Düzce University Journal of Science & Technology

Research Article

Evaluation of the Contribution of Model Factories to Productivity with Multi-Criteria Decision Making Method: Application of Learn & Transform Program

Ali SEVİNÇ[a] *

[a] *KOSGEB Ankara Sincan Müdürlüğü, Ankara, TÜRKİYE*
**Corresponding author's e-mail address:ali.sevinc@kosgeb.gov.tr*
DOI: 10.29130/dubited.1628405

ABSTRACT

Model factory offers a wide range of training and consultancy services, including experiential learning techniques on continuous improvement, lean production, and digital transformation for businesses in the manufacturing sector. The Industry 4.0 approach guides the design of these applied trainings and consultancy services, which aim to significantly boost enterprises' productivity levels. Ten provinces in Türkiye have established model factories since 2015. One of them is the Ankara Chamber of Industry (ACI) model factory. The aim of this study is to examine the benefits of the companies participating in Learn & Transform Program of the ACI model factory. To evaluate the benefit of the companies participating in the Learn & Transform Program, the number of employees, the production increase rate as a result of the Learn & Transform Program, and the return on investment periods were examined using the WASPAS method. I ranked the participating companies in the program from the highest benefit to the lowest. According to this ranking, F12 was the firm that provided the highest benefit, F2 ranked second, and F6 ranked third. The first-ranked company was determined to be the one that participated in the Learn & Transform Program, and provided the highest benefit among these companies. The last ranked firm, F18, was considered to be the least benefited firm. This analysis gives the model factory managers, experts, and business managers the opportunity to evaluate the Learn & Transform Program.

Keywords: *WASPAS method, Multi-Criteria decision making, Model factory, Learn & Transform program*

Model Fabrikaların Verimliliğe Katkısının Çok Kriterli Karar Verme Yöntemi ile Değerlendirilmesi: Öğren-Dönüş Programı Uygulaması

ÖZ

Model Fabrikalar, üretim sektöründeki işletmeler için sürekli iyileştirme, yalın üretim ve dijital dönüşüm konularında deneyimsel öğrenme tekniklerini içeren geniş kapsamlı eğitim ve danışmanlık hizmetleri sunmaktadır. Bu uygulamalı eğitimler ve danışmanlık hizmetleri, Endüstri 4.0 yaklaşımına uygun olarak tasarlanmış olup, işletmelerin verimlilik düzeylerini önemli ölçüde artırmayı hedeflemektedir. Türkiye'de 2015 yılından itibaren on ilde model fabrika kurulmuştur. Bunlardan biri Ankara Sanayi Odası (ASO) model fabrikadır. Bu çalışmanın amacı, Ankara Sanayi Odası (ASO) model fabrika Öğren-Dönüş programına katılan firmaların programdan elde ettikleri fayda durumunu incelemektir. Öğren-Dönüş programına katılan işletmelerin programdan fayda durumunu değerlendirmek amacıyla, çalışan sayısı, Öğren-Dönüş programı sonucundaki üretim artış oranı ve yatırımın geri dönüş süreleri WASPAS yöntemi kullanılarak incelenmiştir. Programa katılan firmalar arasında en yüksek faydayı

Received: 28/01/2025, Revised: 10/04/2025, Accepted: 11/04/2025

sağlayan firmadan en düşüğe doğru bir sıralama yapılmıştır. Bu sıralamaya göre en yüksek fayda sağlayan F12 firması, ikinci sırada F2 ve üçüncü sırada F6 firması yer almıştır. Birinci sıradaki firma, Öğren-Dönüş programına katılan ve bu firmalar arasında en fazla fayda sağlayan firma olarak belirlenmiştir. Son sıradaki firma ise F18 nolu firma, en az fayda gören firma olarak olduğu değerlendirilmiştir. Bu analiz, model fabrika yönetici, uzmanlarına ve işletme yöneticilerine Öğren-Dönüş programı hakkında değerlendirme yapma imkânı vermektedir.

Anahtar Kelimeler: *WASPAS yöntemi, Çok kriterli karar verme, Model fabrika, Öğren-Dönüş programı*

I. INTRODUCTION

Model factory is a simulation-based learning tool developed specifically for the industry. It allows company employees to gain new competencies in various areas, from lean production to digital technologies. Participants embark on a transformational learning journey through model factory and have an interactive and practical learning experience. In this way, model factory provide knowledge and competence in transforming this knowledge into practice, making learning outcomes tangible and valuable. The target audience of model factory includes for-profit companies and organizations as well as non-profit organizations. By interacting with the simulation-based learning tool, these organizations learn more effectively how to use the techniques in their daily practice routines. This allows the organization to focus on continuous improvement and success [1], [2], [3], [4], [5].

Model factory offers applied training and consultancy services to enterprises in Türkiye's manufacturing sector to boost productivity in production through Learn & Transform Program. Businesses can achieve their strategic goals with the help of these training and consultancy services. Guidance on critical issues such as productivity improvement, cost optimization, and quality control contributes to a more competitive position. In addition, Model Factories' sustainability-focused approach supports businesses in taking strategic steps to reduce their environmental impact and fulfill their social responsibilities. This strategy ensures not only short-term but also long-term success. The Learn & Transform Program and consultancy services offered by Model Factories significantly strengthen Turkish manufacturing businesses and build a sustainable and competitive future [6], [7].

In Türkiye, model factories are established under the leadership of the Ministry of Industry and Technology. These institutions provide practical training and consultancy services for a certain period of time within the scope of the Learn & Transform Program. Businesses participating in the program in the manufacturing sector aim to increase their productivity levels. Under the leadership of training coaches, enterprises evaluate their situation before and after participating in the program and determine the increase in production productivity. Model factory management records the productivity increase and return on investment periods for the enterprises [6], [7]. But there is no scientific analysis of the productivity increase and return on investment for the companies in the Learn & Transform Program, nor is there a tool to compare their utilization status. In addition, there is no study in the literature that compares the benefits of the program to the enterprises participating in the Learn & Transform Program.

