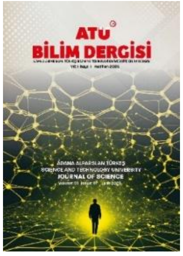
ADANA ALPARSLAN TÜRKEŞ BİLİM VE TEKNOLOJİ ÜNİVERSİTESİ BİLİM DERGİSİ

ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY JOURNAL OF SCIENCE

Research Article www.dergipark.com/atujscience



Efficiency analysis of clutch production line stations in the automotive industry using multi-criteria decision-making methods

Adnan Abdulvahitoğlu[1], Aslı Abdulvahitoğlu[2#], İrem Salman[3]

[1]Mudanya University, Department of Industrial Engineering, 16940 Bursa, Türkiye

ORCID: 0000-0002-2659-6709

[2]Adana Alparslan Türkeş Science and Technology University, Department of Mechanical Engineering, 01250 Adana, Türkiye

ORCID: 0000-0002-3603-6748

[3]Feka Automotive, 16140 Bursa, Türkiye

ORCID: 0009-0007-5406-8026

#Corresponding Author:

E-mail: aabdulvahitoglu@atu.edu.tr

Abstract

Today, companies that best meet customer demands stand out in the competitive landscape. As a result, businesses strive to improve their production processes to achieve timely delivery, high quality, and low cost. Lean manufacturing philosophy, which aims to reduce waste and increase efficiency, has become an effective strategy in achieving these goals. In this study, improvements were made in an automotive company by utilizing lean production techniques. Following these improvements, the efficiency of each station within the production line was evaluated. The new data obtained were analysed using Multi-Criteria Decision Making (MCDM) methods to determine at which station the optimum efficiency increase occurred. Additionally, a model was proposed to identify which stations should be prioritized in future improvement efforts. This model provides a scientific approach to assessing the tangible outcomes of lean manufacturing applications and contributes to the process of continuous improvement.

Keywords: Automotive Industry; Clutch Production; Efficiency; Lean Production; MCDM

Otomotiv endüstrisinde debriyaj üretim hattı istasyonlarının verimliliğinin çok kriterli karar verme yöntemleri ile analizi

Öz

Günümüzde müşteri taleplerini en iyi şekilde karşılayabilen firmalar, rekabet avantajı elde etmektedir. Bu nedenle şirketler; zamanında teslimat, yüksek kalite ve düşük maliyet hedeflerine ulaşabilmek adına üretim süreçlerini sürekli olarak iyileştirmeye çalışmaktadır. Bu hedeflere ulaşmada etkili bir strateji olan yalın üretim felsefesi, israfı azaltarak verimliliği artırmayı amaçlamaktadır. Bu çalışmada, bir otomotiv işletmesinde yalın üretim teknikleri uygulanarak gerçekleştirilen iyileştirmeler ele alınmıştır. Yapılan uygulamalar sonucunda, üretim hattında yer alan her bir istasyonun verimliliği değerlendirilmiştir. Elde edilen yeni veriler, Çok Kriterli Karar Verme (ÇKKV) yöntemleriyle analiz edilerek, verimlilik artışının en fazla hangi istasyonda gerçekleştiği tespit edilmiştir. Ayrıca, gelecekte yapılacak iyileştirme çalışmalarında hangi istasyonlara öncelik verilmesi gerektiğine dair bir model önerisi geliştirilmiştir. Bu kapsamda geliştirilen model, yalın üretim uygulamalarının somut çıktılarla değerlendirilmesine olanak tanımakta ve sürekli iyileştirme sürecine bilimsel bir yaklaşım sunmaktadır.

Anahtar Kelimeler: Otomotiv Sektörü; Debriyaj Üretimi; Verimlilik; Yalın Üretim; ÇKKV

Received: 15/04/2025

Revised: 2/05/2025

Accepted: 21/05/2025

Online Published: 20/06/2025

How to Cite: Abdulvahitoğlu A., Abdulvahitoğlu A. Salman İ., *"Efficiency Analysis of Clutch Production Line Stations in the Automotive Industry Using Multi-Criteria Decision-Making Methods"* Adana Alparslan Türkeş Science and Technology University Journal of Science, **1** (1): 28-39 (2025).

1. Introduction

The automotive industry is defined as a branch of industry encompassing the design, development, production, and marketing of motor vehicles. Globally, this sector is regarded as one of the fundamental drivers of economic growth in industrialized countries and represents one of the highest export volume sectors in Türkiye. The Turkish automotive industry operates in a highly competitive environment driven by price, performance, and particularly comfort, in line with technological advancements. Today, rapid changes in global economic dynamics, technology-driven transformations, and the increasing diversity of customer expectations have intensified competition across many sectors, including the automotive industry [1]. The key to success in this competitive environment lies in the ability to provide the most suitable, timely, high-quality, and cost-effective solutions to meet customer demands. High-quality production alone is no longer sufficient; timely delivery, efficient resource utilization, and cost minimization have also become strategically important for businesses [2].

In this context, it has become inevitable for businesses to restructure their customer-focused production processes and turn to various production strategies in order to gain competitive advantage. However, traditional production methods do not always produce the desired results; fundamental problems such as waste, inefficiency and quality problems are among the main difficulties faced by companies [3]. The lean production system, which was developed as a solution to these problems and is widely applied in many sectors today, offers businesses the opportunity to make their production processes more efficient, flexible and customer-focused [4]. The lean production approach dates its origins to the Toyota Production System (TPS), developed in Japan in the mid-20th century. TPS aims to systematically eliminate all activities that do not create added value in the production process, i.e. waste. The success of the system has enabled the lean production philosophy to be adopted not only in Japan but also worldwide and to spread internationally since the 1990s [5]. Subjects such as optimization of automobile clutch and power transmission units [6], clutch damping studies in passenger cars [7], improvement of clutch diaphragm springs [8], temperature analysis in dry friction clutches [9], effect of clutch systems on vehicle comfort [10], materials used in clutch disc production [11], surface hardness analysis in clutch manufacturing [12], optimization of clutch engagement process [13], design of clutch testing apparatus [14], safety effects of dry clutches [15], use of composite materials in clutch manufacturing [16], future clutch systems [17], design of aluminium clutch housing molds [18], improvement of thermo-mechanical properties of clutches [19], clutch cover design in light commercial vehicles [20] and clutch and shuttle lever locking mechanisms in tractors [21], have been studied in detail in the literature. In addition, studies on the effects of the lean manufacturing system on the socio-economic structures of enterprises [22], the contributions of lean manufacturing applications to firm profitability and efficiency [23] and the applicability of lean manufacturing techniques in logistics activities [24] reveal the multi-dimensional effects of this approach.

