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Research Article

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Risk prioritization model driven by success factor in the light of multicriteria decision making

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Abstract: Some factors in the product development process can increase success. Evaluating the risks and success factors is necessary for a more successful product development process. Some inadequacies arise in classical risk assessment methods due to the subjective nature of likelihood and severity ratings. Different probability and impact values can give the same risk size. Due to these inadequacies, doubts about the accuracy of risk prioritization may arise. In this study, a new risk prioritization model is proposed to eliminate these doubts and to consider their contribution to the success of the process they affect while prioritizing the risks, with a detailed literature review and the support of the experts of the applied company, the risks affecting the product development process. The importance levels of risks and success factors were calculated using the analytical hierarchy process. With the proposed model, unlike the classical method, when calculating the risk size, the risk weight and the total score from the success factors are added to the likelihood and severity values of the risk. Thus, companies will obtain more detailed and objective results, considering success factors and risk importance levels, and use the resources they allocate for risk reduction activities more efficiently.

Keywords: risk prioritization, success factor, analytical hierarchy process, product development

1 Introduction

In today's business world where customer demands change/differentiate every day and the life cycles of products are shortened, one of the most critical factors in providing competitive advantage and rapidly adapting to the product needed in the market is new product development. Therefore, companies must invest in the product development to increase their competitiveness or survive. Although the product development process is essential for the competitive advantage of companies, it also brings many risks. Risks are inherent in every product development [1]. The elimination of these risks will also be effective in deciding whether to continue with the new product. By preventing risks before they occur, it will be possible to increase the production quality by reducing the product's development cost to be produced.

The term "new product" has other meanings besides making significant changes to an existing product or attempting a new product. There are seven new products: cost reduction, product improvements, new product categories, diversification in the product, new markets, new uses, and new products [2]. The product development process aims to introduce products that meet customer expectations, including producing new products, changing the existing product, renewing it, or converting it into another product.

Generally, new product production ideas are driven by the emergence of a new technology that pushes the product to the market or by a new development that creates a need for the product. Since new product projects have long life cycles, significant investments, and high levels of uncertainty, risk management is essential for the success of such projects [3]. In addition, since there may be uncertainties regarding access to sufficient information while managing product development projects, it is essential to carry out risk management to control the risks caused by these uncertainties.

It is inevitable for companies to engage in product development activities from time to time to have a good place in the market and maintain their current market share. Rapid changes in technology and the accompanying increase/differences in customer expectations increase the product development efforts of companies. At the same time, changing and developing needs, regardless of technology, are the pioneers of the product development (such as the Covid-19 pandemic). Especially in the last year,

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customer needs have changed considerably due to the Covid-19 pandemic. Due to the observance of the mask-distance-hygiene rule to protect against Covid-19, the demand for masks and hygiene products has increased considerably. Current brands of surgical masks and hygiene products in the market cannot keep up with this demand. In this study, when a company that currently produces textile products realizes the need for surgical masks in the market, it will be discussed whether to switch to surgical mask production with the product development activity to take advantage of this opportunity. One of the most critical factors in the favorable decision is the risk size of the activities carried out to produce surgical masks.

