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Research Article

Risk Prioritization in A Manufacturing Project with Fuzzy SWARA and Fuzzy MOORA Methods

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Abstract

Businesses must constantly change and develop to keep up with customer needs and changes in the market. Being unable to adapt to change or being unprepared can bring risks. These changes and risks can affect both the process and the outputs of the process. It is essential to be prepared for the possible risks experienced in the operations, especially in project-based, production-to-order enterprises, to meet the customer's demands and to comply with the delivery date. Businesses must implement an effective risk assessment process to achieve this. This study implemented a risk prioritization for a new business project that produces energy storage systems by having to order. Changes must be made in the production process for an additional feature to be added to the product per the customer's request. The risks posed by the change and the short deadline were analyzed and prioritized. A new model was developed by developing the classical Decision Matrix Risk Assessment (DMRA) method, one of the risk assessment methods to evaluate the ten identified risks. The "severity" component of the classical DMRA method is divided into three sub-components (the severity of delivery time, the severity of cost, and the severity of quality) to be evaluated more specifically. Moreover, since the weights of these sub-components on the risks are different, the components are weighted with the Fuzzy SWARA method. The weights obtained from the Fuzzy SWARA method are used in the Fuzzy MOORA method, and the risks are prioritized. Thus, the effectiveness of the classical risk assessment approach has increased by detailing the "severity" component of the risk assessment components and weighting and prioritizing the components using multi-criteria decision-making (MCDM) techniques. With the fuzzy SWARA method, the weights of the risk components (severity of delivery time (C_1), severity of cost (C_2), severity of quality (C_3) and likelihood (C_4)) to be used in risk assessment were determined. BNP (best non-fuzzy performance) values for risks were calculated according to C_1, C_2, C_3 and C_4 values with the fuzzy MOORA method. As a result of the study, the most priority risk was determined as the risk of going to the customer with the QR code written in incorrect or non-desired quality of the product (Risk 8).

Keywords: Risk Analysis, Risk Prioritization, Matrix Risk Assessment Method, Fuzzy SWARA, Fuzzy MOORA

Bir Üretim Projesinde Bulanık SWARA ve Bulanık MOORA Yöntemleri ile Risk Önceliklendirme

Öz

İşletmeler müşteri ihtiyaçları ve pazardaki değişime ayak uydurabilmek için sürekli değişmek ve gelişmek zorundadırlar. Değişime uyum sağlayamamak veya yeterince hazır olamamak beraberinde riskleri getirebilmektedir. Bu değişiklikler ve riskler hem süreci hem de sürecin çıktılarını etkileyebilmektedir. Özellikle proje bazlı, siparişe göre üretim yapan işletmelerde süreçlerde yaşanabilecek olası risklere hazırlıklı olmak müşterinin isteklerini karşılayabilmek ve teslim tarihine uyabilmek için oldukça önemlidir. Bunu sağlayabilmek için de etkili bir risk değerlendirme sürecinin uygulanması gerekmektedir. Bu çalışmada siparişe göre üretim yaparak enerji depolama sistemleri üreten bir işletmenin yeni bir projesi için risk önceliklendirmesi çalışması yapılmıştır. Müşterinin talebi doğrultusunda ürüne eklenecek ek bir özellik için üretim sürecinde değişiklik yapılması gerekmektedir. Değişikliğin ve termin süresinin kısa olmasının getireceği riskler analiz edilerek önceliklendirilmiştir. Belirlenen on adet riskin değerlendirilmesi için risk değerlendirme yöntemlerinden klasik karar matrisi risk değerlendirme yöntemi geliştirilerek yeni bir model geliştirilmiştir. Klasik karar matrisi risk değerlendirme yönteminin "etki" bileşeni daha spesifik halde değerlendirilebilmek için üç alt bileşene ayrılmıştır (teslim süresine etki, maliyete etki ve kaliteye etki). Ve bu alt bileşenlerin riskler üzerindeki ağırlıkları farklı olduğu için çok kriterli karar verme tekniklerinden Bulanık SWARA yöntemi ile bileşenler ağırlıklandırılmıştır. Bulanık SWARA yönteminden elde edilen ağırlıklar, çok kriterli karar verme tekniklerinden Bulanık MOORA yönteminde kullanılarak riskler önceliklendirilmiştir. Böylece hem risk değerlendirme bileşenlerinden "etki" bileşeninin detaylandırılması hem de çok kriterli karar verme teknikleri kullanılarak bileşenlerin ağırlıklandırılması ve önceliklendirilmesi ile klasik risk değerlendirme yaklaşımının etkinliği arttırılmıştır. Bulanık SWARA yöntemi ile risk değerlendirmesinde kullanılacak risk bileşenlerinin ağırlıkları (teslim süresinin etkisi (C_1), maliyetin etkisi (C_2), kalitenin etkisi (C_3) ve olasılık (C_4)) belirlenmiştir. Risk bileşenlerinin ağırlıkları kullanılarak risklere ilişkin öncelik durumlarını gösteren BNP (Best non-fuzzy performance-bulanık olmayan en iyi performans) değerleri Bulanık MOORA yöntemi ile hesaplanmıştır. Çalışma sonucunda en öncelikli riskin, ürünün yanlış veya istenmeyen kalitede yazılmış QR kod ile müşteriye gitme riski olduğu ortaya çıkmıştır (Risk 8).

Anahtar Kelimeler: Risk Analizi, Risk Önceliklendirme, Matris Risk Değerlendirme Yöntemi, Bulanık SWARA, Bulanık MOORA

1. Introduction

In businesses where the general structure of the product is known and the details are shaped according to customer requests, production is made according to the order. Customer satisfaction is critical in ensuring the continuity of sales and production in businesses that make order production [1]. One of the essential criteria for ensuring customer satisfaction is the timely delivery of products. In make-to-order production, each new order is considered a new project. Production and process planning is done according to the customer order, the workloads to be undertaken by the machines are determined, and the production line is rearranged if necessary. Effective project management must know the risks that will delay production, reduce customer satisfaction, and take precautions accordingly. Risk management is very effective in the project's success, especially for new projects requiring changes in production processes. Risk management determines, analyzes, and evaluates risks and takes necessary precautions before they occur.