The purpose of this study is to show that model factory managers, experts, and business officials have information about the benefits of the Learn & Transform Program for their businesses. But no tool can compare the benefits of this program to those of the Learn & Transform Program 's companies. The objective of this research is also to examine the benefits of the program for the companies participating in the Ankara Chamber of Industry (ACI) model factory, the Learn & Transform Program. In this context, It is used the WASPAS method to examine the number of employees, the production increase rate resulting from the Learn & Transform Program, and the return on investment periods. I ranked the participating companies in the program from the most beneficial to the least beneficial. With this analysis, it will be possible to compare the benefits of the companies participating in the Learn & Transform Program. Thus, It can be evaluated the top-ranked companies that derive sufficient benefits from the program and those that do not. This information can provide feedback on the Learn & Transform Program for model factory managers and experts.

II. LITERATURE

The problems of selecting a flexible production system, a machine in a flexible production cell, an automatic guided vehicle, an automatic control system, and an industrial robot were determined by the WASPAS method. It was determined that the method gave acceptable results [8]. The performance of the companies in the automotive sector traded in Borsa Istanbul was ranked by us using the MAUT (Multi-Attribute Utility Theory) and SAW (Simple Additive Weighting) methods. According to both methods, the same firms are ranked in the first three places [9]. In this study, a model factory was established to disseminate additive manufacturing technologies to be used in the production of mechatronic products in the industry. It enabled the participants to increase their knowledge of innovative production technologies and accelerate their industrial transformation [10]. The performances of banks were analyzed with the WASPAS method [11]. The quality of life of European Union countries was evaluated with ENTROPY, ARAS, and MOOSRA methods. It was determined that the most important criterion for quality of life is pollution. It was determined that Finland is the best country in terms of quality of life [12]. This study presents a transformation model encompassing value creation, value chain development, information and communication technology infrastructure enhancement, and the integration of cyber-physical systems to assist the shift. Industry 4.0 at EAFIT University aims to reform production engineering methodologies through the implementation of the learning factory idea inside engineering education [13]. The methodical design of a maturity model was resented for its purpose of evaluating the design and ongoing development of learning factories, as well as assessing the model's applicability in such environments [14]. In their study, they aim to design a teaching factory for engineering students based on the requirements expected by the industry. A model factory design suitable for developing the needs and abilities of mechanical engineering students was obtained [15]. The study employed ENTROPY and EDAS methods to analyze the performance of logistics companies. nieces. It was determined to be the "Mars" company with the best performance [16]. Designed and implemented a model factory in a public university in Brazil to ensure the implementation and dissemination of Industry 4.0 technologies. The model factory was designed and successfully implemented [17]. To facilitate the adoption of Industry 4.0, automation, and lean manufacturing technologies by small and medium-sized enterprises (SMEs), İt is introduced a learning factory concept known as IdeaLab. This Lab offers a learning factory concept to provide solutions to the problems faced by SMEs [18]. The financial performance of logistics companies in the Fortune 500 list was evaluated. The study determined that exports significantly influenced the performance of logistics companies between 2015 and 2019 [19]. This study elucidates the design and implementation process of a learning factory aimed at facilitating Industry 4.0 training for students in Croatia. The factory commenced operations in 2022, promoting awareness of Industry 4.0 and the implementation of these technologies in Croatia [20]. Logistics performance of OECD member countries was analyzed with the ENTROPY and WASPAS methods. According to the ranking results, the top five countries are Germany, Sweden, Denmark, the Netherlands, and Austria [21]. The performance of the Serbian economy was analyzed according to the MEREC-WASPAS method. According to the WASPAS method, the Serbian economy showed the best performance in 2012 [22].

III. CONCEPTUAL FRAMEWORK

A. FUNCTION OF THE MODEL FACTORY

The first, second, and third industrial revolutions in the evolution of industrial revolutions symbolize the industrial transformation processes in which energy resources diversified and automation developed. The Third Industrial Revolution brought automation with the integration of information and communication technologies into production processes, paving the way for smart systems and robotic technologies, and Industry 4.0, which emerged after this evolution, aims to transform traditional machines into a learning structure, optimizing performance and maintenance management with environmental interaction. Industry 4.0 represents an industrial revolution that interacts with its environment by minimizing human intervention through the integration of smart production systems

and information technologies [23], [24], [25]. In these processes, each stage of the developments in the industry is referred to as a revolution. Model factories provide training and consultancy services that include theory and practice to achieve the goal of Industry 4.0 and its competitive advantage.

The Model Factory concept aims to adapt quickly to customer demands and offer flexible capacity. This structure makes it possible to set up new production lines around the world and increase capacity with minimal effort. This model accelerates the company's production processes and provides flexible capacity by working according to different customer requests and expectations, using the standard line setup while customizing the customers' product. Model factory aim to provide hands-on training for field workers, balance between efficiency and flexibility, and be responsive to local demands and the supply chain network [26].

Model factories adopt active learning methods, aiming to give participants experience in industrial projects. They simulate various Industry 4.0 application scenarios for use in education, research, and training and provide a learning environment that includes real-world experiences through modules such as "Inspection/Creation" and "Production Control." This learning model aims to increase collaboration between industry, academia, and professionals by promoting the adoption of Industry 4.0. However, especially in less developed countries, the importance of model factory is evident in efforts to overcome challenges such as the slow pace of technological progress, high costs, and lack of employee access to new technologies [13], [27], [17], [20]. These challenges can limit the implementation of Industry 4.0, making it difficult to keep pace with technological development. However, adopting various strategies to overcome them, such as international collaborations and resource sharing, can help these countries transition to Industry 4.0 more effectively.