The aim of this study is to develop a new risk prioritization model that includes the factors that will ensure the success of the relevant process. Thus, risks will be prioritized not only according to their likelihood and severity values but also by considering their effects on the success of the process they affect. The product development process risks for surgical masks will be evaluated and prioritized with the "Risk Prioritization Model Driven by Success Factors (RPDSF)," which will be used for the first time in the literature to obtain more detailed and realistic results. With this evaluation, the company will have made a critical analysis to decide whether to produce surgical masks. In the study where "Covid-19 surgical mask production" was addressed, first, the principal risks and subrisks that will affect the new product performance were determined by using a detailed literature review and the opinions of the experts in the company. Since the effects of the risks on the product development process are not the same, the importance level (weight) of each risk on the product development process has been determined by the analytical hierarchy process (AHP) method, one of the multicriteria decision-making (MCDM) methods. Similarly, to be included in the proposed RPDSF model, the success factors affecting the product development process were determined by literature and expert knowledge. Since the effects of success factors on the product development process are not the same, the importance of success factors was also determined by the AHP method. The risks' total score from the success factors was calculated by determining which factors affected each risk. Finally, according to the proposed RPDSF model, besides the standard risk scores consisting of the likelihood (P) and severity (S) of all risks, the importance levels (weights) of risks determined by AHP and their total scores from success factors were also multiplied. Thus, the "risk sizes driven by success factors – RSDSF" of the risks of the product development process were calculated. This detailed calculation provides a new perspective on classical decision matrix risk assessment (DMRA) methods. In addition, the method developed offers a new-different-focused risk prioritization methodology since it considers the effects of product development risks on product development success and calculates the importance levels (weights) of risks and success factors. The developed model will serve many areas thanks to its ability to be used for all processes in the company by changing the success factors.

2 Literature and theoretical background

2.1 Product development and success factors in product development

The product can be defined as the parts that provide value for the customer and integrate talent and solutions [4]. It is possible to define the product as a combination of attributes (functions, features, benefits, uses) [5]. Product development is the way forward of the innovation activity to reach the market, and it often plays a rescuer role for businesses. In a questionnaire conducted by the PDMA (Product Development Management Association), it stated that the period in which businesses perform the most and make the most profit is when they launch a new product [6]. Therefore, the most crucial aim of the product development process is to create value. In this context, value can be financial, time, physical, emotional, image, sensory, psychological, and functional. Support can be obtained from both internal stakeholders (organizational structure, employees, economic assets, and brand value) and external assets (current customer base, targeting new customer base, and general community of consumers) to create value [7]. Especially in rapidly changing and competitive markets, it is essential to produce successful new products for companies to continue their activities.

Measuring the success of product development will help decide whether to continue producing the product. Roy et al. [8] defined success factors in product development as meeting quality needs, achieving specified performance, and designing the goals of the product. De Brentani [9] divided the criteria used to measure the success of a new product into financial measures (sales, profit, growth, and cost) and nonfinancial criteria (success status and customer preference compared to competitors' products). Paksoy [10] listed the success factors as the quality of the new product process, and the business has the appropriate organizational structure, the development is market-oriented, and a good development plan has been made. McDonough et al. [11] listed a few items to measure the success of a product put on the market, such as getting products to market quickly, achieving commercial success (profit) from products, ability to produce quality products, providing customer needs, and ensuring good overall performance. Gruner and Homburg [12] have defined some criteria for evaluating success in the product development: new product quality from the customer's point of view, quality of the product development process, sales profitability for the new product, and the cost to the customer of owning a new product. Hajli et al. [13] stated that the product success depends on many factors such as the ability to integrate marketing and R&D, the shaping of relationships, and the management's ability to control. Driva et al. [14] researched firms to determine the performance criteria used to measure whether a new project is successful and determined 15 criteria. According to the research, the first five criteria most preferred by companies among these 15 criteria can be listed as follows: the total cost of the project, the delivery time of the developed project, the actual project cost compared to the budgeted, the comparison of the estimated and actual times for the project delivery time, and the time to market. Chung and Hsu [15] proposed five indicators to measure success performance in product development: the timing of the new product's introduction to the market, the level of quality in the new product, the market share of new products, the rate of new products successfully introduced to the market, and the cost of the introduction of a new product to the market.

Salnikova et al. [16] measured the success rates of newly introduced food products and showed the relationship between new product success and market entry strategy. The study provided a quantitative approach to measuring success in food products. Rajagopal [17] conducted a study in Mexico to analyze new products in some self-service stores selling food products. The study showed that it is essential to adjust the new product launch timing according to the market demand and seasonality factors while increasing the success of the new product. Jimenéz-Jimenéz et al. [18] evaluated the success of the new product with the application of Spanish Manufacturing companies. They stated that the new product innovation strategy was influential on the success of the new product. However, a study examining the success of new products developed in technology-intensive industries states that the organizational learning process does not contribute significantly to the success of the new product [19].