Although many theses have been written on clutch systems in Türkiye, it is noteworthy that these studies have not been widely disseminated through national and international academic publications. In this context, a bibliometric visualization conducted using VOSviewer software based on studies published in the Web of Science database is illustrated in Figure 1; related publications are widely dispersed and cover a broad thematic range. This dispersion reflects the complex structure of the automotive industry and the presence of numerous sub-sectors, resulting in a fragmented and multi-dimensional research landscape. The visualization results indicate that, to date, there appears to be no comprehensive study in the literature that holistically addresses lean manufacturing, clutch systems, and MCDM methods together.

Therefore, in this study, the improvement results of bottlenecks and waste elements identified using a lean production tool, aimed at increasing efficiency in the clutch disc production line of an automotive company, were analyzed using MCDM methods. In the first stage of the study, the theoretical foundation of the lean production philosophy was explained. In the second stage, the clutch production process was discussed. In the third stage, MCDM methods were introduced. In the fourth stage, the efficiency of the stations—where improvement works had been implemented based on the lean production philosophy—was analysed using MCDM methods. In the final stage, the findings were evaluated and various conclusions and recommendations were provided. The stages of the study are illustrated in Figure 2 below.

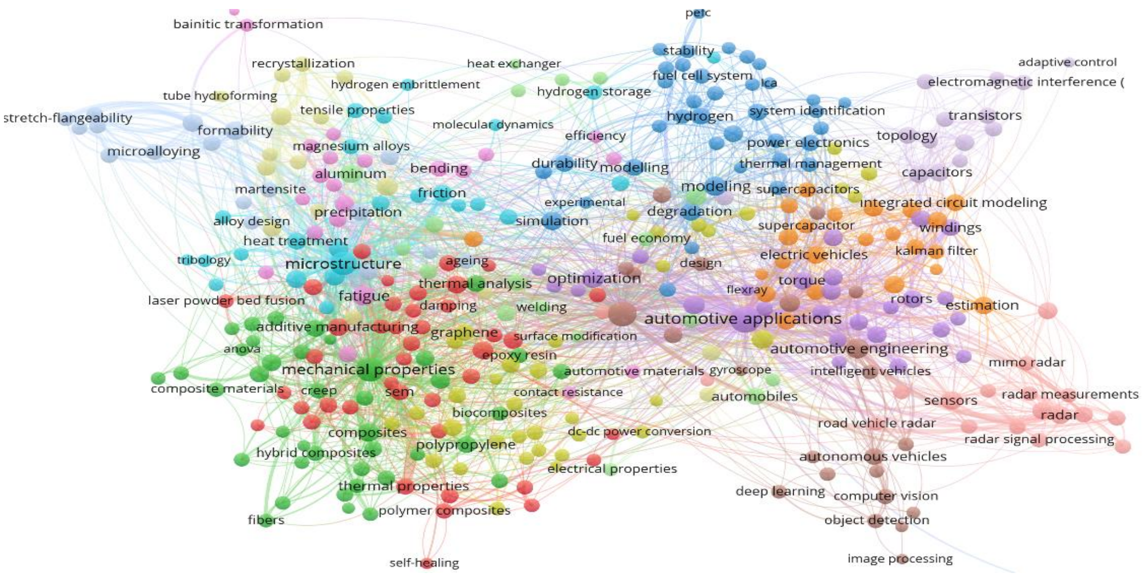


Figure 1. Visualization Showing Lack of Integrated Studies on Lean Production, Clutch Systems, and MCDM (created by the authors).

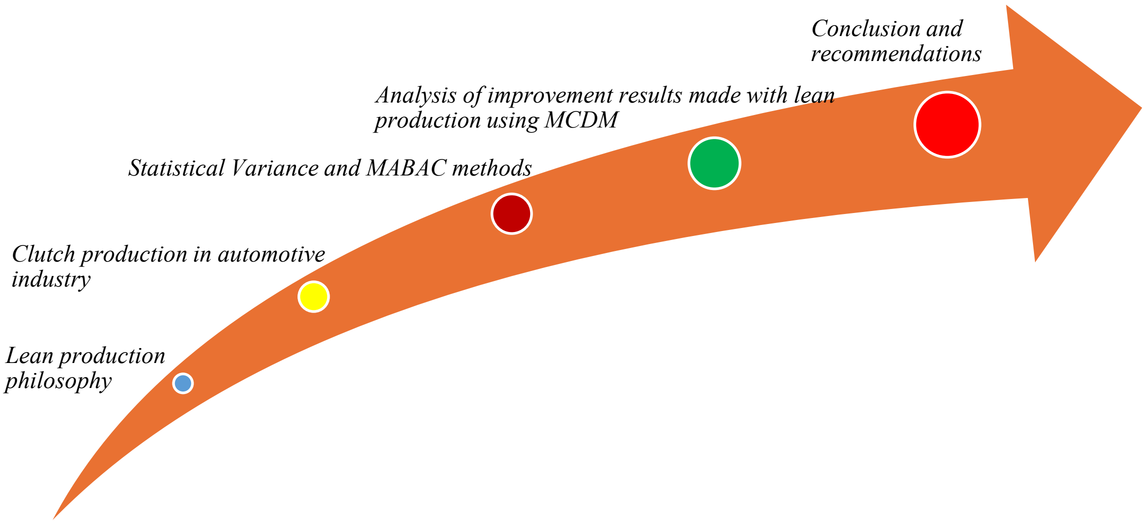


Figure 2. Stage of the study.

