | **Probability** | **Control** | **Detection** | **RPN** |
|---|---|---|---|---|---|---|---|---|
| 1 | Material folding in the sidewall of the tire | Deformity of the baked tire Discarding the carcass | 6 | Machine error Operator error | 4 | 100% control of the cheek pressing process | 3 | 72 |
| 2 | Parallel generation application | Belts to be in the same direction and direction | 10 | Operator error | 6 | Belt direction control Machine process control | 7 | 420 |
| 3 | Splice join error | Lack of material and deformity in the tread of the tire Discarding the carcass | 5 | Incorrect use of equipment | 5 | Machinery equipment control Back material length control | 3 | 75 |
| 4 | Folding the backing material | Deformity of the baked tire Discarding the carcass | 6 | Operator error machine error Operator error Incorrect use of equipment | 5 | Machinery equipment control Machine process control 100% control of the ridge stamping process | 3 | 90 |

FMEA were shared with experts and their opinions were taken. In the evaluations, since the BX line is more autonomous than the AX lines, it is less likely to encounter high-severity errors. BX lines are more powerful and flexible in the actions to be taken due to the high technology and modification power they use. Therefore, it is in a more advantageous position compared to AX lines. In order not to lose this advantage and to benefit more from the strengths of the line, it was decided to increase the production capacity of the BX lines.

### 3.5. Process Change Decision

BX lines consist of different zones called 1, 2, and 3 zones. It produces uncooked tires by completing different processes. The operator carries out the processes in Zone 1 of the line. After the processes in the first region are completed, the robot arm brings the semi-finished product to the second region. There needs to be operator access to Zone 2 of the line. The process here is completed autonomously with the help of a five-axis robotic arm. 2. The back of the semi-finished product is wrapped in the region. After the back wrapping, the process of the package in the second region is completed, and the tire package is sent to the tired phase placed by the operator in the determined area in the third region with the help of the robotic arm. Now the process continues in the 3rd zone of the line under operator control. After the operator controls the package transfer, the unbaked tire, which is in two separate phases, is subjected to the squeezing process. This process finalizes the tire. The operator measures the weight of the finished tire and sends it to the curing process to be cured if it is within the specified quality limits. Within the scope of the process improvement work to be carried out to increase the capacity of the expert opinions and the meetings held, the process in the first region is taken to the second region, and in the trial process in the second region, the winding of the tread of the tire has a faster cycle time. It was decided to increase the pressure.

### 3.6. BX Line Balancing

The tread region of the tire is currently wrapped in the B region of the BX line. The pressure of the extruder pump and the speed of the extruder screw have been increased to reduce the cycle time.

Figure 2 examined the screw speed trend when the screw speed and pump speed were 15 rpm and 18 rpm. The reason for increasing the screw and pump pressure values at the same rate is; If the pump works slowly while the screw is working fast, the accumulation of material in the extruder and the congestion in the pump prevent the process from working continuously. Within the scope of the values seen in Figure 2., the effect of the pressure value change made in the working recipe of the extruder on the process was evaluated, and it was approved by the electronic and mechanical maintenance team that the change did not prevent the process from working correctly. The increase in the pressure value increased the screw speed, and as it can be seen in Figure 2., when the pressure value was 15 rpm, the process that took 270 seconds was completed in 210 seconds when the value was increased to 18 pm.

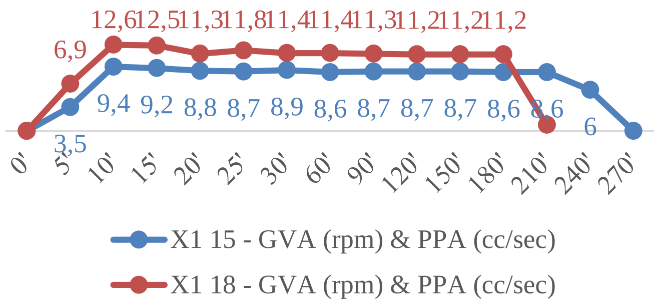


***Figure 2.*** *Screw Speed Trend (rpm)*

Figure 3 examined the pump speed trend when the pump speed and screw speed were 15 rpm and 18 rpm. Within the scope of the values seen in Figure 3., the effect of the pressure value change made in the working recipe of the extruder on the process has been evaluated, and it has been approved by the electronic and mechanical maintenance team that the change does not prevent the process from working correctly. The increase in the pressure value increased the pump speed, and as can be seen in Figure 3. when the pressure value was 15 rpm, the process that took 270 seconds was completed in 210 seconds when the value was increased to 18 rpm.