It is not always easy to ensure the customer's satisfaction, which is one of the stakeholders, during the design and production activities of the products. The design, production, and delivery activities of consumer products should meet customer demands and be economical and sustainable to continue their production. Jreissat et al. [20] stated that increasing the product's success in the market is necessary to consider customer requests during new product design and production. Customer wishes must also be included at the beginning of the product development; this is one of the critical success factors for the product development. Van Kleef et al. [21] cited the ten most common methods to include customer desires in the product development. According to Horvat et al. [22], with a consumer-oriented product development approach, the success of the new product in the market will increase. In their study of European food companies, researchers emphasize that an optimum match between consumer needs and the new product should increase their success.

New products are essential for the success of companies. However, many new products introduced fail. For this reason, companies consider launching a new product to the market as an essential risk and avoid producing new products. One of the reasons for being successful in the market is the timely and fast launch of the new product [23]. Therefore, one of the critical factors in the product development is timely production, and one of the critical factors in this is the supplier.

For this reason, managing supplier collaboration is an increasingly important issue in the product development success. According to Dvorsky et al. [24], good relationships between small mdium enterprises and their suppliers over the years will not automatically lead to better management of supplier risks. Therefore, effective supplier risk management is essential. Le Dain and Merminod [25] proposed a conceptual framework for information sharing in a structure involving three different suppliers.

Although there are many studies evaluating success factors in the product development, no reference uses these success factors to evaluate the risks in the product development.

2.2 Risk management

Risk can define as uncertain events that positively (opportunity) or negatively (threat) affect the time–cost–performance objectives of the project if they occur [26]. Companies must protect themselves against risks that may result in financial difficulties, loss of image, decreased credit ratings, difficulties accessing information, etc. In addition, organizations need risk management to gain a competitive advantage and support decision-making processes [27]. Risk management is also about managing these emerging risks. Risk management is an iterative process consisting of five key activities: identification, analysis, evaluation, treatment, and monitoring/control [28]. Risk management is a powerful tool used to improve the security performance of companies' operations [29]. Given that unmanaged risks can divert projects from their original goals, it is clear that the effectiveness of the risk management is crucial to project success [30].

Risks are standard, especially in engineering activities, due to the complexity of machines and processes, the intensity of human factors, and uncertainty. There are many techniques used to prevent the occurrence or recurrence of malfunctions/accidents by evaluating the risks that may cause undesirable consequences on the performance of the work: DMRA, HAZOP (hazard and operability), fault tree analysis, event tree analysis, failure mode and effect analysis (FMEA), and so on. These techniques are used to analyze the root cause of problems, and they are often used in conjunction with techniques such as MCDM methods, fuzzy set theory, social network analysis, interpretative structural modeling, and Monte Carlo simulation to increase the applicability and effectiveness of techniques and to manage risks more effectively. The function of MCDM methods (such as AHP (analytic hierarchy process), TOPSIS (technique for order preference by similarity to ideal solution), ELECTRE (elimination and choice translating reality), WASPAS (weighted aggregated sum product assessment), BWM (best-worst method), and MARCOS (measurement of alternatives and ranking according to compromise solution) used in conjunction with risk assessment methods is generally to prioritize risks.

Bid and Siddique [31] used TOPSIS and WASPAS techniques to prioritize the risks posed by dams on humans. Celik and Gul [32] evaluated the dam construction's occupational health and safety risks with the DMRA method. Then, they weighed the likelihood and severity values used to determine the risk score with the BWM. In the continuation of the study, they made the priority ranking of the risks with the MARCOS technique. Samaras et al. [33], in their study evaluating the dam projects, first classified the projects according to their risks with the AHP. Later, they made the same classification with the ELECTRE method and compared the results. Unver and Ergenc [34] used the AHP technique while calculating the importance of risks faced by chainsaw operators in their studies.