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Risks are uncertain events that can affect the time-cost-performance objectives of the relevant process/department/project [2]. Businesses must protect themselves against risks that may have consequences such as financial difficulties, failure to meet customer deadlines, loss of image, production disruptions, and loss of critical personnel. Businesses manage risk by helping decision-making processes and providing a sustainable competitive advantage [3]. Risks that are unknown and necessary precautions are not taken can deviate projects from their targets. Therefore, effective risk management is essential for successful projects [4].

Especially in engineering and manufacturing processes, it is possible to encounter risks due to the diversity and complexity of machines and techniques, the frequency of unexpected and uncertain events, and the intense human factor. There are many techniques used to prevent failures/delays/accidents from occurring or reoccurring by assessing the risks: Such as the DMRA (Decision Matrix Risk Analysis) Method, HAZOP (Hazard and Operability), Fine-Kinney, FMEA (Fault Mode and Effects Analysis) [5]. MCDM techniques and fuzzy set theory are generally used in integration with risk assessment techniques to manage risks more effectively by increasing the applicability and effectiveness of the techniques. The function of the MCDM methods used is usually to prioritize risks. The risk prioritization activity can be considered an MCDM problem in which many criteria must be evaluated.

In the literature, there are studies in which MCDM techniques are used in risk assessment and prioritization. Tomak and Korkusuz Polat [6] used the AHP (Analytical Hierarchy Process) technique to determine the criterion weights in their models developed for success factor-triggered risk prioritization. Becker et al. [7] used the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to rank the micropollutants they identified by conducting a risk assessment. Bid and Siddique [8] used TOPSIS and WASPAS (Weighted Aggregated Sum Product Assessment) techniques, which are MCDM techniques, to prioritize the risks posed by dams on humans. Jena et al. [9] used AHP and VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenjemethods) to assess the risks that increase vulnerability to earthquakes in urban areas. Senthill et al. [10] conducted a study in which they integrated TOPSIS, PROMETHEE (Preference Ranking Organization METHOD for Enrichment Evaluations), and AHP methods to prioritize the risks that may arise in reverse logistics activities. Sivageerthi et al. [11] used the SWARA (Stepwise Weight Assessment Ratio Analysis) method to prioritize risks in the coal supply chain.

Risks contain uncertainty due to their structural characteristics. There are studies in which the Fuzzy Logic approach, which has the feature of processing uncertain information, is used to increase the effectiveness of risk assessment techniques. Tian et al. [12] developed a new model for the oil industry, in which experts added their risk attitudes to the assessment as fuzzy while assessing risks. Korkusuz Polat [13] used fuzzy logic approach while prioritizing the risks in the textile factory. Moreno-Cabezali and Fernandez-Crehuet [14] applied a fuzzy logic-based model to evaluate risks in R&D projects developed for additive manufacturing. Lin et al. [15] used fuzzy set theory and machine learning techniques to assess the risks in the construction excavation system.

There are also studies in which MCDM techniques are used together with the Fuzzy Logic approach to eliminate the disadvantages of evaluating uncertain information. Yazdani et al. [16] developed a model that integrated Triangular Fuzzy Hesitant Sets, FMEA, and Combined Compromise Solution methods to assess outsourcing risks. Xu et al. [17] identified the risk factors that threaten the reliability of integrated energy systems. They developed a new model to evaluate the risks with integrated HFS (Hesitant Fuzzy Sets), DEMATEL (Decision Making Trial and Evaluation Laboratory), and CPT (Cumulative Prospect Theory). In their study, Shannazi and Alimohammadlou [18] determined the risks in renewable energy sources and prioritized them using MCDM techniques based on type-2 fuzzy sets. Singer and Över Özçelik [19] used Fuzzy AHP, Fuzzy EDAS (Evaluation based on Distance from Average Solution), and Fuzzy FMEA methods in an integrated way to evaluate the risks in metallic biomaterials. Gölcük et al. [20] proposed a new model by combining the whole consistency method and graph theory matrix approach in a fuzzy environment to overcome the disadvantages of the classical FMEA risk assessment method in prioritizing occupational health and safety risks. Ali et al. [21] used the Fuzzy VIKOR method to evaluate the risks that may occur in the China-Pakistan Fiber Optic Project. Jokar et al. [22] evaluated and prioritized the risks in highway projects carried out with public-private cooperation in Iran with Fuzzy AHP and Fuzzy TOPSIS. Severi et al. [23] developed the classical HAZOP risk assessment technique with MCDM. Researchers combined Fuzzy AHP and Fuzzy TOPSIS, which are MCDM techniques, with classical HAZOP and proposed the Fuzzy Multi-Attribute HAZOP technique, in which the weight risk factors and rank risks. Yücenur and Şenol [24] used SWARA and Fuzzy VIKOR methods to determine the most appropriate lean technique to eliminate waste in construction processes. Dehshiri [25] used Fuzzy SWARA and Fuzzy WASPAS (Weighted Aggregated Sum Product Assessment) methods in an integrated way to prioritize risks in offshore wind farms. Arabsheybani and Khasmeh [26] developed a mathematical model for the coordinated operation of production planning-supplier selection-order-distribution activities for a food factory in Iran. Researchers wanted to determine resilience factors to reveal risks and uncertainties, and they used Fuzzy AHP and Fuzzy MOORA (Multi-Objective Optimization based on Ratio Analysis) methods for this. Arabsheybani et al. [27] used FMEA supported by the Fuzzy MOORA method to evaluate supplier performance.

Although there are frequent risk assessment and prioritization studies in the literature in which MCDM techniques are integrated with the fuzzy logic approach, there are very few applications where the "severity" component used in risk assessment is detailed. In this study, the risks that may occur in the new project of an enterprise producing energy storage systems are predetermined and evaluated, and the risks that may arise are prioritized by using MCDM techniques. In the study, first of all, the risks that may occur were determined by taking support from the past experiences of the experts in the business. While evaluating risks, a new risk assessment model has been developed since the meaning of the "severity" component of the classical DMRA method on risks may differ. In the new model, the "severity" component is evaluated as three different sub-components: "severity on delivery time," "severity on cost," and "severity on quality." The new model differs from the classical DMRA method in the literature because it provides a more detailed analysis of the "severity" component. In addition, the weight of the three different "severity sub-components" on the risks is also additional.