2. Methods

In the automotive industry, the application of lean manufacturing techniques in the clutch production line has strategic importance in terms of increasing process efficiency, reducing waste and reducing production costs. Especially by integrating lean manufacturing tools such as 5S, Kaizen, Value Stream Mapping (VSM) and Kanban, bottlenecks in the production line can be determined, cycle times can be optimized and issues such as inventory management can be carried out more effectively. The results of these applications can be evaluated with MCDM methods in order to analyse the effects of lean manufacturing processes on production performance in a systematic and measurable way. In this study, the improvement results of the stations in the clutch production line according to certain criteria were analysed using the Statistical Variance Integrated MABAC method and the efficiency levels of the stations were compared.

Thus, the MCDM approach has made it possible to prioritize among improvement criteria and to optimize the production process. In this respect, lean manufacturing practices not only contribute to increased operational efficiency, but also support strategic planning by providing a quantitative basis for decision-making processes. Such approaches play a significant role in the restructuring of production processes in both developed and developing countries. In this context, a bibliometric visualization conducted using VOSviewer software based on studies published in the Web of Science database illustrates the countries in which research focusing on lean manufacturing and clutch production is concentrated (Figure 3).

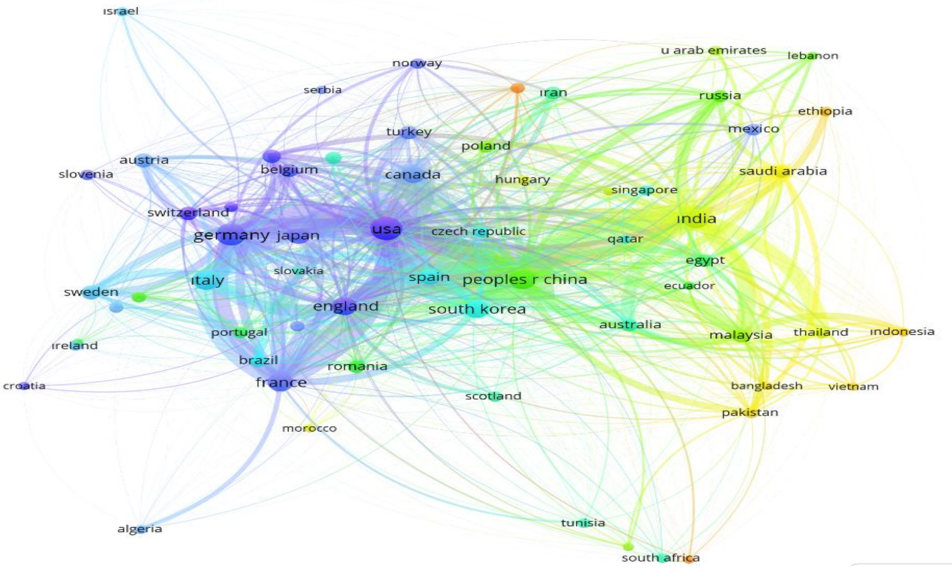


Figure 3. Countries with studies on lean manufacturing, clutch production (Created by the authors).

2.1 Lean production

Lean production is a holistic production approach that aims to prioritize processes that create value for the customer and systematically eliminate activities that do not create value and therefore cause waste. Waste covers all elements other than the minimum equipment, materials, time and labor required for production and is classified under seven headings: overproduction, waiting, transportation, excess inventory, unnecessary process, unnecessary movement, and product defects [25]. Reducing these wastes makes it possible to design production processes with lower costs, fewer errors, and fewer resource usage [26, 27]. The lean production approach is not limited to physical production; it also aims to analyse and eliminate delays in information flow, excess stock, and unnecessary process steps. Thus, businesses achieve a significant competitive advantage by reducing costs and increasing efficiency and quality [28].

The basic components of lean production include encouraging employee participation and adopting a culture of continuous improvement (Kaizen). This approach provides a holistic transformation in many areas, from production to supply chain management, from customer relations to quality control and human resources. In particular, the integration of suppliers into the lean production system creates direct gains such as improvement in product quality, reduction in costs, and shortening in delivery times, while also strengthening cooperation between businesses [29].

The flexibility offered by lean production enables businesses to respond quickly and effectively to changing market conditions; this creates a strategic advantage, especially in sectors such as automotive, which are sensitive to technological transformation and customer demands. In this context, lean production is not only a production model, but also considered one of the fundamental building blocks of contemporary business management [30]. As a result, the lean production approach aims to increase efficiency, reduce costs, and improve quality by preventing waste in all processes from customer order to shipment; thus, it contributes to companies gaining long-term competitive advantage [31]. There are eleven lean production techniques. These are [22];

i. Just In Time (JIT)
ii. Value Stream Mapping
iii. Pull System (Kanban)
iv. Continuous Improvement (Kaizen)
v. Error-Proofing Systems (Poka-Yoke)
vi. 5S
vii Balanced Production (Heijunka)
viii. Jidoka (Automation)
ix. Work and Line Balancing (Yamazumi)

x. Total Productive Maintenance
xi. Single Minute Exchange of Dies (SMED)

In this study, the improvement results of a clutch production facility were analysed with MCDM techniques by applying Value Stream Mapping (VSM). As a result of the analysis, a model was proposed in which the stations that should be addressed first for future improvements in the clutch production line were determined.

2.2 Clutch production

The clutch is a basic transmission organ that provides the connection between the engine and the transmission. It enables the vehicle to be started, stopped, and its speed to be changed depending on the driver's request. The tasks of clutch systems [32];

i. Allowing gear changes while the vehicle is in motion,
ii. Transferring torque to the transmission,
iii. Ensuring a smooth start by reducing torsional vibrations and irregularities coming from the engine,
iv. Equalizing the engine and transmission output speeds by regulating the torque flow.