Model factory, a concept that supports hands-on learning, aim to bridge the skills gap between industry needs and the theoretical knowledge provided in schools. This concept combines innovative learning technologies and effective practices to align student competencies with the needs of the industrial world. Model factory, based on the concept of digitalization, include free-designed virtual systems and virtual replicas of physical systems. This concept aims to offer an ever-expanding learning environment and enhance the personal learning experience by using realistic and modifiable production processes. It offers participants task-oriented learning opportunities, such as analyzing and optimizing processes. Covering various topics such as Industry 4.0, manufacturing efficiency, and sustainability, specialized learning factories have become common among industries and universities for practical training [15], [14], [28], [29], [18].

Model factories are clearly differentiated from other teaching and learning formats by providing the ability to effectively use realistic and modifiable production processes. Its main function is to offer different learning methods, such as analyzing and optimizing production systems through realistic simulations [2]. Model factories help participants gain practical skills beyond theoretical knowledge by allowing them to experience real industry practices [31].

People around the world understand the importance and benefits of model factory. In Türkiye, studies on model factory designs have begun, and efforts are underway to make them widespread. Model factories have been established in different cities, especially ACI, to contribute to manufacturers' productivity. It is observed that Model Factories have been established in Adana, Ankara, Bursa, Eskişehir, Gaziantep, İzmir, Kayseri, Konya, Mersin, and Samsun. Model Factories in Türkiye are established to enhance industrial efficiency and innovation [6].

The first model factory studies were initiated in 2015 under the coordination of the Ministry of Industry and Technology, and a total of 10 model factories were established and put into operation in Adana, Ankara, Bursa, Gaziantep, Izmir, Kayseri, Konya, Eskişehir, Samsun, and Mersin provinces through national and international funds. Model factories provide training and consultancy on lean production by guiding the transformation processes of enterprises and continue to develop infrastructure and human resources within the scope of Learn & Transform Program so that they can operate in the field of digital transformation [6].

A.1. Target Audience of the Ankara Chamber of Industry Model Factory

The ACI model factory appeals to companies in many different sectors operating in the manufacturing industry and producing various products and technologies. Machinery manufacturing companies, companies in the food sector, and companies in the textile sector are among the target audience of the model factory. There is no distinction between companies producing low- and high-technology products [7].

Model factory experts identify the productivity-related problems of the companies that apply for service. They provide applied training and consultancy services to companies in groups for three to four months. During this period, solutions are produced to the problems identified about productivity. At the end of the study, companies have a productivity report card. Each company participating in the Learn & Transform Program can prepare a road map for itself [7].

A.2. Fields of Activity of the Companies Included in the Study

The companies in this study are involved in the production of buildings, highways, tunnels, streets, recreation and sports areas lighting, plastic parts design, injection, grouping, mold production, paint, primer, coating, varnish, insulation materials, construction chemicals, buildings, shopping malls, stores, hospitals, schools, highways, street lighting, automatic doors, cabins and complete elevator systems, enamel coated hot water storage tanks, air and sediment separators, balance tanks and apartment entrance stations, porcelain insulator production, power plant infrastructure projects, structural steel manufacturing and assembly for skyscrapers and industrial buildings, earthquake isolation devices, compound feed production, microfiber cloth production, women's underwear and outerwear, medium voltage electrical equipment, home and office furniture, urban furniture, Tactical mini UAV systems, chocolate, cream, paste production, industrial kitchen equipment manufacturing.

A.3. Model Factory Activities and Learn & Transform Program

The ACI Model Factory offers an approach model that allows companies to make mistakes on actual production lines with learn-and-transform programs. These programs include theoretical teaching of "Lean Production" principles and methods, as well as workshops that provide participants with experience. Learn & Transform Program aim to train companies' own lean leaders. This approach demonstrates that businesses can implement scalable lean applications that yield cost-effective results within a short timeframe and budget. Learn & Transform Program: These programs include theoretical training, group workshops, and field coaching to train lean leaders. This program aim to reduce costs, increase productivity, and improve competitiveness. The program consists of sequential "Learn" and " Transform " themes. In the "Learn" phase, participants receive experiential training in the Model Factory, while in the "Transform" phase, they apply what they have learned in their own production sites, accompanied by field coaches [7].

The Learn & Transform Program forms the basis of model factory activities and aims to provide permanent competence to enterprises. In the learning phases of the program, participants are taught lean management theory and make their first applications in the model factory. One of the most essential activities of the program is the applications that the participants will carry out in their own companies. To achieve the targeted outputs, Model Factory trainers conduct transformation visits to the selected companies and implement lean transformation in the pilot area determined in the enterprise [6].

Within the scope of the Learn & Transform Program, in each period, a joint working group is formed with project leaders of two and four people for four months, with 4-8 enterprises coming together. These groups receive theoretical and practical training in 4 main sessions under diagnosis, design, implementation, and sustainability for 12 days. After each session, the methods they have learned and experienced in the model factory are repeated for 3 weeks in a pilot area selected in their enterprises [6], [7].

A.4. Participant Profile and Learn & Transform Program

Senior executives such as the chairman of the board of directors, members of the board of directors, factory managers, production managers, and new-generation management candidates can participate in the Learn & Transform Program. In addition, employees who have a good command of the work done in the pilot area, who are willing to participate in the program, who are open to innovations, who do not have a planned leave, and who can participate in training and coaching full-time can be included in the program. Firms from different sectors can also participate in the program [7].

B. METHOD

In this study, the ENTROPY method, a multi-criteria decision-making (MCDM) method, was used for weighting. The analysis used the WASPAS method, an MCDM method that takes benefits and costs into account.