Considering this situation, in the third stage of the study: "severity sub-components" in the proposed new model and the "likelihood" component, which is the other component of the classical DMRA model, were weighted using the Fuzzy SWARA method, which is one of the MCDM techniques. In the fourth stage of the study: The risks were prioritized with the Fuzzy MOORA method using the weights obtained from the Fuzzy SWARA method. Finally, risk strategies were determined for priority risks. The contribution of this article is threefold: firstly, it is to fill the deficiency of the classical DMRA method in assessing the severity of risks in different areas. Secondly, since the weight of the newly determined sub-components of the "severity" component on the risks was not equal, the "severity sub-components" were weighted in this study. Third, in the risk prioritization applications in the literature, there has yet to be an application in which Fuzzy SWARA and Fuzzy MOORA methods are integrated. This study is expected to contribute to the literature in this respect significantly. In the second part of the study, Decision Matrix Risk Assessment, Fuzzy Logic, Fuzzy SWARA and Fuzzy MOORA methods are explained respectively. In the third section, the risk assessment practice carried out in a company that produces energy storage systems is explained. In practice, the Fuzzy SWARA method was used when determining the weights of risk criteria, and the Fuzzy MOORA method was used when prioritizing risks. In the last section, Conclusion, it is given in detail which risk emerged as a priority as a result of the application.

2. Material and Methods

The methodological approach of the study is presented in this section. First, the DMRA method, a classical risk assessment approach, is included. Then, Fuzzy SWARA and Fuzzy MOORA methods are explained by defining the essential functions of Fuzzy Logic.

2.1. Decision Matrix Risk Assessment Method

Activities in all processes of a manufacturing or service business may involve risk. So, it is necessary to risk assessment in all companies, especially in new and critical processes. The DMRA (Decision Matrix Risk Assessment Method - Also known as the Risk Matrix method), developed in the 1990s, can be analyzed in which the probability of occurrence of risks and their after-effects are used to assess risks [28].

DMRA is a very convenient and frequently encountered method in practical applications to evaluate and prioritize risks according to the determined risk sizes while considering possible hazards. The Risk Matrix is commonly used to assist in setting priorities and assigning resources and is recommended by national/international standards [29].

There are two components in the risk matrix method (severity and likelihood), and the combination of the "severity" and "likelihood" values (Equation (1)) gives the size of the risk [30-31].

$$Risk\ Size\ (RS) = Severity\ (S)\ x\ Likelihood\ (L) \tag{1}$$

In the DMRA method, the expected risks are determined first. The likelihood of occurrence for the identified risks and the severity of the exposed person/process/department, if the risk occurs, is determined. Relevant experts and old records should be used to determine the risks' likelihood and severity [6].

2.2. Fuzzy Logic

Fuzzy Logic is an approach developed by Lotfi Zadeh in 1965 to solve problems where information cannot be accurately measured in cases of uncertainty and insufficiency [32]. Fuzzy Logic is a method that uses approximate thinking rather than definite values. The Fuzzy Logic approach provides subjective evaluation for the evaluation process in complex and uncertain decision problems [33].

Fuzzy numbers are defined as a fuzzy subset of real numbers expressing linguistic uncertainty. The membership function establishes the degree of fuzziness in the subset to which any element belongs [34]. Triangle Fuzzy numbers (l, m, u) were used in this study. The numbers represent the lowest, best, and highest possible values. The membership function is shown in Equation (2) (adapted from Alvand et al. [35]):

$$\mu_{\widehat{A}}(x; l, m, u) = \begin{cases} l \leq x \leq m & ; \quad \frac{x-1}{m-1} \\ m \leq x \leq u & ; \quad \frac{u-x}{u-m} \\ x > u \ or \ x < l & ; \quad 0 \end{cases} \tag{2}$$

The basic algebraic operations of any two positive fuzzy numbers are as shown in Equation (3)-(4)-(5) (adapted from Alvand et al. [35]):

- Fuzzy Sum:

$$M_1 + M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2); \tag{3}$$

- Fuzzy Subtraction:

$$M_1 - M_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2); \tag{4}$$

- Fuzzy Multiplication:

$$M_1 \times M_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \tag{5}$$

2.3. Fuzzy SWARA

The SWARA method is an approach developed by Kersuliene et al. [36], and the technique has been developed for weight criteria in decision-making processes. It is an uncomplicated MCDM technique in which experts can incorporate their tacit knowledge and experience into decision-making [37-38]. One of the advantages of the method is that it provides tools for assessing the accuracy of expert opinions about the weights determined for the decision-making process [39]. The SWARA technique is a technique that can also be used in cases where expert opinions are not compatible and the degree of consistency values are not within limits [40]. The method provides the opportunity to evaluate the experts' opinions and determine the relative importance weights of each criterion accordingly [41]. There are also studies in which the SWARA method is used together with the Fuzzy Logic approach to eliminate the method's weaknesses in evaluating uncertain information.

The fuzzy SWARA method consists of six steps [40, 42-44]:
Step 1: Ranking the criteria from most important to least important by each decision-making expert, considering the decision-making purpose of the problem. Table 1 shows the fuzzy scales used for this step.

Table 1: Fuzzy Member Function Values

	Fuzzy Number		
Equal importance	0.75	1.00	1.00
Relatively low importance	0.50	0.75	1.00
Low importance	0.25	0.50	0.75
Very low importance	0.00	0.25	0.50
Extremely little importance	0.00	0.00	0.25

Step 2: From the second criterion, decision-makers will compare each criterion (j) with the previous one (j-1).
Step 3: Determination of k_j coefficient according to Equation (6).

$$\tilde{k_j} = \begin{cases} \tilde{1} & ; \quad j = 1 \\ \tilde{s_j} + \tilde{1} & ; \quad j > 1 \end{cases} \tag{6}$$

(where s_j represents the comparative significance of the mean value)

Step 4: Determining the importance vector q_j according to Equation (7).

$$\tilde{q_j} = \begin{cases} \tilde{1} & ; \quad j = 1 \\ \frac{(\tilde{x_{j-1}})}{\tilde{k_j}} & ; \quad j > 1 \end{cases} \tag{7}$$

(where the notation x_{j-1} refers to q_{j-1}).