Marhavilas et al. [35] used the HAZOP method to detect abnormal situations (deviations) and the DMRA method to evaluate the risks arising from deviations in the oil processing plant. They also used the AHP method to prioritize the identified risks. In a study conducted to evaluate the risks posed by a refinery in Iran, after determining the factors causing the risk, the AHP method was used to find the most important among them [36]. Malekmohammadi and Blouchi [37] conducted a risk assessment practice for wetland ecosystems in their study. After the researchers analyzed the risks, they identified an ecosystem-based approach; they used AHP to prioritize the risks.

Dursun and Çuhadar [38] proposed a "risk-based MCDM" methodology for the unmanned aerial vehicles application area. The likelihood of risks was included in the decision model in the study, and a selection was made among five unmanned aerial vehicles. Jena and Pradhan [39] used a hybrid AHP-TOPSIS model to develop the "earthquake risk assessment" study. Banda [40] evaluated the risks in the mining industry. The researcher used the AHP-expert questionnaire-sensitivity analysis methods in an integrated manner to determine the severity and likelihood scores of the risks. He determined variable risk events with sensitivity analysis. Oturakci and Dagsuyu [41] used the FMEA method as a risk assessment technique, prioritizing the effects of AHP and water–air–soil criteria and then ranking the modes of transportation according to impact categories prioritized TOPSIS. Ristanovic et al. [42] developed a decision-making system using the AHP technique while choosing the appropriate method to manage the operational risks.

Recently, the number of literature studies on risk prioritization has been increasing. However, there are some criticisms regarding the classical probability-effect rating approach that the factors and assumptions hidden in the risk ratings that cannot be communicated to the decision makers affect the reliability of the risk assessment [43].

Different types of MCDM methods are frequently used in risk assessment studies to eliminate the deficiencies in traditional risk assessment methods, especially the presence of multiple risk factors and their varying importance level [44]. It is difficult to precisely examine the risk parameters due to the subjective evaluations 1–5 in the decision matrix. The different likelihood and severity ratings can give the exact size of risk [32]. They independently evaluate the risk matrix and ignore the risks' interdependence [45]. In addition, as Qazi and Dikmen [45] stated, the risk matrix expresses the effects of risks such as time–cost–quality on the target of a specific project. Therefore, measuring risks with only likelihood and severity parameters will not provide efficient results in the complete sense. Therefore, the classical DMRA method has been expanded to eliminate the deficiencies in this study. First, in addition to the calculation in the classical DMRA method, the risks' importance levels (weights) were determined with the AHP method. Success factors have been determined for the activities of the product development process, which is the field of application, and the importance levels (weights) of success factors were determined by the AHP method. The impact of each risk on success factors has been determined. These components are multiplied to calculate the risk size according to the RPDSF model proposed in the study.

Because of the detailed literature research, it is seen that there are studies involving DMRA methods and MCDM techniques. However, as stated earlier, although there are studies in which success factors in the product development are measured, there is no risk analysis study including the effect of success factors in any study. Therefore, this study distinguishes itself as the first to evaluate the processes' risks by synthesizing DMRA-AHP-success factors. The model was also applied in a textile company developing products for the "surgical mask" product, whose need increased after the Covid-19 pandemic.

3 Materials and methods

3.1 DMRA

Risk assessment is essential in almost all sectors, regardless of manufacturing or service sectors. However, the risk assessment process is a process that takes more consideration, especially in sectors where there are high-risk operations or where there is a lot to lose when risk arises.

The DMRA method, developed by the US Air Force Electronic Systems Center in the 1990s, can be defined as qualitative or quantitative analyses using the likelihood of risks and severity after they occur [46]. The DMRA method is a systematic approach used to estimate the size of risks. It is used to measure and classify both likelihood values and severity values of risks with informed judgment [47].