B.1. ENTROPY Method

Claude E. Shannon developed the entropy method in 1948 within the context of information theory. It has been used in many fields of science and engineering, especially in problem-solving. It is used to solve problems to eliminate uncertainty. CRM prefers the entropy method because it makes mathematical calculations, is easy to understand, and doesn't require decision-making expertise. It is used the ENTROPY method, an objective weighting method, to determine the weights of the criteria in the analysis [32]. The ACI model factory provided the data for this study. We preferred the ENTROPY method in the weighting process due to the objective nature of the data.

The entropy method consists of five process steps [11], [21], [32] [38].

B.1.1. Creation of Decision Matrix

Entropy management creates a decision (D) matrix with the values of the priority criteria based on weighted alternatives.

In the decision matrix, m is the number of alternatives, n is the number of criteria, and is the value of the j criteria of alternative i.

$$D = \begin{matrix} x_{11} & x_{12} & \ldots\ldots & x_{1n} \\ x_{21} & x_{22} & \ldots\ldots & x_{2n} \\ \ldots. & \ldots & \ldots\ldots & \ldots. \\ x_{i1}. & x_{i2} & \ldots\ldots & x_{in} \\ \ldots. & \ldots\ldots & \ldots. & \ldots\ldots \\ x_{m1} & x_{m2} & \ldots\ldots & x_{mn} \end{matrix} \quad (1)$$

B.1.2 Constructing the Normalized Decision Matrix

In order to eliminate the effects of different index dimensions in the decision matrix on incommensurability, the indices can be standardized by various methods. According to the benefit and cost indices, the criteria are normalized using Equation (2) and Equation (3).

$$r_{ij=}\frac{x_{ij}}{max_{ij}} (i=1\ldots\ldots\ldots m;\ J=1,\ldots\ldots\ldots,n) \quad (2)$$

$$r_{ij=}\frac{x_{ij}}{min_{ij}} (i=1\ldots\ldots\ldots m;\ J=1,\ldots\ldots\ldots,n) \quad (3)$$

Different units of measurement normalization to eliminate anomalies P_{ij} is calculated. with Equation (4).

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, \quad \forall i,j \tag{4}$$

B.1.3. Finding Entropy Values for Criteria

Entropy value of the criteria (E_j) is calculated by Equation (5).

$$E_{j=-\sum_{i=1}^{m} P_{ij} \ lnp_{ij,\ \forall j}} \tag{5}$$

B.1.4. Calculation Of The Degree Of Differentiation Of Knowledge

In this step, high values of the degree of differentiation of information (d_j) indicate that the distance or differentiation between alternative results regarding the criteria is high.

$$d_j = 1 - E_{J,\ \ \forall J} \tag{6}$$

B.1.5. Calculation of Criterion Weights

In this step, if the decision maker prefers one criterion over the other, the best-expected weight value is calculated using Equation (7)

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{7}$$

The value w_j in the equation expresses the weight values, which are indicators of the importance levels of the criteria. The entropy probability value is 1. (Equation 8)

$$w_1 + w_2 + \cdots .. + w_n = 1 \tag{8}$$

Despite its restricted application in the entropy technique, subjective weights can be derived using Equation (9), considering the weights acquired from Equation (8) and the decision maker's a priori context.

In this step.λ_j refers to the decision maker's relevant prior.

$$w_j^0 = \frac{\lambda_j w_j}{\sum_{j=1}^{n} \lambda_j w_j} \tag{9}$$

B.2. The WASPAS Method

The WASPAS method is a Multi-Criteria Decision Making (MCDM) approach developed by Chakraborty and Zavadskas (2014). This method combines the results of the "Weighted Sum Model" and "Weighted Multiplication Model." It uses the value of the combined optimality criterion calculated based on the results of these two models to determine the ranking of the alternatives. The WASPAS method can perform sensitivity analysis within its own functioning. This serves the purpose of checking the consistency in alternative rankings [33], [34], [35], [36], [37], [38]. Therefore, it can help decision-makers make more informed and reliable choices among alternatives.

In this study, the WASPAS method aims to rank the companies, facilitating performance comparison by evaluating the productivity increase resulting from the applied training and consultancy services received from the model factory. The WASPAS method ranks the companies based on the outcomes of the weighted multiplication method and the weighted sum method. Since the number of employees of the enterprises in the data obtained from the model factory is the cost, production increase, and return on investment benefit, this method was chosen because this method takes these two issues into account.

B.2.1. Defining the Problem

The Problem starts with the following decision matrix: It is determined that the alternatives and criteria in advance. The criteria are determined using information obtained from various sources such as historical data, expert opinions, and literature reviews, and the alternatives to be evaluated are decided. It is constructed the matrix using Equation (10).

$$X = \begin{matrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{matrix} \quad (10)$$

In this framework, *m* represents the number of alternative candidates, while *n* is the number of evaluation criteria. x_{mn} denotes the performance of alternative m concerning criterion *n.*

B.2.2. Decision Matrix Normalisation

Normalization is used to eliminate the effect of unit differences in criterion values. Therefore, It is applied normalization based on whether each criterion in the decision matrix is benefit- or cost-oriented.If the criterion is benefit-based, the formula of Equation (11) comes into play. This formula aims to correct for differences in the range of values in the units of the criteria, making the decision matrix more consistent.

$$\text{For benefit-based : } \bar{x}_{ij} = \frac{x_{ij}}{max_i x_{ij}} \quad (11)$$

For non- benefit-based criteria, normalization is performed using Equation (12).

$$\bar{x}_{ij} = \frac{min_i x_{ij}}{x_{ij}} \quad (12)$$

Equation (11) and Equation (12) result in a normalized decision matrix. Equation (13) performs an additional operation on this matrix.

$$X = \begin{matrix} \bar{x}_{11} & \bar{x}_{12} & \dots & \bar{x}_{1n} \\ \bar{x}_{21} & \bar{x}_{22} & \dots & \bar{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \bar{x}_{m1} & \bar{x}_{m2} & \dots & \bar{x}_{mn} \end{matrix} \quad i = 0,1,2, \dots \dots, m \quad \text{ve j: } 1,2, \dots . n \quad (13)$$