Step 5: Calculation of fuzzy weight values (w_j) (Equation (8)).

$$\tilde{w_j} = \frac{\tilde{q_j}}{\sum_{k=1}^{n} \tilde{q_k}} \tag{8}$$

Step 6: Performing the defuzzification (Equation (9)).

$$w_j = \frac{\left(w_j^u - w_j^l\right) + \left(w_j^m - w_j^l\right)}{3} + w_j^l \tag{9}$$

2.4. Fuzzy MOORA

The MOORA method was first developed in 2006 [45]. There are some reasons for applying MOORA instead of other well-known MCDM methods in the recent literature. The MOORA method is the proposed MCDM technique to overcome the weaknesses of the old methods, and MOORA is easy to implement and has a stable structure [46].

The Fuzzy MOORA method, which is used to process the uncertain information of decision-makers, consists of six steps [44, 46-48]:

Step 1: Evaluation of m alternatives by each of the k decision makers (using the Triangular Fuzzy Numbers shown in Table 2)

Table 2: Linguistic Variables and Fuzzy Numbers

Linguistic Variables	Fuzzy Number		
Very Low (VL)	0.0	0.0	0.1
Low (L)	0.0	0.1	0.3
Medium Low (ML)	0.1	0.3	0.5
Medium (M)	0.3	0.5	0.7
Medium High (MH)	0.5	0.7	0.9
High (H)	0.7	0.9	1.0
Very High	0.9	1.0	1.0

Step 2: Combining the fuzzy evaluations made by the decision makers for the alternatives according to Table 2 (Equation (10)) and the formation of the fuzzy decision matrix (the decision matrix in which *p* decision makers evaluate *n* alternatives as fuzzy for *m* criteria).

$$X = \begin{bmatrix} [x_{11}^l, x_{11}^m, x_{11}^u] & [x_{12}^l, x_{12}^m, x_{12}^u] & \dots & [x_{1n}^l, x_{1n}^m, x_{1n}^u] \\ [x_{21}^l, x_{21}^m, x_{21}^u] & [x_{22}^l, x_{22}^m, x_{22}^u] & \dots & [x_{2n}^l, x_{2n}^m, x_{2n}^u] \\ \dots & \dots & \dots & \dots \\ [x_{m1}^l, x_{m1}^m, x_{m1}^u] & [x_{m2}^l, x_{m2}^m, x_{m2}^u] & \dots & [x_{mn}^l, x_{mn}^m, x_{mn}^u] \end{bmatrix} \quad (10)$$

Step 3: Normalize the fuzzy decision matrix using Equation (11)-(12)-(13).

$$r_{ij}^l = \frac{x_{ij}^l}{\sqrt{\sum_{i=1}^m \left[\left(x_{ij}^l\right)^2 + \left(x_{ij}^m\right)^2 + \left(x_{ij}^u\right)^2\right]}} \quad (11)$$

$$r_{ij}^m = \frac{x_{ij}^m}{\sqrt{\sum_{i=1}^m \left[\left(x_{ij}^l\right)^2 + \left(x_{ij}^m\right)^2 + \left(x_{ij}^u\right)^2\right]}} \quad (12)$$

$$r_{ij}^u = \frac{x_{ij}^u}{\sqrt{\sum_{i=1}^m \left[\left(x_{ij}^l\right)^2 + \left(x_{ij}^m\right)^2 + \left(x_{ij}^u\right)^2\right]}} \quad (13)$$

Step 4: Weighting of the normalized decision matrix using Equation (14)-(15)-(16).

(In this study, the weights obtained by the Fuzzy SWARA method were used).

$$v_{ij}^l = w_j r_{ij}^l \quad (14)$$

$$v_{ij}^m = w_j r_{ij}^m \quad (15)$$

$$v_{ij}^u = w_j r_{ij}^u \quad (16)$$

Step 5: Ranking of alternatives in terms of benefit and cost criteria.

For benefit criteria (Equation (17)-(18)-(19)):

$$s_i^{+l} = \sum_{j=1}^{n} v_{ij}^{l} \Big| j \in j^{max} \tag{17}$$

$$s_i^{+m} = \sum_{j=1}^{n} v_{ij}^{m} \Big| j \in j^{max} \tag{18}$$

$$s_i^{+n} = \sum_{j=1}^{n} v_{ij}^{n} \Big| j \in j^{max} \tag{19}$$

For cost criteria (Equation (20), (21) and (22)):

$$s_i^{-l} = \sum_{j=1}^{n} v_{ij}^{l} \Big| j \in j^{min} \tag{20}$$

$$s_i^{-m} = \sum_{j=1}^{n} v_{ij}^{m} \Big| j \in j^{min} \tag{21}$$

$$s_i^{-n} = \sum_{j=1}^{n} v_{ij}^{n} \Big| j \in j^{min} \tag{22}$$

Step 6: Establishing the performance index value of each alternative. Defuzzification of the fuzzy utility and cost values calculated for the alternatives (Equation (23)). Thus, each alternative calculates the best non-fuzzy performance (BNP) value. Moreover, ranking the alternatives according to their performance values (by BNPs) from highest to lowest.

$$S_i(s_i^{+}, s_i^{-}) = \sqrt{\frac{1}{3}\left[\left(s_i^{+l} - s_i^{-l}\right)^2 + (s_i^{+m} - s_i^{-m})^2 + (s_i^{+u} - s_i^{-u})^2 \right]} \tag{23}$$

3. Results and Discussion

The business that produces energy storage systems has made-to-order. The company makes changes to its production lines for each new project. Changes to be made in production lines and risks that may occur before the project starts are presented to the management. Changes are made after management approval. In the sample implementation determined for this study: a new activity should be added to the production process due to an additional feature requested by the customer for their products. The customer wants to add traceability to their products.