A two-dimensional matrix chart is created in the DMRA, better known as the risk matrix method. In general, the values for the likelihood are shown in the rows, and the values for the severity component are shown in the columns [48,49]. Risk levels within the decision matrix are usually represented using three colors: red (unacceptable and urgent risk level), yellow (unacceptable but some time to resolve risk level), and green (generally acceptable risk level) [50]. For example, Table 1 presents the likelihood and severity components for the 5×5 risk matrix (prepared with the support [47,51–55]).

A sample risk assessment decision matrix prepared with the support from the likelihood and severity scale in Table 1 is shown in Table 2 (prepared with support [52,56–59]).

The risk matrix method is a very convenient method for evaluating the risks and prioritizing the risks according to the risk sizes determined while considering the possible dangers. Risk matrices are a frequently used method to help identify priorities and assign resources [49]. In addition, risk prevention/reduction activities can be decided according to a priority order created using this technique [60].

The combination of severity and likelihood values (equation (1)) in the DMRA method gives the risk size [61,62].

$$\text{Risk size} = (\text{Likelihood } (P)) \times (\text{Severity } (S)). \quad (1)$$

The beginning of creating a risk matrix is primarily determining the risks that are expected to occur.

Table 1: Description of likelihood and severity scales

Likelihood scale		Likelihood Description	Severity scale		Severity description
1	Impossible	Hardly ever	1	Insignificant	Minimal or no impact
2	Unlikely	Only in abnormal conditions	2	Minor	Small consequence
3	Likely	Occasional	3	Moderate	Significant short-term consequence
4	Highly likely	Likely to occur sometimes	4	Serious	Severe or nonpermanent long-term consequence
5	Almost certain	Likely to occur many times	5	Critical	Irreversible/catastrophic consequence

Table 2: Example of risk assessment decision matrix

Severity (*S*)	Likelihood (*P*)				
	Remote (1)	Unlikely remote (2)	Likely (3)	Highly likely (4)	Almost certain (5)
Insignificant (1)	Acceptable	Acceptable	Acceptable	Acceptable	Tolerable
Minor (2)	Acceptable	Acceptable	Tolerable	Tolerable	Tolerable
Moderate (3)	Acceptable	Tolerable	Tolerable	Tolerable	Intolerable
Serious (4)	Tolerable	Tolerable	Tolerable	Intolerable	Intolerable
Critical (5)	Tolerable	Tolerable	Intolerable	Intolerable	Intolerable

Afterward, the risk components are determined that show the likelihood of each risk and the severity of the person/department to be exposed after it occurs. Again, it is helpful to benefit from data and expert opinions while determining the values of risk components.

3.2 AHP

The AHP method was developed by Saaty [63], and AHP is an MCDM technique that creates priority vectors through pairwise comparisons and ratings and prioritizes according to these values [64,65]. With the AHP technique, which is based on expert pairwise comparisons, evaluation is made for each criterion by considering these pairwise comparisons [66].

The AHP technique is a decision-making approach used to solve problems with a hierarchical structure consisting of goals, criteria, subcriteria, and alternatives. In addition, Saaty's standard 1–9 preference scale is used to make pairwise comparisons of those at the same hierarchical level [67]. Table 3 presents the preference scale [63,68–70].

The steps of the AHP method can be briefly listed as follows [66,71–73]:

- Defining the problem, determining the goal – decision criteria – alternatives
- Creating the hierarchical model
- Preparation and normalization of pairwise comparison matrices for each criterion and alternative (although different methods are used for normalization, in this study, normalization will be done with the calculation method shown in equation (2))

$$b_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}. \tag{2}$$

- Calculation of importance level (weights) for criteria and alternatives (the arithmetic mean will calculate it).
- Prioritization of alternatives.