In order to change gears, the engine must be separated from the transmission; this process is undertaken by the clutch. It ensures that the engine and gearbox with different rotational speeds are reunited in a harmonious way and dissipates the heat generated in a way that will not harm it. It also acts as a safety valve that protects the transmission against sudden and high torques.

When the clutch operates, relative movements occur between the internal components and friction forces occur as a result of these movements. The effect created by these forces is called hysteresis and is controlled by friction. Hysteresis washers increase driving comfort by damping vibrations coming from the transmission [33].

The clutch provides a connection between 2 shafts that transfer motion and torque, which can separate the drive shaft from the driven shaft if desired [34]. Clutch systems allow the operation of high inertia loads with small forces and are also widely used in all types of production machines [35]. The clutch system is less complex than the engine and transmission and consists of 3 main components and 2 auxiliary components (Figure 4). These are [34];

i. Clutch Pressure Plate
ii. Clutch Disc
iii. Clutch Bearing
iv. Flywheel (Auxiliary)
v. Clutch Fork (Auxiliary)

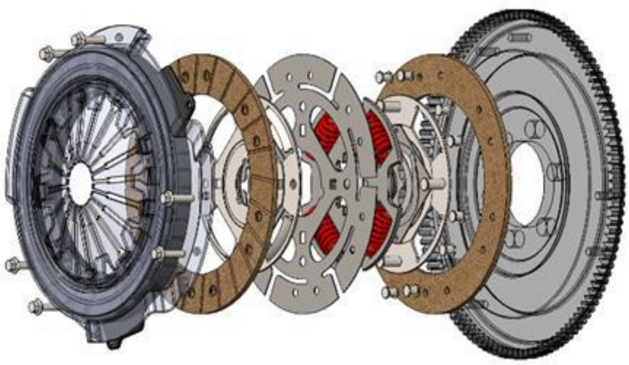


Figure 4. Clutch system [34].

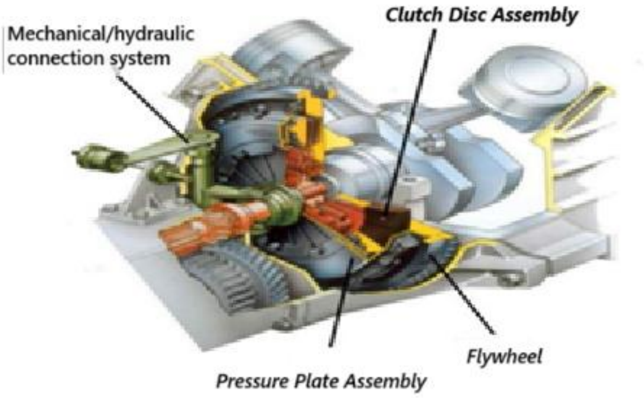


Figure 5. Parts of the clutch system [10].

The clutch system is the system that provides separation and engagement between the engine and the gearbox in manual vehicles. The parts in the clutch system, which protect the gearbox by preventing the irregular vibrations coming from the engine from being dampened and transferred to the gearbox during engagement, have different functions within themselves. The main parts that make up the system, the Flywheel, the Pressure Assembly and the Disc Assembly, are shown in Figure 5 as a whole [10].

Clutches are a fundamental element in the transmission systems of automobiles and play a critical role in the efficient and sustainable operation of vehicles. Clutches, which act as an intermediary between the engine and the gearbox, facilitate the starting, braking and gear changing processes of the vehicle by enabling the engagement and disengagement of the transmission systems; they also contribute to the protection of the system components [36]. The importance of this component cannot be ignored, because poor clutch performance can lead to premature failure of other parts of the transmission system, as well as pose safety risks for the driver and passengers [37]. In today's context, where technological developments are accelerating and demands in engineering and industry are increasing, research and development of materials and production processes are becoming more important than ever. Modern materials must meet high performance and durability requirements; it is also important that they are produced in compliance with environmental and safety standards [11]. Therefore, in this study, clutch production line stations are considered holistically, and the results of improvements made in a company in Bursa are shown in Table 1.

Table 1. Results of line improvement in disc production [38].

Assembly Line	Number of operator	Cycle time (minute)	Operation time (minute)	Downtime (minute)	Defective part count	Die change time (minute)	Production Quantity	Number of die changes	Overall Equipment Effectiveness (OEE)(%)
Criterion Type	min	min	min	min	min	min	max	max	max
Op10 Disc	1	64	1105	5	1	25	1025	2	86.60
Op20 Disc	1	45	1111	29	2	20	1024	2	60.77
Op30 Disc	0.5	45	1132	8	4	20	1022	2	60.54
Op40 Disc	1	42	1073	7	3	30	1018	2	56.33
Op10 Disc Assembly	0	35	1047	33	2	20	1015	3	46.85
Op20 Disc Assembly	1	25	1118	22	3	20	1013	2	33.37
Firewall	1	56	1251	9	1	0	1010	0	74.67
Pressure Plate Packaging	1	70	1253	7	0	0	1009	0	93.33

2.3 Multi- Criteria Decision Making

In the decision-making process, the number of alternatives and the factors influencing the selection of these alternatives play a significant role. As the number of alternatives and influencing factors increases, the process becomes more complex, thus requiring the use of MCDM methods to reach optimal solutions and make the most accurate decisions. There are nearly 200 MCDM methods available in the literature [39]. In MCDM methods, the decision-making process typically follows the sequence of steps illustrated in Figure 6. The data presented in Table 1 are objective in nature and do not require the intervention of decision-makers; therefore, the Standard Deviation method was used for weighting. The alternatives were ranked using the MABAC method, which is one of the most recent MCDM techniques. This method was preferred due to its computational simplicity, sensitivity to decision-makers' evaluations, and ability to provide direct comparison with the ideal performance.