For this reason, it switches to QR (Quick Response) code application in its products and requests a QR code application from its suppliers in the raw materials it sends. The business writes the QR code the customer wants with a laser printer. However, since no laser printer can write a QR code on top of the product's cover on the production lines, the laser printer should also be included in the production process. When the project started, a deadline was given by the customer company. All evaluations were made considering the closeness of the deadline and the short duration. Risks may arise due to this new demand and the short deadline. Considering the past project experiences, ten possible risks were determined with an expert team from the business (sales and marketing specialist, logistics specialist, production team leader, and project management specialist).

- **Risk 1: The risk that the laser printer will not fit on the line:** A laser printer and its components should be placed on the production line at the customer's request. However, since the supplier company and laser printer have not been decided yet, it is unclear whether all the equipment will fit on the line. There is a risk that the areas positioned on the lines of the laser printer devices are insufficient.
- **Risk 2: The risk that production stops due to a malfunction and the order is not fulfilled:** In case of a sudden breakdown or failure of the purchased laser printer, production may stop. Since the deadline is also short, this may cause problems in the timely delivery of the product.
- **Risk 3: The risk of not growing new QR code products due to being unable to find a budget for two devices:** The customer's products are currently produced on two separate production lines. For this reason, the laser printer will need to be positioned for two different lines. Laser printers cost much more than label devices. If the business is still looking for a budget for two new laser printers to be purchased, there is a risk that the new products with QR codes cannot be delivered within the customer's deadline.
- **Risk 4: Due to the long purchasing process, the risk of delaying the installation of the laser printer and failing to comply with the customer deadline:** Due to the purchasing process in the enterprise, offers from three companies are required. During the collection of bids, technical details are explained to the supplier companies in the field, and it may take a long time to determine the companies' qualifications. For this reason, there is a risk that the commissioning of laser printers will fail to meet the customer deadline.
- **Risk 5: The risk that the installation does not reach the customer deadline due to the contract process:** Due to the long duration of the contract sub-process within the purchasing process of the enterprise, there is a risk that the laser printer installation will not reach the customer deadline (Contract sub-process takes approximately one month).
- **Risk 6: Risk of product not reaching customer deadline due to installation delays caused by laser printer company:** Supplier companies that bid for laser printers bring laser printers from abroad (The supply time can take up to eight weeks). If there is no laser printer in the stock of the supplier company that can meet the needs of the business, the supplier company will order the laser printer from abroad. A problem during the order may cause the risk of delay in the customer delivery time.
- **Risk 7: Risk of injury to workers from laser beams:** It is planned to place laser printers in a cabinet on the production line, considering occupational health and safety conditions. However, if the cover of the cabinet used for machine adjustment is opened while the laser printer is operating, the workers may be harmed by the light beams.
- **Risk 8: The risk of the product going to the customer with the QR code written with the wrong content or not of the desired quality.** The customer company requires a unique

code that contains different parts codes for the QR code, written with a laser printer, and will be different in each product. Therefore, there is a risk that the content of the QR code needs to be of the correct or desired quality.

- **Risk 9: Risk of writing the QR code in the wrong place on the product and sending it to the customer in this way:** If the laser printer located on the production line is moved from its position, there may be a risk that the QR code will be written in the wrong place.
- **Risk 10: Risk of sending a product without a QR code to the customer:** A QR code may not be written on the product for any reason that may occur during production. The company can send the customer a product without a QR code if the error is not noticed.

According to the classical DMRA method, one of the most used methods for risk assessment, two risk components are used in the evaluation: The probability of risk and the effect of the formation. The impacts of risks (severity) after they occur may occur differently in many different areas. Therefore, more than measuring the impact with a single component will be required to assess it objectively. This study proposes a new risk assessment model detailing the "severity" component in the classical matrix risk assessment method, including different areas, to increase objectivity. According to the recommended model, risk size (RS) is calculated as shown in Equation (24).

$$RS = the\ severity\ of\ delivery\ time\ (C_1) \times the\ severity\ of\ cost\ (C_2) \times the\ severity\ of\ quality\ (C_3) \times likelihood\ (C_4) \quad (24)$$

The flow chart of the implementation is shown in Figure 1.

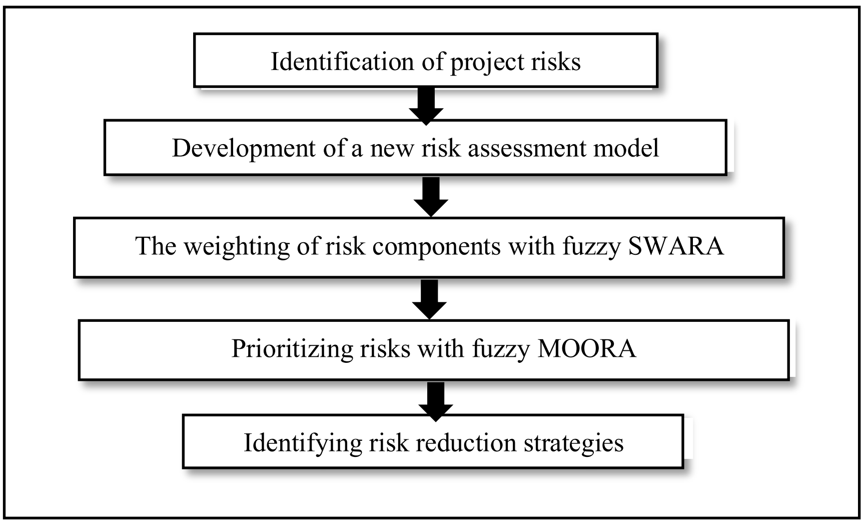

Figure 1: Flow chart for implementation

Fuzzy Swara Results

Since the importance of the four components in determining the risk size is different, the components are weighted using the Fuzzy SWARA method. The fuzzy SWARA method is used to solve problems with different decision-makers. The opinions of four experts were utilized in this study. The first decision maker (KV_1) is the sales and marketing specialist, the second decision maker (KV_2) is the logistics specialist, the third decision maker (KV_3) is the production team leader, and the fourth decision maker (KV_4) is the project management specialist. According to the first step of the fuzzy SWARA method, the ranking of the decision makers' criteria in order of importance is shown in Table 3.