The AHP method is a technique that is used frequently in solving problems in the manufacturing and service sectors. Applications of MCDM techniques are frequently seen in the solution of problems in various subjects such as determining the best plastic waste collection methods [74], selecting the most popular organic fertilizer production method [66], selecting a supplier for the packaging company [75], prioritizing climate change mitigation strategies [76], assessing sustainable manufacturing practices [77], prioritizing the barriers that prevent the implementation of green supply chain management [78], evaluating suppliers according to environmental compliance criteria [79,80], choosing the most suitable project among renewable energy project alternatives [81], prioritizing project risks [82], comparing performance metrics of real-time scheduling and parts routing decisions [83], developing a credit evaluation system [84,85], and prioritizing distribution targets for microgrids [86].

Table 3: The scale of preferences

Numerical value	Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong importance
8	Very, very importance
9	Extreme importance
1/3, 1/5, 1/7, 1/9	If the two activities are compared, the first activity has one of the numbers above, and the second activity also has a reciprocal value
1/2, 1/4, 1/6, 1/8	The reciprocal value of comparisons between two judgments

4 RPDSF

A textile company that does not produce surgical masks during its regular production aims to switch to surgical masks to benefit from the market created due to the COVID-19 pandemic. The product development will be done for this. In this study, the risks that may occur during the product development process will evaluate and prioritize the company that plans to switch to surgical masks. Unlike the classical DMRA method and eliminating the disadvantages, the "RPDSF," which will be used for the first time in the literature, is suggested. With the RPDSF (which works with the AHP method), it is desired to help the company decide whether to produce surgical masks by ensuring that the risks are evaluated/prioritized before the product development.

4.1 General framework for RPDSF

While evaluating the risk, the classical matrix method is insufficient to measure the actual size of the risk because the evaluation can be subjective; the risks can have the same risk size even if they have different likelihood and severity values. In this study, the "RPDSF" supported by the AHP method was developed to eliminate these shortcomings of the classical decision matrix. Thus, while eliminating the deficiencies of the classical decision matrix, at the same time, since the effect of risk on the success factors of the relevant process is also taken into account, the risk assessment will be more effective in terms of the process. The RPDSF model calcifies risk sizes according to equation (3).

$$\mathrm{RSDSF} = (P) \times (S) \times (\mathrm{IL}) \times (\mathrm{RSF}), \tag{3}$$

where RSDSF is the risk size driven by success factors; P is the likelihood value of the risk; S is the severity value of risk; IL is the importance level calculated with AHP (weight); and RSF is the total score the risk gets from the success factors (which the risk affects)).

The flowchart of the proposed RPDSF model and its implementation in this study are shown in Figure 1.

According to the RPDSF model, the risks affecting the product development activities are determined. Since the risks consist of subrisks and each risk has a different