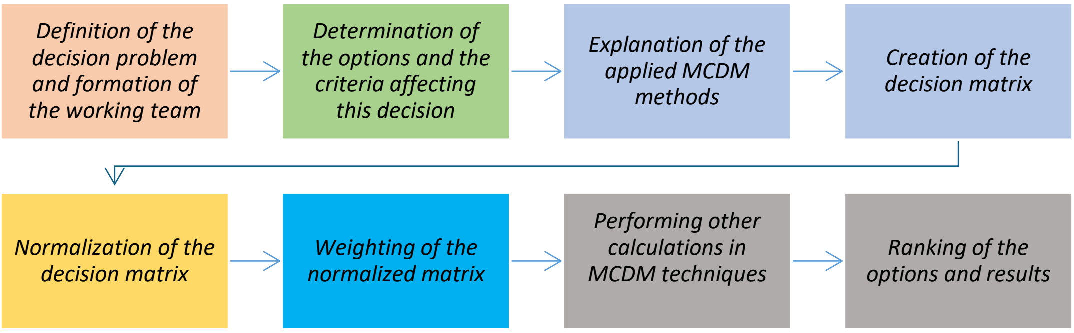


Figure 6. Multi-Criteria Decision-Making (MCDM) Process [40].

2.3.1. Statistical variance method

The Statistical Variance (SV) method, also known as the Variance Method, was developed by Rao and Patel in 2010 to determine the objective weights of criteria [41]. The calculation steps of the SV method are outlined below [42].

Step 1. Construction of the decision matrix. The decision matrix X of size (m×n) is constructed as shown in Equation (1). The element x_{ik} represents the values in the decision matrix, where n denotes the alternatives and m represents the criteria.

$$X=\begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \dots & X_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \quad (1)$$

Step 2. Normalization of the decision matrix. Criteria with a maximization direction are normalized using Equation (2), while criteria with a minimization direction are normalized using Equation (3).

$$n_{ij}^{*} = \frac{X_{ij}-X_j^{min}}{X_j^{max}-X_j^{min}} \quad (2)$$

$$n_{ij}^{x}=\frac{X_j^{max}-X_{ij}}{X_j^{max}-X_j^{min}} \quad (3)$$

Step 3. Calculation of the variance values of the criteria. The variance (σ^2) value for each criterion is calculated using Equation (4). In the equation, V_j represents the variance of the data corresponding to the j[th] criterion.

$$V_j = \left(\frac{1}{n}\right) \sum_{i=1}^{n} \left(a_{ij}^{*} - \bar{a}_{ij}^{*}\right)^2 \quad (4)$$

Step 4. Calculation of the weights of the criteria. The weight of each criterion is determined using Equation (5).

$$W_{jSV} = \frac{V_j}{\sum_{i=1}^{m} V_j} \tag{5}$$

2.3.2. MABAC method

MABAC (Multi-Attributive Border Approximation Area Comparison) is one of the Multi-Criteria Decision-Making (MCDM) methods. Developed by Pamučar and Ćirović in 2015, the MABAC method is based on evaluating decision alternatives by considering the distances of their criterion functions from the border approximation area. The MABAC method is implemented using the following steps [43-45].

Step 1. Constructing the decision matrix. Once the problem is defined, the alternatives and criteria related to the problem are used to construct the decision matrix using Equation (6).

$$X=\begin{bmatrix} x_{11}\ x_{12} & \cdots & x_{1n} \\ x_{21}\ x_{22} & \ddots & x_{2n} \\ \dots. & \dots. & \dots. \\ x_{m1} x_{m2} & \dots.. & x_{mn} \end{bmatrix} \tag{6}$$

Step 2. Normalization of the decision matrix: For benefit-oriented criteria, Equation (7) is used, while for cost-type criteria, Equation (8) is applied.

$$r_{ij} = \frac{x_{ij} - X_j^{min}}{X_j^{max} - X_j^{min}} \tag{7}$$

$$r_{ij} = \frac{x_{ij} - X_j^{max}}{X_j^{min} - X_j^{max}} \tag{8}$$

Step 3. Calculation of the weighted normalized matrix: Using the weights determined for each criterion through the SV method, the normalized values are weighted as shown in Equation (9).

$$V_{ij} = W_j * \left(1 + r_{ij}\right) \tag{9}$$

Step 4. Obtaining the border proximity matrix. The border proximity area matrix (G) is obtained using Equations (10) and (11).

$$g_i = \left(\prod_{i=1}^{m} V_{ij}\right)^{1/m} \tag{10}$$

$$G = [g_i]_{1*n} \tag{11}$$

Step 5. Determining the distances of the alternatives from the border proximity values.
These distances are calculated using Equations (12) and (13).

$$Q = (v_i - G) = \begin{bmatrix} v_{11} - g_1 & v_{12} - g_2 & \dots & v_{1n} - g_n \\ v_{21} - g_1 & v_{22} - g_2 & \cdots & v_{1n} - g_n \\ \dots & \dots & \dots & \dots \\ v_{m1} - g_2 & v_{m2} - g_2 & \cdots & v_{mn} - g_n \end{bmatrix} = \begin{bmatrix} q_{11}\ q_{12} & \dots & q_{1m} \\ q_{21}\ q_{22} & \cdots & q_{2m} \\ \vdots & \ddots & \vdots \\ q_{n1}\ q_{n2} & \cdots & q_{nm} \end{bmatrix} \tag{12}$$

$$A_i \in \begin{cases} G^+ & if \quad q_{ij} > 0 \\ G & if \quad q_{ij} = 0 \\ G & if \quad q_{ij} < 0 \end{cases} \tag{13}$$

Step 6. Ranking of the alternatives. The alternatives specified in the decision matrix X are calculated using Equation (14) and then ranked in descending order.

$$S_i = \sum_{j=1}^{n} q_{ij} \tag{14}$$

3. Results and Discussion

There are a total of 8 stations in the clutch production line. The results obtained from improvements made using lean manufacturing techniques through the VSM are presented in Table 1. In Table 1, the improvement results are listed under 9 main headings. In this study, the significance level of each improvement result will first be calculated using the Statistical Variance method. Then, using the obtained significance levels, the performance values of the 8 stations on the production line will be determined through a comparative analysis conducted with the MABAC method. The normalized version of the data in Table 1 using the Statistical Variance method is shown below in Table 2.