B.2.3. Evaluation by Weighted Sum Method

According to the weighted sum method, the score of each alternative$i$ is calculated using Equation (14). In this equation,$w_{j,} J$ represents the weight value of the criterion and $Q^{(1)}, i$ is the evaluation score of the alternative.

$$Q_i^{(1)} = \prod_{j=}^{n} \bar{x}_{ij.} \ \ w_j \quad (14)$$

B.2.4. Evaluation by the weighted Multiplication method

According to the weighted multiplication method, the total relative importance of the alternative is calculated using Equation (15).$Q_i^{(2)}$ refers to the evaluation score of alternatives based on the weighted multiplication method.

$$Q_i^{(2)} = \prod_{j=}^{n} (\bar{x}_{ij})^{w_i} \quad (15)$$

B.2.5. Integration of Weighted Sum and Multiplication Results

The scores obtained by weighted sum and weighted multiplication methods are integrated to form a single value to facilitate decision making. The weighted common criterion value of alternative *i* is expressed as *Q(i)* and is calculated using Equation (16).

$$Q_i = 0{,}5Q_i^{(1)} + 0{,}5Q_{\text{i}}^{(2)} = 0.5 \ \sum_{j=1}^{n} \bar{x}_{ij} \ \ w_j + 0.5 \prod_{j=}^{n} (\bar{x}_{ij})^{w_i} \quad \textit{(16)}$$

The model based on the assumption that the results obtained from the weighted sum and multiplication methods are of equal importance is expressed by Equation (17). However, this assumption is replaced by a generalized weighted common criterion score formula that expresses the importance of the weighted sum model in terms of λ. Here, λ can take values between 0 and 1.

$$Q_i = \lambda Q_i^{(1)} + (1-\lambda) Q_{\text{i}}^{(2)} = \lambda \sum_{j=1}^{n} \bar{x}_{ij} \ \ w_j + (1-\lambda) \prod_{j=}^{n} (\bar{x}_{ij})^{w_i} \textit{(17)}$$

As the value of λ approaches 0, the method becomes more similar to the weighted multiplication model, while as it approaches 1, it becomes the weighted sum method.

B.2.6. Selection

The weighted common criterion score ranks the alternatives from high to low. The alternative with the highest score is the best. According to this score ranking, the order of alternatives is determined. In the implementation phase, the WASPAS method will analyze 19 companies in the Learn & Transform Program from the model factory based on the production increase rate as a percentage, the return on investment period, and the number of employees.

IV. RESULTS

The data were obtained from the Model Factory web page for 19 manufacturing companies participating in the Model Factory, Learn & Transform Program of the ACI. Three variables were used. The number of employees variable is the total number of blue and white-collar employees in each firm. The criterion for the increase in the amount of production expresses the increase in production as a percentage after the end of the Learn & Transform Program in the firm. The other benefit to the firm is the return on investment period, which is the number of days that the cost incurred by the firm for the Learn & Transform Program returns to the firm as profit. The total number of blue and white-collar employees is a cost-side criterion. The rate of increase in production and the return on investment are given in days. Two criteria are benefit-oriented.

The managers and experts of the model factory analyze the productivity problems of the companies applying to the Learn & Transform Program and determine the current situation. They analyze the issues that cause productivity problems: idle resources in terms of raw materials, equipment, and time spent in the company; inefficient situations related to labor; machinery and and equipment problems; raw materials; product scraps and wastes, machine programming times, idle situations in production capacity, and and cycle times of equipment. They prepare a report that determines the productivity status for each company. Work is carried out to solve the problems in the report. In the Learn & Transform Program company employees who participate in the training by providing with practical training work to produce solutions to company productivity problems. By providing solutions to the problems of the companies, many gains, such as increased increased labor productivity, increasedd capacity, reduction in the rates of poor-quality products, waste, and scrap products, reduction in additional shifts and savings in shift production, acquisition of new areas of use, savings in production time, and shortening product transportation times within the factory, are provided. Since these gains cause an increase in productivity in the company and are reflected in the increase in product production, they are calculated as "increase in production quantity." Therefore, "productivity increase in production" represents a large number of variables. Therefore, the number of benefit-side criteria was limited. The number of employees was available as a cost-side criterion.

Table 1. *Model Factory Decision Matrix of the Results of the Companies Participating in the Learn & Transform Program*

Firms	Firms Number of Employees	Increase in Production Amount (%)	Return on investment (Days)
F1	250	124	14
F2	60	150	180
F3	40	83	90
F4	140	33	30
F5	250	47	180
F6	48	310	48
F7	175	200	10
F8	273	56	30
F9	603	10	45
F10	37	15,5	51
F11	60	15	30
F12	30	230	141
F13	273	14	120
F14	200	40	7,5
F15	450	211	11
F16	165	50	150
F17	78	400	8
F18	848	115	3
F19	182	162	36

The study uses data from firms named F1 to F19. All of these firms are in the manufacturing sector and produce in different fields. Firms produce office furniture, power plants, earthquake insulation materials, textiles, microfiber cloth, feed, electrical equipment, and security equipment. There are also companies in the ceramic, casting, chemical, and lighting sectors. Matrix of the results of the model factory participating in the Learn & Transform Program was created and given in Table 1.

Table 2. *Weighting of Criteria by ENTROPY Method*

Firms Number of Employees	Increase in Production Amount (%)	Return on investment (Days)
0,3135	0,3225	0,3640

The ENTROPY method calculated every step of the table's criteria and carried out the weighting process. ENTROPY weighting scores are presented in Table 2. The weighting sum of each criterion is equal to 1. I prefered the ENTROPY method because it is objective.