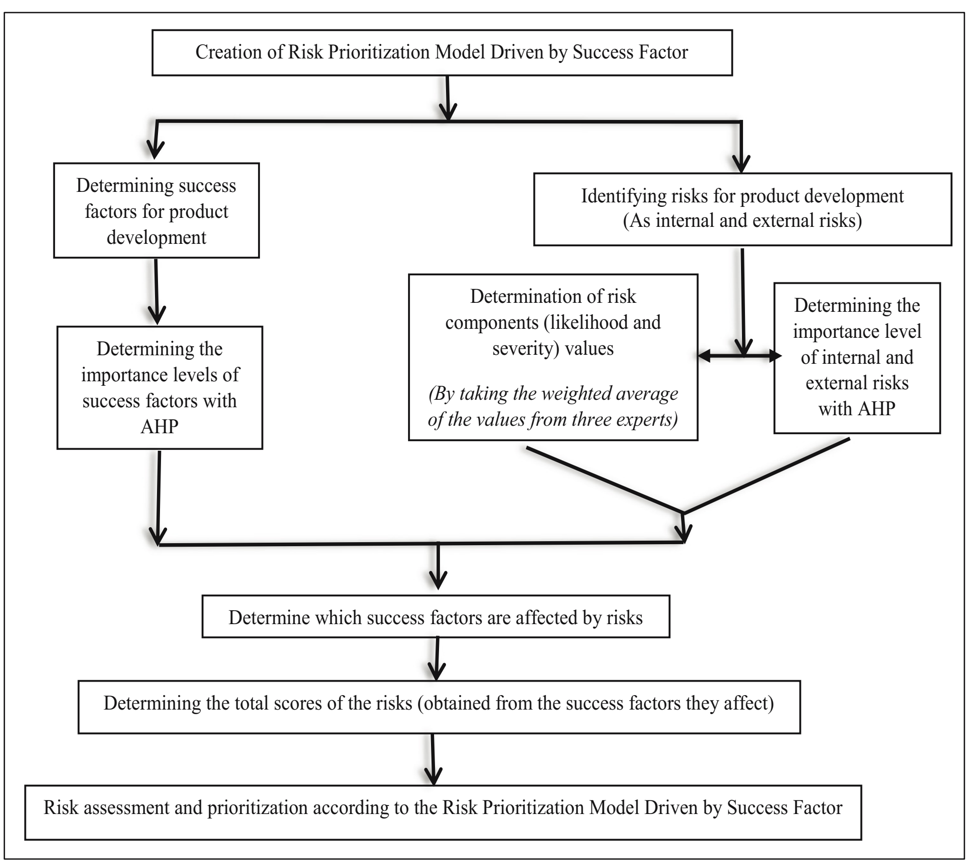

Figure 1: The flowchart of the RPDSF.

impact on product development activities, the importance level (weight) has been determined by the AHP method. Then, the likelihood and severity values of the risks to be evaluated are calculated with the weighted average of the values obtained from the three experts of the company. The preparation of AHP pairwise comparison matrices to determine the importance level (weight) of the risks and the determination of the likelihood and severity values of the risks was carried out together with three product development experts working in the company. Due to the unequal knowledge/experience of the experts, weighting was made according to their knowledge/experience. The weight of the first and second decision makers with almost similar work experience (they have 6 and 7 years of product development and risk management work experience) was calculated as 2. The weight of the third decision-maker with less work experience (she has 2 years of product development and risk management work experience) was calculated as 1. While calculating the importance level of risks and their likelihood-severity values, success factors affecting the product development were also determined simultaneously. Since the effect of each success factor on the product development process will not be the same, the importance levels of success factors are determined by the AHP method. The next step of the model determined which success factor affected each risk, and the total score each risk received from success factors was calculated. For the last stage of the model, risk sizes were calculated according to the calculation shown in equation (3), and the priority of each risk was determined.

4.2 Determination of product development risks and calculation of importance levels

With the effective management of the risks in the product development process, the product's chance of success on the market will increase. In addition, effective risk management before starting the product development activities will reduce many problems such as the organizational structure of the product development process, the suitability of the technology, the competence of the workforce, and the financial/production/market uncertainties. For this reason, effective risk management will also help decision makers make better strategic decisions about whether to develop the product.

While applying the RPDSF, the risks that may occur during the product development process were determined. While determining the risks, support was obtained from the literature, and the product development experts in the company [87–90]. In Table 4, external risks (7 main risks) and subrisks (18 sub-risks) of these risks are given; Table 5 presents the internal risks (8 main risks) and their subrisks (22 sub-risks).

The AHP method was used to calculate the importance level of the identified internal and external risks. First, company experts (three decision makers) made pairwise comparisons of risks. The weighted averages of the values of the decision makers were taken while making pairwise comparisons while calculating the weighted average, since the decision makers do not have an equal