Table 2. Normalized Matrix in the Statistical Variance Method

Assembly Line	Number of operator	Cycle time (minute)	Operation time (minute)	Downtime (minute)	Defective part count	Die change time (minute)	Production Quantity	Number of die changes	Overall Equipment Effectiveness (OEE)(%)
Criterion type	min	min	min	min	min	min	max	max	max
Op10 Disc	0	0.133	0.718	1	0.75	0.167	0.667	1	0.888
Op20 Disc	0	0.556	0.689	0.143	0.5	0.333	0.667	0.938	0.457
Op30 Disc	0.5	0.556	0.587	0.893	0	0.333	0.667	0.813	0.453
Op40 Disc	0	0.622	0.874	0.929	0.25	0	0.667	0.563	0.383
Op10 Disc Assembly	1	0.778	1	0	0.5	0.333	1	0.375	0.225
Op20 Disc Assembly	0	1	0.655	0.393	0.25	0.333	0.667	0.25	0
Firewall	0	0.311	0.01	0.857	0.75	1	0	0.063	0.689
Pressure Plate Packaging	0	0	0	0.929	1	1	0	0	1

As a result of the calculations performed using the Statistical Variance method, the weights of the performance evaluation criteria for the clutch production line stations are shown below in Table 3.

Table 3. Performance Evaluation Criteria and Weights for Clutch Production Line Stations.

Criteria	Number of operator	Cycle time (minute)	Operation time (minute)	Downtime (minute)	Defective part count	Die change time (minute)	Production Quantity	Number of die changes	Overall Equipment Effectiveness (OEE)(%)
Weight	0.1177	0.0934	0.1166	0.1367	0.0911	0.1144	0.1063	0.1291	0.0946

After the weights of each performance criterion in the clutch production line were determined, the efficiency of the eight production stations was analysed comparatively using the MABAC method. The normalized decision matrix used in the MABAC method is presented in Table 4.

Table 4. Normalized Matrix in the MABAC Method

Assembly Line	Number of operator	Cycle time (minute)	Operation time (minute)	Downtime (minute)	Defective part count	Die change time (minute)	Production Quantity	Number of die changes	Overall Equipment Effectiveness (OEE)(%)
Criterion type	min	min	min	min	min	min	max	max	max
Criterion weight	0.118	0.093	0.117	0.137	0.091	0.114	0.106	0.129	0.095
Op10 Disc	0	0.133	0.718	1	0.75	0.167	0.667	1	0.888
Op20 Disc	0	0.556	0.689	0.143	0.5	0.333	0.667	0.938	0.457
Op30 Disc	0.5	0.556	0.587	0.893	0	0.333	0.667	0.813	0.453
Op40 Disc	0	0.622	0.874	0.929	0.25	0	0.667	0.563	0.383
Op10 Disc Assembly	1	0.778	1	0	0.5	0.333	1	0.375	0.225
Op20 Disc Assembly	0	1	0.655	0.393	0.25	0.333	0.667	0.25	0
Firewall	0	0.311	0.01	0.857	0.75	1	0	0.063	0.689
Pressure Plate Packaging	0	0	0	0.929	1	1	0	0	1

After the processes indicated in the other stages of the MABAC method (formulas (6)–(14)) were carried out, the scores and rankings of each production line station were determined, as shown in Table 5 below. The stations ranked as the top three with the highest performance were stations 6, 7, and 8, respectively.

Table 5. MABAC Scores and Performance Ranking of Clutch Production Line Stations

Number	Line station	MABAC Score	MABAC Score	OEE ranking
1	Op10 Disc	0.116959	8	2
2	Op20 Disc	-0.01676	4	4
3	Op30 Disc	0.070679	6	5
4	Op40 Disc	0.002072	5	6
5	Op10 Disc Assembly	0.079277	7	7
6	Op20 Disc Assembly	-0.09984	1	8
7	Firewall	-0.08412	2	3
8	Pressure Plate Packaging	-0.06037	3	1

As a result of lean manufacturing, the ranking of the stations in the production line based on the overall equipment effectiveness (OEE) values showed that the top three stations were station 8, station 1, and station 7. As seen here, the total equipment effectiveness obtained through the lean manufacturing process evaluates each station in the production line individually. However, when all processes are evaluated as a whole using MCDM (Multi-Criteria Decision Making), the results change. The key observation here is that, when considering the production line as a whole, the stations with the lowest performance according to the MCDM evaluation are identified. These stations, in order from the lowest performance, are station 1, station 5, and station 3. In the subsequent lean manufacturing study, focusing on improvements specifically at these three stations will contribute to achieving a holistic performance improvement in clutch production. The analysis was conducted using Microsoft Excel.

4. Conclusions

In today's competitive business world, businesses that can best meet customer expectations stand out. In this direction, companies aim to deliver their products and services on time, with high quality and at low cost. Lean production, which is an effective method for achieving these goals, is a strategic approach that aims to increase process efficiency by reducing waste. VSM, one of the lean production techniques, analyses the production process from beginning to end, visualizes waste elements and improves processes. VSM, which visualizes the production flow through special symbols, provides holistic information about cycle times, stock levels, transitions between stations and quality control points.

In this study, the production process of an automotive sub-industry company producing clutch discs in Bursa province was analysed with lean production techniques. The clutch system is a critical component in the automobile's power transmission mechanism and undertakes an important function in terms of driving safety, comfort, fuel efficiency and vehicle life by controlling the torque transfer between the engine and transmission. The quality and precision production of this system, which ensures that the engine continues to operate especially during gear changes, has become even more critical with the developing automatic and hybrid technologies.

Lean production aims not only to increase operational efficiency, but also to systematically eliminate activities that do not create value and to adopt a culture of continuous improvement with employee participation. However, as the findings of the study reveal, the integration of MCDM methods is important to increase the effectiveness of lean production applications. MCDM allows for the numerical and systematic analysis of the improvements made, and ensures that which applications are more effective or ineffective and that resources are directed to priority areas.