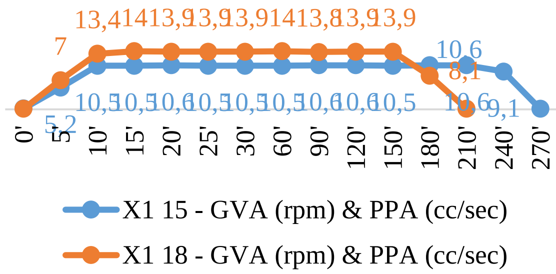


***Figure 3.*** *Pump Speed Trend (bar)*

After the changes made, 9 samples were taken from the process working with the new values. The curing properties of all samples were tested in the rheometer. As a result of the vulcanization test, chemical compatibility values and limit evaluations for 9 samples taken from the process are shown in Figure 4. These values give information about the flow behavior of the mixture in the process. Limits have been determined by the company's R&D Laboratory experts. As seen in Figure 4., all values are within the determined limits.

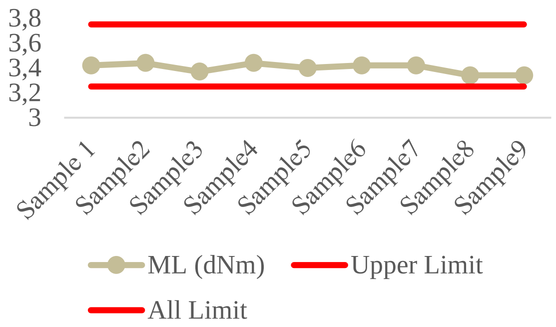


***Figure 4.*** *Chemical Compatibility Values and Limits*

The cooking time and limit evaluations for nine samples are shown in Figure 5. This value gives an idea about the number of tires produced per unit of time.

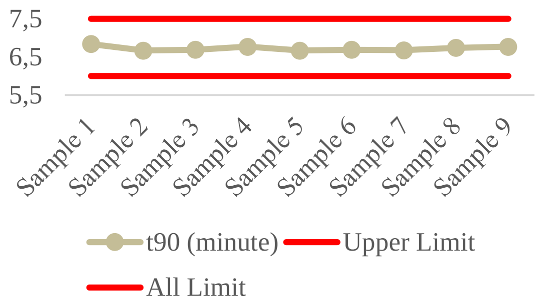


***Figure 5.*** *Cooking Time and Limit Values*

According to this evaluation, it is seen that the changes made in the extruder do not have a negative effect on the viscosity of the rubber material. In order to calculate the effect of the changes made on the cycle time, time analysis was made by separating each process down to its simplest element. The cycle times of the current situation are given in Table 5. After the time analysis study, the new state cycle times are shown in Table 6. Since zones 1, 2 and 3 can operate simultaneously, the zone with the maximum value from these three zones represents the cycle time. 2$^{nd}$ region has the maximum cycle time, and the actual cycle time has been reached with a tolerance of 6%. For example; It gives the value of cycle time = 4.8*(1+0.06) = 5.1 for the tire coded X1.

### 3.7. BX Product Quality Analysis

Problems in terms of quality were determined in the tires produced after the accelerated cycle. An unacceptable error is the formation of air pockets in the tread compound after the tire is cooked. The detected product defect was examined within the scope of the five-reason analysis, and action was taken. The five-reason analysis is as in Figure 6.The root cause identified is the manufacture of rubber strips with a wider mold opening. The wide opening of the mold reduces the cycle time. However, the problem encountered due to the increased width needs to be at an acceptable level. For this reason, the mold mouth width used in producing rubber strips has been reduced from 32.5 mm to 28.5 mm. In the examinations made after the action taken, it was observed that the problem disappeared.

## 4. Statistical Analysis

The hypothesis test was established using the cycle times given in Table 5 and Table 6, and the result was obtained with the T-Test. Whether there is an improvement in the current situation will be analyzed by T-Test. In this case, the hypotheses created are as follows:

H0: The optimization could not be performed.
H1: The improvement has been carried out.