Table 3. *Decision Matrix Normalisation*

Firms	Firms Number of Employees	Increase in Production Amount (%)	Return on investment (Days)
F1	0,120	0,310	0,078
F2	0,500	0,375	1,000
F3	0,750	0,208	0,500
F4	0,214	0,083	0,167
F5	0,120	0,118	1,000
F6	0,625	0,775	0,267
F7	0,171	0,500	0,056
F8	0,110	0,140	0,167
F9	0,050	0,025	0,250
F10	0,811	0,039	0,283
F11	0,500	0,038	0,167
F12	1,000	0,575	0,783
F13	0,110	0,035	0,667
F14	0,150	0,100	0,042
F15	0,067	0,528	0,061
F16	0,182	0,125	0,833
F17	0,385	1,000	0,044
F18	0,035	0,288	0,017
F19	0,165	0,405	0,200

Table 4*. Evaluation of the Companies Participating in the Learn & Transform Program by Weighted Sum Method and Weighted Multiplication Method*

Firms	Ranking of Alternatives according to WSM	Ranking of Alternatives according to WPM
F1	0,166	0,326
F2	0,642	0,586
F3	0,484	0,428

Table 4*. (continued) Evaluation of the Companies Participating in the Learn & Transform Program by Weighted Sum Method and Weighted Multiplication Method*

F4	0,154	0,144
F5	0,440	0,258
F6	0,543	0,491
F7	0,235	0,161
F8	0,140	0,138
F9	0,115	0,072
F10	0,370	0,207
F11	0,230	0,145
F12	0,784	0,765
F13	0,288	0,146
F14	0,094	0,083
F15	0,213	0,126
F16	0,401	0,280
F17	0,459	0,239
F18	0,110	0,053
F19	0,255	0,236

The weighted sum and weighted multiplication determined the combined optimal value. Therefore, weights were determined by integrating the weighted values. I applied weightings based on WSM and WPM. It is presented in Table 4.

Table 5. *Integration of Weighted Sum Method and Weighted Multiplication Method Results and Ranking According to WASPAS Method*

Firms	Weights of Alternatives	Ranking of Alternatives
F12	0,775	1
F2	0,614	2
F6	0,517	3
F3	0,456	4
F17	0,349	5
F5	0,349	6
F16	0,341	7
F10	0,289	8
F1	0,246	9
F19	0,246	9
F13	0,217	10
F7	0,198	11
F11	0,187	11
F15	0,170	13

Table 5. *(contınued) Integration of Weighted Sum Method and Weighted Multiplication Method Results and Ranking According to WASPAS Method*

F4	0,149	14
F8	0,139	15
F9	0,093	16
F14	0,089	17
F18	0,081	18

The level of importance was set at λ=0.50 in calculating the firms' score values based on the integrated weighted values. The combined optimum value was determined. The alternatives are ranked according to these values and given in Table 5. This ranking determined F12 as the firm with the highest efficiency score. F2 and F6 were ranked second and third, respectively. Company F3 ranked fourth, and company F17 ranked fifth. The first-ranked company was determined to be the company that benefited the most from the Learn & Transform Program, while the company that benefited the least was F18. It allows for a comparison between the companies that benefit the most and the companies that benefit the least from the Learn & Transform Program.

V. DISCUSSION

Restructuring manufacturing engineering practices with the learning factory concept in the context of engineering education [13]. Development of a maturity model for the design and continuous improvement of learning factories [14]. Design of a teaching factory for engineering students based on industry-expected requirements [15]. Designing and implementing a model factory in a public university in Brazil [17]. A learning factory called IdeaLab to enable small and medium-sized enterprises (SMEs) to adopt Industry 4.0, automation, and lean manufacturing technologies [18]. In Croatia, there are studies involving the design and establishment of a learning factory to facilitate Industry 4.0 training for students [20]. Generally, these studies focus on the design of model factories. The concept of model factories is new in Türkiye. There are no studies on model factories and their services in the Turkish literature. Furthermore, a study evaluating the services of model factories for firms in the international literature faces limitations. It may be a start for further academic studies on model factories and the program they offer in Türkiye. I used the ENTROPY method for the weighting process in this study. I conducted the analysis using the WASPAS method. The analysis was conducted starting from the company that provides the most benefit from the Learn & Transform Program to the company that provides the least.

VI. CONCLUSION

Model factories in Türkiye aim to increase the efficiency of businesses in production through the Learn & Transform Program. The programs provide participants with the opportunity to practice the key principles of Industry 4.0 through experiential trainings and then apply these gains in their businesses. The results of the Learn & Transform Program point to significant increases in the productivity levels of companies in a variety of sectors. Model factory Learn & Transform Program offer an effective way for businesses to improve their performance in critical areas such as sustainability, productivity, and competitiveness. By providing participants with experience in real production environments and the opportunity to apply theoretical knowledge in practice, Learn & Transform Program contribute to the transformation of Turkish businesses in line with Industry 4.0 principles.

The WASPAS method ranks the alternatives based on weighted values. It can be determined the rank of each alternative. This method allows comparison between alternatives. If a choice is desired, it can

be made with the WASPAS method. The ENTROPY method performs the weighting of objective data. These methods were found to be suitable for this study.

Within the scope of this study, using the WASPAS method, the production increase rate, return on investment period, and number of employees of 19 companies participating in the ACI model factory Learn & Transform Program was analyzed, and weights were revealed. Weights were ranked. According to this ranking, F12 was identified as the firm with the highest benefit. F6 ranked second, and F17 ranked third. The company in the first place was determined to be the company that benefited the most from the Learn & Transform Program among the companies, while the company that benefited the least was the company coded F9.