In conclusion, the lean production approach integrated with MCDM contributes to the optimization of production processes; it provides not only increased efficiency but also a scientific basis for strategic decision-making processes. This approach can be re-applied by changing both the lean production technique used and the decision-making method used in the analysis; the results obtained can be evaluated with sensitivity analysis. Thus, businesses can develop more effective improvement strategies in order to achieve maximum efficiency, and decision support mechanisms can be provided to managers.

Authors' Contributions

AA: Conceptualization, Methodology, Software, Validation, Writing- Original Draft. **AA:** Writing - Review & Editing, Visulization, Validation. **İS:** Data curation, Writing- Original Draft.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Conflict of Interest

There is no conflict of interest in this study.

References

[1] Gül, E. C. (2018). İnsan Kaynakları Yönetiminin Bağlamsal (Contextual) Modele Göre Stratejikleşmesi Ve Kalite Anlayışının Aktörler Arası İlişkilere Etkisi. Uluslararası İktisadi ve İdari Bilimler Dergisi, 4(1), 70-83.
[2] Ceran, M. B. (2018). Sürdürülebilir rekabet üstünlüğü sağlamada zaman etkenli faaliyet tabanlı maliyetleme ve tarım makinaları sektöründe uygulanabilirlik düzeyinin belirlenmesi üzerine bir araştırma. Doktora Tezi, Selçuk Üniversitesi Sosyal Bilimler Enstitüsü, Konya.
[3] Demirkıran, D. (2019). Yalın üretim teknikleri ve Porsche firmasında uygulanması. Y.lisans Tezi, İstanbul Kültür Üniversitesi Lisansüstü Eğitim Enstitüsü, İstanbul.
[4] Aydın, H. (2009). Yalın üretim sistemi, değer akış haritalama yöntemi ve yalın üretim sisteminin çalışanlara etkileri. Doktora tezi, Marmara Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.
[5] Solding, P., & Gullander, P. (2009). Concepts for simulation based value stream mapping. In Proceedings of the 2009 Winter Simulation Conference (WSC), 2231-2237, IEEE.
[6] Ozansoy, O. (2015). Multi-objective optimization of dynamic behaviour of automotive clutch system and power transmission. Doktora Tezi, İTÜ Fen Bilimleri Enstitüsü, İstanbul.
[7] Avcı, M. (2022). Binek araçlarda debriyajın titreşim sönümleme performansının iyileştirilmesi ve prototip üretimi. Y.lisans Tezi, Uludağ Üniversitesi, Fen Bilimleri Enstitüsü, Bursa.
[8] Özbakiş, M. (2008). Debriyaj sistemlerinde kullanılan diyafram yayların karakteristiğinin incelenmesi ve optimizasyonu. Y.lisans Tezi, Dokuz Eylül Üniversitesi, İzmir.
[9] Abdullah, O. I., & Schlattmann, J. (2012). Finite element analysis of temperature field in automotive dry friction clutch. Tribology in Industry, 34(4), 206.
[10] Dündar, A. (2022). Debriyaj sistemlerinde yastıklamalı yay üretim prosesinin araç konforuna etkisinin incelenmesi. Y.lisans Tezi, Uludağ Üniversitesi, Fen Bilimleri Enstitüsü, Bursa.
[11] Necsulescu, D. A., Cıurdas, M., & Robu, A. Studıes And Research On The Materıals Used In The Manufacture Of Clutch Dıscs. U.P.B. Sci. Bull., Series B, 86(4), 269-280.
[12] Gavaskar, S. S., Karthick, K., & Bibin, C. (2021). Statistical analysis on hardness of clutch facing at various stages in clutch face manufacturing. Materials Today: Proceedings, 46, 3730-3734.
[13] Garofalo, F., Glielmo, L., Iannelli, L. & Vasca, F., (2002). Optimal tracking for automotive dry clutch Engagement. IFAC Proceedings Volumes, 35(1), 367-372.
[14] Lu, Y., Guo, B., Fan, W., & Jin, L. (2011, August). Design and Realization of Testing and Analyzing Apparatus for Automobile Clutch. In 2011 Second International Conference on Digital Manufacturing & Automation (pp. 381-384). IEEE.
[15] Pourgol-Mohammad, M., Hejazi, A., Soleimani, M., Ghasemi, P., Ahmadi, A., & Jalali-Vahid, D. (2017). Design for reliability of automotive systems; case study of dry friction clutch. International Journal of System Assurance Engineering and Management, 8, 572-583.
[16] Gaikwad, P. B., Girme, S. R., Bagal, P. N., Raut, N. N., & RM, K. (2017). A review on alfa composite material for automotive clutch plate application. JournalNX, 3(04), 22-26.
[17] Freitag, J., Gerhardt, F., Hausner, M., & Wittmann, C. (2010, April). The clutch system of the future. In Proc. 9th Schaeffler Symp (pp. 1-10).
[18] Jeong, S. I., Jin, C. K., Seo, H. Y., Kim, J. D., & Kang, C. G. (2016). Mold structure design and casting simulation of the high-pressure die casting for aluminum automotive clutch housing manufacturing. The International Journal of Advanced Manufacturing Technology, 84, 1561-1572.
[19] Çakmak, T. (2018). Taşıtlarda kullanılan debriyaj sistemlerinin termo-mekanik özelliklerinin iyileştirilmesi. Y.lisans Tezi, Uludağ Üniversitesi Fen Bilimleri Enstitüsü, Bursa.