Table 3: Criteria ranking according to decision-makers

Criteria	KV_1	KV_2	KV_3	KV_4
C_1 (The severity of delivery time)	3	1	1	1
C_2 (The severity of cost)	1	4	3	2
C_3 (The severity of quality)	2	2	4	3
C_4 (Likelihood)	4	3	2	4

The decision makers' comparison of criteria (s_j) with each other according to the fuzzy number transformations given in Table 1, k_j values calculated according to Equation (6), q_j importance vectors calculated according to Equation (7), and w_j fuzzy weight values calculated according to Equation (8) are shown in table 4.

Table 4: Fuzzy Weight Values

KV_1	s_{jl}	s_{jm}	s_{ju}	k_{jl}	k_{jm}	k_{ju}	q_{jl}	q_{jm}	q_{ju}	w_{jl}	w_{jm}	w_{ju}
C_2	0.75	1.00	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.38	0.52	0.58
C_3	0.50	0.75	1.00	1.25	1.75	2.00	0.60	0.57	0.50	0.31	0.30	0.29
C_1	0.25	0.50	0.75	1.50	2.25	2.75	0.40	0.25	0.18	0.21	0.13	0.11
C_4	0.50	0.75	1.00	2.00	3.00	3.75	0.20	0.08	0.05	0.10	0.04	0.03
KV_2	s_{jl}	s_{jm}	s_{ju}	k_{jl}	k_{jm}	k_{ju}	q_{jl}	q_{jm}	q_{ju}	w_{jl}	w_{jm}	w_{ju}
C_1	0.75	1.00	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.27	0.45	0.53
C_4	0.25	0.50	0.75	1.00	1.50	1.75	0.75	0.67	0.57	0.27	0.30	0.30
C_3	0.00	0.25	0.50	1.00	1.75	2.25	0.75	0.38	0.25	0.27	0.17	0.13
C_2	0.50	0.75	1.00	1.50	2.50	3.25	0.50	0.15	0.08	0.18	0.07	0.04
KV_3	s_{jl}	s_{jm}	s_{ju}	k_{jl}	k_{jm}	k_{ju}	q_{jl}	q_{jm}	q_{ju}	w_{jl}	w_{jm}	w_{ju}
C_1	0.75	1.00	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.22	0.41	0.49
C_4	0.00	0.25	0.50	0.75	1.25	1.50	1.00	0.80	0.67	0.29	0.33	0.32
C_2	0.25	0.50	0.75	1.00	1.75	2.25	1.00	0.46	0.30	0.29	0.19	0.14
C_3	0.50	0.75	1.00	1.50	2.50	3.25	0.67	0.18	0.09	0.20	0.07	0.04
KV_4	s_{jl}	s_{jm}	s_{ju}	k_{jl}	k_{jm}	k_{ju}	q_{jl}	q_{jm}	q_{ju}	w_{jl}	w_{jm}	w_{ju}
C_1	0.75	1.00	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.41	0.53	0.59
C_2	0.50	0.75	1.00	1.25	1.75	2.00	0.60	0.57	0.50	0.33	0.31	0.29
C_3	0.50	0.75	1.00	1.75	2.50	3.00	0.34	0.23	0.17	0.19	0.12	0.10
C_4	0.50	0.75	1.00	2.25	3.25	4.00	0.15	0.07	0.04	0.08	0.04	0.02

The fuzzy weights calculated separately for the four decision makers (shown in Table 4) are combined and given in Table 5.

Table 5: Combined fuzzy weights

	KV_1			KV_2			KV_3			KV_4			Criterion weight		
	w_{jl}	w_{jm}	w_{ju}	w_{jl}	w_{jm}	w_{ju}	w_{jl}	w_{jm}	w_{ju}	w_{jl}	w_{jm}	w_{ju}	p_{jl}	p_{jm}	p_{ju}
C_1	0.21	0.13	0.11	0.27	0.45	0.53	0.22	0.41	0.49	0.41	0.53	0.59	0.28	0.38	0.43
C_2	0.38	0.52	0.58	0.18	0.07	0.04	0.29	0.19	0.14	0.33	0.31	0.29	0.30	0.27	0.26
C_3	0.31	0.30	0.29	0.27	0.17	0.13	0.20	0.07	0.04	0.19	0.12	0.10	0.24	0.17	0.14
C_4	0.10	0.04	0.03	0.27	0.30	0.30	0.29	0.33	0.32	0.08	0.04	0.02	0.19	0.18	0.17
													1.00	1.00	1.00

The combined fuzzy weights of the criteria (shown in Table 5) and defuzzification according to Equation (9) are given in Table 6.

Table 6: Defuzzification criterion weights

	p_{jl}	p_{jm}	p_{ju}	
C_1	0.28	0.38	0.43	0.36
C_2	0.30	0.27	0.26	0.28
C_3	0.24	0.17	0.14	0.18
C_4	0.19	0.18	0.17	0.18

After determining the weight of each criterion with the Fuzzy SWARA method, the weights obtained were used in the Fuzzy MOORA method to prioritize the risks.

Fuzzy Moora Results

The prioritization of project risks by the Fuzzy Moora method was performed in six steps.

Step 1: The decision-makers evaluate the risks (alternatives) affecting the customer's deadline. Linguistic variables in Table 2 were used for evaluation. Table 7 shows risk assessments made by decision-makers.