The T-test result is given in Table 7. 26 observations were examined with a 95% confidence interval, and a t-value of 12.83 was reached. The acceptance value at both ends is 2.06. Since the value of 12.83 is outside the acceptance region, the H_0 hypothesis is rejected. H_1 hypothesis was accepted. According to these results, it has been proven by T-Test that an improvement is observed in the current situation

***Table 7.*** *T-Test Analysis of Cycle Times*

| | **Old Cycle Time** | **New Cycle Time** |
|---|---|---|
| **Average** | 5,30 | 4,88 |
| **Variance** | 0,19 | 0,11 |
| **Observation** | 26 | 26 |
| **Pearson Correlation** | 0,94 | |
| **Projected Average Difference** | 0,00 | |
| **Df** | 25,00 | |
| **t Stat** | 12,83 | |
| **P(T<=t) single-ended** | 0,00 | |
| **t Critical single-ended** | 1,71 | |
| **P(T<=t) double-ended** | 0,00 | |
| **t critical two-ended** | 2,06 | |

## 5. Conclusion

This study is an evaluation study using methods such as SWOT Analysis and Failure Modes and

| ***Table 5.*** *Baseline Cycle Times* **Tire Size Code** | **2022 Production Volume (pieces/year)** | **Cycle Time (Specified)** | **Tread Cycle Time (min)** | **1. Cycle Time (min)** | **2. Cycle Time (min)** | **3. Cycle Time (min)** | **Cycle Time (Real Time Study)** |
|---|---|---|---|---|---|---|---|
| X1 | 1617 | 5,42 | 2,7 | 1,6 | 5,3 | 3,1 | 5,6 |
| X2 | 144 | 5,42 | 2,8 | 2,6 | 5,2 | 3,1 | 5,5 |
| X3 | 168 | 5,42 | 2,7 | 4,7 | 4,1 | 3,0 | 5,0 |
| X4 | 312 | 5,42 | 2,6 | 1,7 | 5,3 | 3,1 | 5,6 |
| X5 | 552 | 5,42 | 2,5 | 2,4 | 5,0 | 3,0 | 5,3 |
| X6 | 432 | 5,42 | 2,5 | 2,4 | 5,0 | 3,0 | 5,3 |
| X10 | 3875 | 5,42 | 2,7 | 4,0 | 4,3 | 3,1 | 4,5 |
| X11 | 14258 | 5,42 | 2,8 | 2,6 | 5,0 | 3,1 | 5,3 |
| X12 | 13463 | 5,42 | 2,5 | 1,7 | 5,3 | 3,1 | 5,6 |
| X13 | 4894 | 5,42 | 2,7 | 2,6 | 5,1 | 3,2 | 5,4 |
| X14 | 4894 | 5,42 | 2,8 | 1,7 | 5,5 | 3,1 | 5,8 |
| X15 | 10918 | 5,42 | 2,8 | 2,5 | 5,3 | 3,0 | 5,7 |
| X18 | 3923 | 5,42 | 2,8 | 1,7 | 5,5 | 3,1 | 5,8 |
| X19 | 2324 | 5,42 | 2,5 | 2,4 | 5,0 | 3,0 | 5,3 |
| X20 | 1051 | 5,42 | 2,7 | 4,0 | 4,3 | 3,1 | 4,5 |
| X21 | 1356 | 5,42 | 2,7 | 2,5 | 5,3 | 3,0 | 5,6 |
| X22 | 1128 | 5,42 | 2,7 | 4,0 | 4,3 | 3,1 | 4,5 |
| X23 | 802 | 5,42 | 2,8 | 1,7 | 5,5 | 3,1 | 5,8 |
| X24 | 550 | 5,42 | 2,8 | 2,6 | 5,1 | 3,2 | 5,4 |
| X25 | 191 | 5,42 | 2,7 | 4,0 | 4,3 | 3,1 | 4,5 |
| X26 | 144 | 5,84 | 2,0 | 1,6 | 5,5 | 3,1 | 5,8 |