[20] Köprübaşı, U. (2024). Hafif ticari araç debriyaj kapağının optimum tasarımı. Y.lisans Tezi, Uludağ Üniversitesi Fen Bilimleri Enstitüsü, Bursa.
[21] Çakır, Z., Kullukçu, A., Karayel, D., Atalı, G., & Özkan, S. S. (2018). Kabinli Traktörlerde Çubuklu Debriyaj ve Direksiyon Altı Shuttle Kolunun Kilitleme Mekanizmasının Tasarımı ve Analizi. Academic Perspective Procedia, 1(1), 458-466.
[22] Etçi, F., & Terzi, A. (2024). Yalın Üretim Tekniklerinin İşletmelerin Sosyo-Ekonomik Boyutları Üzerindeki Etkileri Ve Sürdürülebilir Maliyet Muhasebesi Perspektifinden İncelenmesi. Uluslararası Muhasebe ve Finans Araştırmaları Dergisi, 6(1), 1-18.
[23] Çetindaş, A. (2024). Yalın üretimin maliyetler ve firma performansı üzerine etkisi. Akademik Araştırmalar ve Çalışmalar Dergisi (AKAD), 16(30), 256-264.
[24] Uçar, A., & Şirin, B. T. (2024). İç lojistik faaliyetlerinde yalın tekniklerin kullanılması ve bir uygulama. Black Sea Journal of Engineering and Science, 7(3), 423-435.
[25] Taj, S. (2008). Lean Manufacturing Performance İn China: Assessment Of 65 Manufacturing Plants. Journal of Manufacturing Technology Management, 19(2), 217-234.
[26] Wyrwicka, M. K., & Mrugalska, B. (2017). Mirages of lean manufacturing in practice. Procedia engineering, 182, 780-785.
[27] Panwar, A., Jain, R., & Rathore, A. (2015). Lean implementation in Indian process industries–some empirical evidence. Journal of Manufacturing Technology Management, 26(1), 131-160.
[28] Sarıkaya, H. A., Soydemir, E. K., Sardaş, B., Çayır Ervural, B., et al. (2022). Bisküvi Üretim Hatlarında Hazırlık Sürelerinin Azaltılmasına Yönelik Yalın Üretim ve Smed Uygulaması. Endüstri Mühendisliği, 33(2), 413-439.
[29] Chun Wu, Y. (2003). Lean manufacturing: a perspective of lean suppliers. International Journal of Operations & Production Management, 23(11), 1349-1376.
[30] Hines, P., Holweg, M., & Rich, N. (2004). Learning to evolve: a review of contemporary lean thinking. International journal of operations & production management, 24(10), 994-1011.
[31] Yurtseven, Ç., Aydın, D., Ekici, M., Aktepe, S., Yürek, E. E., & Orbak, A. Y. Değer Akış Haritalama Tekniğinin Otomotiv Sektöründe Bir Uygulaması. Uludağ Üniversitesi Mühendislik Fakültesi Dergisi, 29(1), 19-36.
[32] Kabacaoğlu, S., Pekedis, M., & Yıldız, H. (2021). Debriyaj Sistemlerinde Kullanılan Diyafram Yaylarda Formun Yorulma Dayanımı ve Mekanik Karakteristiğe Olan Etkisinin Teorik ve Deneysel Olarak İyileştirilmesi. Uludağ Üniversitesi Mühendislik Fakültesi Dergisi, 26(3), 1121-1138.
[33] Sayaca, S., & Bayram, A., (2008). Debriyajlardaki Histerezis Rondelası İçin Yeni Bir Malzeme Kullanımı ve Parça Geometrisinin Değiştirilmesi. Uludağ Üniversitesi Mühendislik Fakültesi Dergisi, 13(1), 129-142.
[34] Yıldız, Ö., Eş, C., Akbulut, S., Kaymaz, İ. C., Kurt, U., & Çakılı, H. (2022). Debriyaj Diski Dış Ana Sac Batma Prosesinin Etkilerinin İncelenmesi. Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 10(5), 127-136.
[35] Purohit, R., Khitoliya, P., & Koli, D. K., (2014). Design and finite element analysis of an automotive clutch assembly. Procedia materials science, 6, 490-502.
[36] Hajnayeb, A., Fernando, J. S., & Sun, Q. (2022). Effects of vehicle driveline parameters and clutch judder on gearbox vibrations. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 236(1), 84-98.
[37] Cakmak, S., Yildiz, Ö., Kaymaz, İ. C., Kurt, U., & Eş, C. (2022). Alternatif Polimer Esaslı Malzemelerin Debriyaj Diski Stoperine Entegrasyonu. International Joint Conference on Engineering, Science and Artificial Intelligence-IJCESAI 2022, 17 Temmuz 2022, Bursa
[38] Salman, İ. & Yıldız, A., (2024). Değer Akış Haritalama (VSM) Yöntemi Kullanılarak Debriyaj Üretim Sürecinin İyileştirilmesi. 6th International Conference on Applied Engineering and Natural Sciences, September 25-26, 2024 : Konya, Türkiye.
[39] Abdulvahitoğlu, A., Vural, D. & Macit, İ., (2024a). Selecting Facility Location of Gendarmerie Search and Rescue (GSR) Units; An Analysis of Efficiency in Disaster Response. Computers & Industrial Engineering, 197;110639.
[40] Abdulvahitoğlu, A., Abdulvahitoğlu, A. & Cengiz, N., (2024b)., A Comprehensive Analysis of Apricot Drying Methods via Multi-Criteria Decision Making Techniques. Journal of Food Process Engineering, 47:e14759.
[41] Yürüyen, A.A., Ulutaş, A. & Özdağoğlu, A., (2023). Lojistik işletmelerinin performansının bir hibrit ÇKKV modeli ile değerlendirilmesi. BMİJ, 11 (3): 731-751
[42] Rao, R. V., & Patel, B. K. (2010). A subjective and objective integrated multiple attribute decision making method for material selection. Materials & Design, 31(10), 4738 4747.
[43] Pamučar, D. & Ćirović, G. (2015). The Selection of Transport and Handling Resources in Logistics Centers Using Multi-Attributive Border Approximation Area Comparison (MABAC), Expert Systems with Applications, 42(6), 3016-3028.
[44] Stojanović, I. & Puška, A. (2021). Logistics Performances of Gulf Cooperation Council's Countries in Global Supply Chains, Decision Making: Applications in Management and Engineering, 4(1) : 174-193.
[45] Raj, D., Maity, S. R., & Das, B. (2024). Optimization of process parameters of laser cladding on AISI 410 using MEREC integrated MABAC method. Arabian Journal for Science and Engineering, 49(8), 10725-10739.