The ranking process of the results obtained by the firms from the Learn & Transform Program was evaluated as the ranking of the benefits obtained by the firms from this program. In other words, the top-ranked firm was considered the most beneficial, while the last-ranked firm was considered the least beneficial. The ranking of the outputs obtained by the firms from the Learn & Transform Program was made from the highest value to the lowest value. The ranking of the firms also allows for a comparison of the benefit status of the firms. These analyses can provide a basis for understanding the value of Learn-To-Transform programs to businesses and their overall efficiency for a more effective transformation process. By examining the most and least benefited companies, model factory managers can make evaluations to increase the benefit of the Learn & Transform Program. In other words, the feedback from the top and bottom-ranked companies can inform improvements to the program. Additional modules can be added to the program for companies that benefit less from the Learn & Transform Program. The sectors that provide the most and least benefit can be identified. Target sectors can be determined by the model factory management. In the ranking, the top, middle, and bottom-ranked companies can be grouped as A, B, and C, which means satisfactory, medium-level, or unsatisfactory, to give an idea about their benefit status. To increase the effectiveness of the model factory, further studies can be conducted to compare the companies that participated in the Learn & Transform Program with the companies that did not participate in this program.

Model factory management can present the work of the companies that provide the most benefits in the ranking made by the WASPAS method as an example to other enterprises; sharing these success stories with the business world can create a source of inspiration for other companies. Award programs can be organized, and prizes can be given to the companies that provide the most benefits, and the prizes to be given to the companies that rank high in the ranking can create a competitive environment among other businesses and encourage the emergence of innovative solutions. After this study, the performance evaluation of model factories in Türkiye can be carried out by using the methods of MCDM, such as TOPSIS, VIKOR, MOORA, and COPRAS.

VII. REFERENCES

[1] M. Tisch, C. Hertle, E. Abele, J. Metternich, and R. Tenberg, "Learning Factory Design: A Competency-Oriented Approach İntegrating Three Design Levels," *International Journal of Computer Integrated Manufacturing*, pp. 1–21, 2015.

[2] E. Abele, J. Metternich, M. Tisch, G. Chryssolouris, W. Sihn, H. Elmaraghy, and F. Ranz, "Learning Factories For Research, Education, And Training ", *Procedia Cirp*, *32*, 1-6, 2015

[3] J. Cachay, J. Wennemer, E. Abele, and R. Tenberg, "Study On Action-Oriented Learning With A Learning Factory Approach," *Procedia-Social And Behavioral Sciences*, vol. 55, pp. 1144–1153, 2012.

[4] S. Kreitlein, A. Höft, S. Schwender, and J. Franke, "Green Factories Bavaria: A Network of Distributed Learning Factories for Energy Efficient Production," *Procedia CIRP*, vol. 32, pp. 58–63, 2015.

[5] L. Morell, and M. Trucco, "A Proven Model to Re-Engineer Engineering Education in Partnership with Industry," in World Engineering Education Forum, *Buenos Aires, Argentina*, 2012

[6] Sanayi ve Teknoloji Bakanlığı. (2024, 01 Ocak). Model Fabrika Yaklaşımı [çevrimiçi]. Erişim: https://www.sanayi.gov.tr/merkez-birimi/92d9c73bddbb/model-fabrika.

[7] ASO Model Fabrika. (2023, 17 Aralık). Hizmetler [Çevrimiçi]. Erişim: https://www.modelfabrika.org/ogrendonus-programi.

[8] S. Chakraborty, E. K. Zavadskas, and J. Antuchevičienė, "Applications Of WASPAS Method As A Multi-Criteria Decision-Making Tool", *etalpykla.vilniustech.lt, 2015.*

[9] N. Ömürbek, M. Karaatlı ve H. F. Balcı, "Entropi Temelli MAUT Ve SAW Yöntemleri ile Otomotiv Firmalarının Performans Değerlemesi", *Dokuz Eylül Üniversitesi İktisadi İdari Bilimler Fakültesi Dergisi*, *31*(1), 227-255, 2016.

[10] I. S. Yoo, T. Braun, C. Kaestle, M. Spahr, J. Franke, P. Kestel, ve E. Feige, (2016). "Model Factory For Additive Manufacturing Of Mechatronic Products: İnterconnecting World-Class Technology Partnerships With Leading AM Players", *Procedia CIRP, 54*, 210-214, 2016.

[11] Ö. Akçakanat, H. Eren, E. Aksoy, ve V. Ömürbek, "Bankacilik sektöründe ENTROPI ve WASPAS yöntemleri ile performans değerlendirmesi", *Süleyman Demirel Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *22*(2), 285-300, 2017.

[12] N. Ömürbek, H. Eren ve O. Dağ, "Entropi-Aras ve Entropi-Moosra yöntemleri ile yaşam kalitesi açısından AB ülkelerinin değerlendirilmesi", *Ömer Halisdemir Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *10*(2), 29-48, 2017.

[13] F. Baena, A. Guarin, J. Mora, J. Sauza, and S. Retat, "Learning Factory: The Path To İndustry 4.0.", *Procedia Manufacturing, 9*, 73-80, 2017.

[14] J. Enke, R. Glass, ve J. Metternich, "Introducing A Maturity Model For Learning Factories", *Procedia Manufacturing,9*, 1-8. 2017, 2017.

[15] R. C. Putra, I. H. Kusumah, M. Komaro, Y. Rahayu, and E. P. Asfiyanur, "Design Learning of Teaching Factory in Mechanical Engineering", In *IOP Conference Series: Materials Science and Engineering* (Vol. 306, No. 1, p. 012104). IOP Publishin, 2018, February.

[16] A. Ulutaş, "Entropi Tabanli Edas Yöntemi İle Lojistik Firmalarinin Performans Analizi", *Uluslararası İktisadi Ve İdari İncelemeler Dergisi*, (23), 53-66, 2018.

[17] L.. F. Leal, A. Fleury, and E. Zancul, "Starting up a Learning Factory focused on Industry 4.0.", *Procedia Manufacturing, 45*, 436-441, 2020.