***Table 6.*** *New State Cycle Times*

| **Tire Size Code** | **Time [RPM:18] (min)** | **1. Cycle Time (min)** | **2. Cycle Time (min)** | **3. Cycle Time (min)** | **Cycle Time (Real Time Study)** |
|---|---|---|---|---|---|
| X1 | 2,2 | 1,6 | 4,8 | 3,1 | 5,1 |
| X2 | 2,3 | 2,6 | 4,7 | 3,1 | 5,0 |
| X3 | 2,2 | 4,7 | 3,6 | 3,0 | 5,0 |
| X4 | 2,1 | 1,7 | 4,8 | 3,1 | 5,1 |
| X5 | 2,1 | 2,4 | 4,5 | 3,0 | 4,8 |
| X6 | 2,1 | 2,4 | 4,6 | 3,0 | 4,8 |
| X10 | 2,2 | 4,0 | 3,8 | 3,1 | 4,3 |
| X11 | 2,3 | 2,6 | 4,5 | 3,1 | 4,7 |
| X12 | 2,1 | 1,7 | 4,8 | 3,1 | 5,1 |
| X13 | 2,2 | 2,6 | 4,6 | 3,2 | 4,9 |
| X14 | 2,3 | 1,7 | 5,0 | 3,1 | 5,3 |
| X15 | 2,3 | 2,5 | 4,8 | 3,0 | 5,1 |
| X18 | 2,3 | 1,7 | 5,0 | 3,1 | 5,3 |
| X19 | 2,1 | 2,4 | 4,6 | 3,0 | 4,9 |
| X20 | 2,2 | 4,0 | 3,8 | 3,1 | 4,3 |
| X21 | 2,2 | 2,5 | 4,8 | 3,0 | 5,1 |
| X22 | 2,2 | 4,0 | 3,8 | 3,1 | 4,3 |
| X23 | 2,3 | 1,7 | 5,0 | 3,1 | 5,3 |
| X24 | 2,3 | 2,6 | 4,6 | 3,2 | 4,9 |
| X25 | 2,2 | 4,0 | 3,8 | 3,1 | 4,3 |
| X26 | 1,7 | 1,6 | 5,1 | 3,1 | 5,4 |

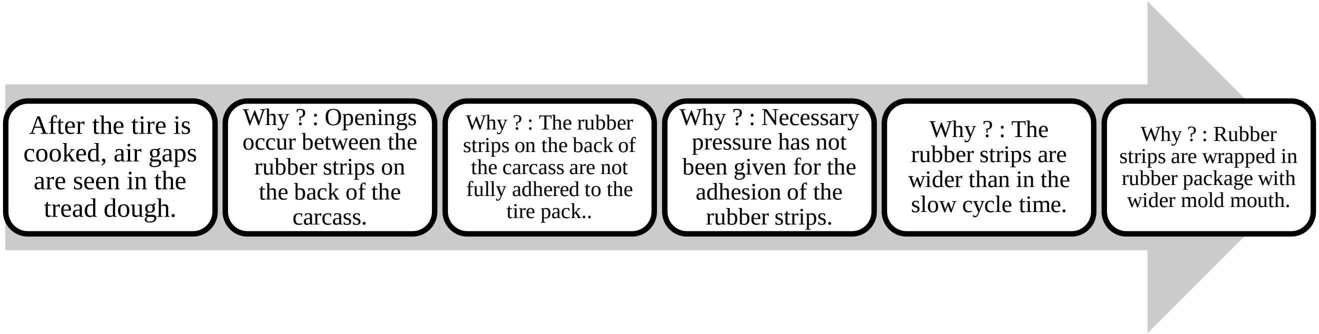


***Figure 6.*** *Root Cause Analysis of the Final Product*

***Table 8.*** *Tire Production Quantities*

| **Tire Size Code** | **2022 Production Volume (pieces/year)** | **Old Cycle Time (Identified )** | **New Cycle Time** | **Production Volume Savings (tire/year)** | **Tire Size Code** | **2023 Production Volume (pieces/year)** | **Old Cycle Time** | **New Cycle Time** | **Production Volume Savings (tire/year)** |
|---|---|---|---|---|---|---|---|---|---|
| X1 | 1617 | 5,42 | 5,1 | 100 | X14 | 4894 | 5,42 | 5,3 | 140 |
| X2 | 144 | 5,42 | 5,0 | 12 | X15 | 10918 | 5,42 | 5,1 | 636 |
| X3 | 168 | 5,42 | 5,0 | 15 | X16 | 3977 | 5,42 | 4,9 | 461 |
| X4 | 312 | 5,42 | 5,1 | 21 | X17 | 144 | 5,42 | 4,3 | 38 |
| X5 | 552 | 5,42 | 4,8 | 73 | X18 | 3923 | 5,42 | 5,3 | 112 |
| X6 | 432 | 5,42 | 4,8 | 52 | X19 | 2324 | 5,42 | 4,9 | 269 |
| X7 | 72 | 5,42 | 5,0 | 6 | X20 | 1051 | 5,42 | 4,3 | 277 |
| X8 | 12 | 5,42 | 5,1 | 1 | X21 | 1356 | 5,42 | 5,1 | 86 |
| X9 | 72 | 5,42 | 5,0 | 6 | X22 | 1128 | 5,42 | 4,3 | 297 |
| X10 | 3875 | 5,42 | 4,3 | 1020 | X23 | 802 | 5,42 | 5,3 | 25 |
| X11 | 14258 | 5,42 | 4,7 | 2080 | X24 | 550 | 5,42 | 4,9 | 58 |
| X12 | 13463 | 5,42 | 5,1 | 886 | X25 | 191 | 5,42 | 4,3 | 50 |
| X13 | 4894 | 5,42 | 4,9 | 567 | X26 | 144 | 5,84 | 5,4 | 11 |