Table 7: Fuzzy assessment of risks by decision-makers

KV_1	C_1			C_2			C_3			C_4		
R_1	0.50	0.70	0.90	0.10	0.30	0.50	0.10	0.30	0.50	0.00	0.10	0.30
R_2	0.70	0.90	1.00	0.10	0.30	0.50	0.30	0.50	0.70	0.00	0.10	0.30
R_3	0.70	0.90	1.00	0.00	0.10	0.30	0.00	0.10	0.30	0.00	0.10	0.30
R_4	0.70	0.90	1.00	0.00	0.10	0.30	0.10	0.30	0.50	0.90	1.00	1.00
R_5	0.70	0.90	1.00	0.00	0.10	0.30	0.10	0.30	0.50	0.90	1.00	1.00
R_6	0.70	0.90	1.00	0.00	0.10	0.30	0.10	0.30	0.50	0.70	0.90	1.00
R_7	0.70	0.90	1.00	0.10	0.30	0.50	0.30	0.50	0.70	0.70	0.90	1.00
R_8	0.50	0.70	0.90	0.50	0.70	0.90	0.70	0.90	1.00	0.50	0.70	0.90
R_9	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.10	0.30	0.50
R_{10}	0.00	0.10	0.30	0.50	0.70	0.90	0.70	0.90	1.00	0.00	0.10	0.30
KV_2	C_1			C_2			C_3			C_4		
R_1	0.70	0.90	1.00	0.30	0.50	0.70	0.10	0.30	0.50	0.10	0.30	0.50
R_2	0.70	0.90	1.00	0.30	0.50	0.70	0.30	0.50	0.70	0.10	0.30	0.50
R_3	0.70	0.90	1.00	0.00	0.10	0.30	0.00	0.10	0.30	0.00	0.10	0.30
R_4	0.70	0.90	1.00	0.00	0.10	0.30	0.30	0.50	0.70	0.90	1.00	1.00
R_5	0.70	0.90	1.00	0.00	0.10	0.30	0.30	0.50	0.70	0.90	1.00	1.00
R_6	0.70	0.90	1.00	0.10	0.30	0.50	0.30	0.50	0.70	0.70	0.90	1.00
R_7	0.70	0.90	1.00	0.30	0.50	0.70	0.50	0.70	0.90	0.70	0.90	1.00
R_8	0.70	0.90	1.00	0.70	0.90	1.00	0.70	0.90	1.00	0.50	0.70	0.90
R_9	0.70	0.90	1.00	0.70	0.90	1.00	0.70	0.90	1.00	0.30	0.50	0.70
R_{10}	0.10	0.30	0.50	0.70	0.90	1.00	0.70	0.90	1.00	0.10	0.30	0.50
KV_3	C_1			C_2			C_3			C_4		
R_1	0.70	0.90	1.00	0.10	0.30	0.50	0.10	0.30	0.50	0.00	0.10	0.30
R_2	0.50	0.70	0.90	0.30	0.50	0.70	0.10	0.30	0.50	0.00	0.10	0.30
R_3	0.70	0.90	1.00	0.10	0.30	0.50	0.10	0.30	0.50	0.10	0.30	0.50
R_4	0.50	0.70	0.90	0.00	0.10	0.30	0.10	0.30	0.50	0.70	0.90	1.00
R_5	0.70	0.90	1.00	0.10	0.30	0.50	0.10	0.30	0.50	0.90	1.00	1.00
R_6	0.70	0.90	1.00	0.10	0.30	0.50	0.10	0.30	0.50	0.70	0.90	1.00
R_7	0.70	0.90	1.00	0.10	0.30	0.50	0.10	0.30	0.50	0.70	0.90	1.00
R_8	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90
R_9	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.10	0.30	0.50
R_{10}	0.10	0.30	0.50	0.70	0.90	1.00	0.70	0.90	1.00	0.10	0.30	0.50
KV_4	C_1			C_2			C_3			C_4		
R_1	0.50	0.70	0.90	0.10	0.30	0.50	0.10	0.30	0.50	0.00	0.10	0.30
R_2	0.50	0.70	0.90	0.10	0.30	0.50	0.30	0.50	0.70	0.00	0.10	0.30
R_3	0.50	0.70	0.90	0.00	0.10	0.30	0.00	0.10	0.30	0.00	0.10	0.30
R_4	0.50	0.70	0.90	0.00	0.10	0.30	0.00	0.10	0.30	0.50	0.70	0.90
R_5	0.50	0.70	0.90	0.00	0.10	0.30	0.00	0.10	0.30	0.70	0.90	1.00
R_6	0.50	0.70	0.90	0.00	0.10	0.30	0.10	0.30	0.50	0.50	0.70	0.90
R_7	0.50	0.70	0.90	0.10	0.30	0.50	0.10	0.30	0.50	0.50	0.70	0.90
R_8	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90
R_9	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.10	0.30	0.50
R_{10}	0.00	0.10	0.30	0.50	0.70	0.90	0.50	0.70	0.90	0.00	0.10	0.30

Step 2: The decision makers' risk evaluations were combined using Equation (10). The combined fuzzy decision matrix created is given in Table 8.

Table 8: Combined fuzzy decision matrix

	C_1			C_2			C_3			C_4		
R_1	0.60	0.80	0.95	0.15	0.35	0.55	0.10	0.30	0.50	0.03	0.15	0.35
R_2	0.60	0.80	0.95	0.20	0.40	0.60	0.25	0.45	0.65	0.03	0.15	0.35
R_3	0.65	0.85	0.98	0.03	0.15	0.35	0.03	0.15	0.35	0.03	0.15	0.35
R_4	0.60	0.80	0.95	0.00	0.10	0.30	0.13	0.30	0.50	0.75	0.90	0.98
R_5	0.65	0.85	0.98	0.03	0.15	0.35	0.13	0.30	0.50	0.85	0.98	1.00
R_6	0.65	0.85	0.98	0.05	0.20	0.40	0.15	0.35	0.55	0.65	0.85	0.98
R_7	0.65	0.85	0.98	0.15	0.35	0.55	0.25	0.45	0.65	0.65	0.85	0.98
R_8	0.55	0.75	0.93	0.55	0.75	0.93	0.60	0.80	0.95	0.50	0.70	0.90
R_9	0.55	0.75	0.93	0.55	0.75	0.93	0.55	0.75	0.93	0.15	0.35	0.55
R_{10}	0.05	0.20	0.40	0.60	0.80	0.95	0.65	0.85	0.98	0.05	0.20	0.40

Step 3: By using Equation (11)-(12)-(13), normalization is done for the combined fuzzy decision matrix. The normalized fuzzy decision matrix is shown in Table 9.