[18] K. K.Vijayan, and O. J. Mork, "Idealab: A Learning Factory Concept For Norwegian Manufacturing SME", *Procedia Manufacturing*, *45*, 411-416, 2020.

[19] H. H. Erdoğan ve G. Kırbaç, "Financial Performance Measurement Of Logistics Companies Based On Entropy And WASPAS Methods", *İşletme Araştırmaları Dergisi*, *13*(2), 1093-1106, 2021.

[20] M. Hegedić, P. Gregurić, M. Gudlin, M. Golec, A. Đenadija, N. Tošanović, N. ve Štefanić, "Design and Establishment of a Learning Factory at the FMENA Zagreb", *Tehnički glasnik, 16*(3), 426-431, 2022.

[21] V. S. Arıkan Kargı, "Evaluation Of Logistics Performance Of The Oecd Member Countries With Integrated Entropy and Waspas Method", *Journal of Management & Economics/Yönetim ve Ekonomi, 29*(4), 2022.

[22] R. Lukić, "Analysis Of The Performance Of The Serbian Economy Based on the MEREC-WASPAS method", *MARSONIA: Časopis za društvena i humanistička istraživanja, 2*(1), 39-52, 2023.

[23] E. Gökalp, U. Şener ve P. E. Eren, "Development Of An Assessment Model For İndustry 4.0: İndustry 4.0-MM. In *Software Process Improvement And Capability Determination: 17th, 2017.*

[24] S. Vaidya, P. Ambad, and S. Bhosle, "Industry 4.0–A Glimpse", *Procedia Manufacturing, 20,* 233-238, 2018.

[25] S. Khin, and D. M. H. Kee, "Factors İnfluencing Industry 4.0 Adoption", *Journal of Manufacturing Technology Management. 33*(3), 448-467, 2022.

[26] P. Kurttila, M. Shaw, and P. Helo, "Model Factory Concept–Enabler For Quick Manufacturing Capacity Ramp-Up. In *European Wind Energy", Conference and Exhibition, EWEC* (Vol. 4),2010.

[27] C. Prinz, F. Morlock, S. Freith, N. Kreggenfeld, D. Kreimeier, and B. Kuhlenkötter, "Learning Factory Modules For Smart Factories İn İndustrie 4.0. ", *Procedia CiRp, 54*, 113-118, 2016.

[28] C. Chau Khac Bao, and T. T. Tran, "Development of a Digital Learning Factory Toward Multi Objectives for Engineering Education: An Educational Concept Adopts the Application of Digital Twin. *Thanh Trung, Development of a Digital Learning Factory Toward Multi Objectives for Engineering Education: An Educational Concept Adopts the Application of Digital Twin (March 5, 2023)*.

[29] E. Abele, C. J. Bauerdick, N. Strobel, and N. Panten, "ETA Learning Factory: *A Holistic Concept For Teaching Energy Efficiency İn Production", Procedia CIRP, 54*, 83-88, 2016.

[30] D. T. Matt, E. Rauch, and P. Dallasega, "Mini-Factory–A Learning Factory Concept For Students And Small And Medium Sized Enterprises", *Procedia CiRP, 17*, 178-183, 2014.

[31] L. Mchauser, C. Schmitz, and M. Hammer, "Model-Factory-In-A-Box: A Portable Solution That Brings The Complexity Of A Real Factory And All The Benefits Of Experiential-Learning Environments Directly To Learners İn İndustry", *Procedia Manufacturing, 45*, 246-252, 2020.

[32] E. Aksakal ve E. Çalışkan, "Olimpiyatlara Aday Şehirlerin Seçim Sürecinde Dikkate Alınacak Kriterlerin Entropi Yöntemi ile Değerlendirilmesi", *Çok Kriterli Karar Verme Yöntemleri MS Excel Çözüm Uygulamaları*", 1. Baskı, Ankara, Türkiye: Nobel Akademik Yayıncılık, M. Kabak, Y. Çınar, Editör, 2020, böl.10, 13, ss.169-179.

[33] Chakraborty, S. and Zavadskas, E. K. (2014). Applications of WASPAS Method in Manufacturing Decision Making. *Informatıca,* Vol. 25, No. 1, 1–20

[34] P. H. Nguyen, T. T. Dang, K. A. Nguyen, and H. A Pham, "Spherical Fuzzy WASPAS-based Entropy Objective Weighting for International Payment Method Selection. *Computers, Materials & Continua*",*72*(1), 2022.

[35] G. Stojić, Z. Stević, J. Antuchevičienė, D. Pamučar, and M. Vasiljević, "A Novel Rough WASPAS Approach For Supplier Selection İn A Company Manufacturing PVC Carpentry Products", *Information*, *9*(5), 12, 2018.

[36] S. K. Vaid, G. Vaid, S. Kaur, R. Kumar, and M.S. Sidhu, "Application Of Multi-Criteria Decision-Making Theory With VIKOR-WASPAS-Entropy Methods: A Case Study Of Silent Genset", *Materials Today: Proceedings*, *50*, 2416-2423, 2022.

[37] E. K. Zavadskas, J. Antucheviciene, S. H. R. Hajiagha, and S.S. Hashemi, "Extension Of Weighted Aggregated Sum Product Assessment With İnterval-Valued İntuitionistic Fuzzy Numbers (WASPAS-IVIF)" *Applied Soft Computing*, *24*, 1013-1021, 2014.

[38] B. Ecer, " WASPAS Yöntemi ile Tedarikçi Seçimi", *Çok Kriterli Karar Verme Yöntemleri MS Excel Çözüm Uygulamaları*", 1. Baskı, Ankara, Türkiye: Nobel Akademik Yayıncılık, M. Kabak, Y. Çınar, Editör, 2020, böl.13, ss.209-219.