Effects Analysis (FMEA) for two different production lines. SWOT Analysis was used to identify each production line's strengths, weaknesses, opportunities, and threats. As a result of this analysis, the advantages between both production lines were evaluated. By Failure Modes and Effects Analysis, the probabilities of detecting the errors encountered in the lines were evaluated, and the line where risky errors could be detected more easily was selected.
With the brainstorming method, a team of experts determined a perfect and even process that needs improvement. The study was completed by evaluating the effects of the changed parameters on the final product and process. It has been determined that the changes made do not constitute an obstacle regarding continuity and final product quality.
It is concluded that the BX line is superior to the AX line. Then, video-time analysis and line balancing work were carried out on the BX line, and an improvement of 10% was achieved. Annual tire revenue is 7299. Since the product quality will directly affect the demand for the product, Root Cause Analysis was applied on the BX line, and a solution was found to the quality problem of the selected line by reducing the width of the mold mouth used in the production of rubber strips from 32.5 mm to 28.5 mm.

Decreased cycle times were calculated for 26 different tire productions. Table 8. shows how many more tires can be produced with the new cycle in the time spent for the number of tires to be produced with the old cycle time.

A total of 7299 volumes were saved for 26 different tire types. For example, In the time taken to produce 1617 pieces of the X1 tire, 1717 pieces can be produced with the new cycle time. The production volume determined at the beginning of the period for 2022 is 71273 units. While 71273 tires were produced in 386,630.1 minutes with the old cycle time, the same pieces can be produced in 351.583.4 minutes with the new cycle times. Total time savings for 2022 production volume is 34,776.7 minutes, ie., 24.15 days. Total time saving is 9%. The % time improvements based on tire types are shown in Table 9.

***Table 9.*** *% Time Recovery by Measure*

| Tire Size Code | % Improvement by Time | Tire Size Code | % Improvement by Time |
|---|---|---|---|
| X1 | 5,85 | X14 | 2,78 |
| X2 | 7,89 | X15 | 5,50 |
| X3 | 8,16 | X16 | 10,38 |
| X4 | 6,35 | X17 | 20,84 |
| X5 | 11,68 | X18 | 2,78 |
| X6 | 10,75 | X19 | 10,39 |
| X7 | 8,16 | X20 | 20,84 |
| X8 | 6,68 | X21 | 5,93 |
| X9 | 8,23 | X22 | 20,84 |
| X10 | 20,84 | X23 | 3,00 |
| X11 | 12,73 | X24 | 9,47 |
| X12 | 6,17 | X25 | 20,84 |
| X13 | 10,38 | X26 | 6,93 |

With the new cycle times, the line's capacity has been increased by 10.24%. The firm can produce 6,398 units of the X26 tire with the highest cycle time of 34,776.7 minutes won and 8105 units of the X22 tire with the lowest cycle time. The averavalue of how many pieces of all tires can be produced with new cycle times in the time gained is 7155. The company shared symbolic information about the cost and sales prices of the tire group for which the process improvement study was carried out. The average production cost of the tire group, whose process has been improved, is 700 TL and the average selling price is 600 EUR. While the production cost of 7155 tires that can be produced in the time saved is 5008500 TL for the company, the selling price is 4293000 EUR. In the calculation made by taking the EUR exchange rate of 17.41 dated 29.05.2022, the company has made a profit of approximately 69.732.630 TL from the improvement work.

This study can be considered a comprehensive evaluation to improve the production process and increase efficiency. Methods such as SWOT Analysis and FMEA have helped to objectively evaluate the results by using them in stages such as identifying strengths and weaknesses, analyzing possible failure modes and their effects, and planning improvement steps.

## Author Statements:

- **Ethical approval:** The conducted research is unrelated to human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgment:** The authors declare that they have nobody or no company to acknowledge.
- **Author contributions:** The authors declare that they have equal rights in this paper.
- **Funding information:** The authors declare no funding to be acknowledged.
- **Data availability statement:** The data supporting this study's findings are available n request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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