Table 9: Normalized fuzzy decision matrix

	C_1			C_2			C_3			C_4		
R_1	0.09	0.15	0.21	0.01	0.05	0.11	0.00	0.03	0.08	0.00	0.01	0.04
R_2	0.09	0.15	0.21	0.01	0.06	0.13	0.02	0.07	0.14	0.00	0.01	0.04
R_3	0.10	0.17	0.23	0.00	0.01	0.05	0.00	0.01	0.04	0.00	0.01	0.04
R_4	0.09	0.15	0.21	0.00	0.00	0.03	0.01	0.03	0.08	0.16	0.24	0.28
R_5	0.10	0.17	0.23	0.00	0.01	0.05	0.01	0.03	0.08	0.21	0.28	0.29
R_6	0.10	0.17	0.23	0.00	0.01	0.06	0.01	0.04	0.10	0.12	0.21	0.28
R_7	0.10	0.17	0.23	0.01	0.05	0.11	0.02	0.07	0.14	0.12	0.21	0.28
R_8	0.07	0.13	0.20	0.11	0.21	0.31	0.12	0.22	0.31	0.07	0.14	0.24
R_9	0.07	0.13	0.20	0.11	0.21	0.31	0.10	0.19	0.29	0.01	0.04	0.09
R_{10}	0.00	0.01	0.04	0.13	0.24	0.33	0.14	0.24	0.32	0.00	0.01	0.05

Step 4: Equation (14)-(15)-(16) weighted normalized fuzzy decision matrix. The weighted fuzzy normalized decision matrix obtained is shown in Table 10.

Table 10: Weighted fuzzy decision matrix

	C_1			C_2			C_3			C_4		
R_1	0.03	0.05	0.08	0.00	0.01	0.03	0.00	0.01	0.02	0.00	0.00	0.01
R_2	0.03	0.05	0.08	0.00	0.02	0.04	0.00	0.01	0.03	0.00	0.00	0.01
R_3	0.04	0.06	0.08	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
R_4	0.03	0.05	0.08	0.00	0.00	0.01	0.00	0.01	0.02	0.03	0.04	0.05
R_5	0.04	0.06	0.08	0.00	0.00	0.01	0.00	0.01	0.02	0.04	0.05	0.05
R_6	0.04	0.06	0.08	0.00	0.00	0.02	0.00	0.01	0.02	0.02	0.04	0.05
R_7	0.04	0.06	0.08	0.00	0.01	0.03	0.00	0.01	0.03	0.02	0.04	0.05
R_8	0.03	0.05	0.07	0.03	0.06	0.09	0.02	0.04	0.06	0.01	0.03	0.04
R_9	0.03	0.05	0.07	0.03	0.06	0.09	0.02	0.03	0.05	0.00	0.01	0.02
R_{10}	0.00	0.00	0.01	0.04	0.07	0.09	0.03	0.04	0.06	0.00	0.00	0.01

Step 5-6: In this implementation, since all alternatives (risks) are about cost, not benefit, risks are listed using Equation (20)-(21)-(22). With the fuzzy SWARA method, the weights of the risk components (severity of delivery time (C_1), severity of cost (C_2), severity of quality (C_3) and likelihood (C_4)) to be used in risk assessment were determined. BNP values for risks were calculated according to C_1, C_2, C_3 and C_4 values with the fuzzy MOORA method. Fuzzy performance index values were defuzzification using Equation (23). The highest BNP value is 0.17, which belongs to risk 8. When the BNP values of the risks are ranked from the highest to the lowest, the order of priority is as follows: Risk 8 > Risk 9 > Risk 7 > Risk 5 > Risk 10 > Risk 4 > Risk 6 > Risk 2 > Risk 1 > Risk 3

4. Conclusion

Anticipating risks and making the necessary action plans are essential for businesses to prevent or reduce undesirable situations (not complying with customer deadlines, malfunctions, delays in production, etc.).

This study discusses the risks of a business producing energy storage systems and starting a new project. It aims to develop a risk assessment model different from the classical matrix risk assessment approach to identify and prioritize the risks that may occur before the start of the project. For this reason, the "severity" component in the classical matrix method is divided into three sub-components due to the different areas that the risk can affect and the different weights in these areas. Therefore, the risk size is not composed of the multiple of two components, "Severity" and "Likelihood," but the multiple of four components of the risk as "The severity of delivery time (C_1)," "The severity of cost (C_2)," and "The severity of quality (C_3)," and "Likelihood (C_4)". The SWARA method was used to calculate the weights of the four risk components. The criteria weights calculated with the Fuzzy SWARA method were used in the Fuzzy MOORA method, and the ten risks identified were prioritized according to these weight values.

As a result of the study, the most priority risk was determined as the risk of going to the customer with the QR code written in incorrect or non-desired quality of the product (Risk 8). Three action plans have been determined to reduce this risk. The first action plan is to add a barcode reader to the laser printer's output on the production line and to verify the accuracy of the written QR code by comparing it with the coding algorithm. Thus, it is aimed to identify and reject the non-conforming product. This way, the risk of going to the customer will be reduced even if a faulty product occurs on the production line. However, the cost of this action plan is high. The second action plan is to control the alphanumeric code under the written QR code with the camera control unit at the end of the production line. Since the serial number cannot be checked with the camera, only the alphanumeric code can be checked, and this plan is not a suitable plan to reduce the risk. The third action plan: A screen where product selection can be made is to be placed next to the laser printer unit in the production line not to write the wrong QR code. The QR code will be written in the correct algorithm by selecting the relevant product from this screen. This way, it will be sufficient for the personnel to select the product's name from the screen without having to design the relevant QR code at the beginning of the process. Thus, the wrong QR code design can be prevented and reduced risk. The business has decided to implement the third action plan.

In the study, Fuzzy SWARA and Fuzzy MOORA techniques were used to take into account the uncertainties in the risks and the evaluations of the decision-makers. Different MCDM techniques can be used and integrated into subsequent studies. In addition, new risk assessment models can be developed by dividing the severity component used in the classical risk assessment method into subcomponents in different ways for different sectors and different problems.

Ethics in Publishing

There are no ethical issues regarding the publication of this study

Author Contributions

Conceptualization, G.S.Y.; methodology, G.S.Y. and T.K.P.; validation, G.S.Y. and T.K.P.; formal analysis, G.S.Y. and T.K.P.; investigation, G.S.Y.; resources, G.S.Y. and T.K.P.; data curation, G.S.Y.; writing – original draft preparation, G.S.Y.; writing – review and editing, T.K.P.; visualization, G.S.Y. and T.K.P.; supervision, T.K.P.; project administration, T.K.P.

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