Table 4: External risks were affecting the product development process

Risks		Subrisks	
F	Financial risks	F_1	The sudden changes in inflation and exchange rates
		F_2	The sudden changes in loan costs
C	Competition risks	C_1	Increase in competitors
		C_2	The sudden changes in domestic and international competition
		C_3	Decrease in market share
S	Supplier risks	S_1	Prolongation of delivery time
		S_2	Logistics service is not good
		S_3	The supplier is not reliable
		S_4	Low supplier quality
L	Legal and regulatory risks	L_1	Conformity with the revised standard
		L_2	Noncompliance with legal matters
P	Political risks	P_1	The sudden changes in in-laws and specifications
		P_2	Cutting government subsidies
		P_3	War and terror
O	Organizational risks (R&D organization that made the design)	O_1	Insufficient number of personnel
		O_2	High staff turnover rate
		O_3	Mobbing
D	Natural disaster risks	D_1	Earthquake, fire, pandemic, etc.

Table 5: Internal risks were affecting the product development process

Risks		Subrisks	
M	Managerial risks	M_1	Insufficient management experience
		M_2	Lack of communication between the manager and staff
		M_3	Failure to follow-up on the project plan
B	Budget risks	B_1	Erroneous estimation of the R&D budget
		B_2	Over budget
		B_3	The sudden changes in the budget plan
FA	Facility risks	FA_1	The facility is not suitable for production
DE	Design risks	DE_1	Deficiencies in the project design
		DE_2	The project is complex.
		DE_3	Lack of product development reviews
T	Technical risks	T_1	Failure to read technical instructions
		T_2	Lack of technical equipment required for production
		T_3	Not using innovative technologies in production
PE	Personnel risks	PE_1	Insufficient number of production personnel
		PE_2	High personnel turnover rate
		PE_3	Mobbing
CO	Contract risks	CO_1	The sudden changes in contract terms
		CO_2	License/patent, etc.
			Risks
PP	Planning and programming risks	PP_1	Not determining the scope of the project
		PP_2	Inappropriate project volume size
		PP_3	Noncompliance with the production planning schedule
		PP_4	Problems in the distribution of tasks

amount of experience, the weight of the first and second decision maker with almost equal work experience was calculated as 2, and the weight of the third decision maker with less work experience was calculated as 1). Table 6 shows the pairwise comparisons of external risks and calculating their importance level with the AHP method. Table 7 shows the same calculations for internal risks. Equation (2) was used to generate the normalized values given in Tables 6 and 7. Then, the importance level of the related criterion was calculated by taking the arithmetic mean of the normalized values.

4.3 Determination of product development success factors and calculation of importance levels

According to the proposed risk prioritization model driven by success factor, while determining the priority of the risk, the impact of risks on the success of the relevant process should also be considered. As the product development process is discussed in this study, success factors in the product development process will be determined. While the risks in another process are evaluated using the

Table 6: Determining the importance level (weight) of external risks

			Normalized values		Importance level (weight)
	F_1	F_2	F_1	F_2	
F_1	1.00	6.60	0.87	0.87	**0.87**
F_2	0.15	1.00	0.13	0.13	**0.13**
Total	1.15	7.60	1.00	1.00	**1.00**

(*Continued*)

Table 6: *Continued*

	Normalized values						Importance level (weight)
	C_1	C_2	C_3	C_1	C_2	C_3	
C_1	1.00	4.20	3.80	0.67	0.78	0.33	**0.59**
C_2	0.24	1.00	6.60	0.16	0.19	0.58	**0.31**
C_3	0.26	0.15	1.00	0.18	0.03	0.09	**0.10**
Total	1.50	5.35	11.40	1.00	1.00	1.00	**1.00**

	Normalized values								Importance level (weight)
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	
S_1	1.00	6.60	8.20	4.60	0.67	0.83	0.49	0.28	**0.57**
S_2	0.15	1.00	7.40	4.20	0.10	0.13	0.44	0.26	**0.23**
S_3	0.12	0.14	1.00	6.60	0.08	0.02	0.06	0.40	**0.14**
S_4	0.22	0.24	0.15	1.00	0.15	0.03	0.01	0.06	**0.06**
Total	1.49	7.97	16.75	16.40	1.00	1.00	1.00	1.00	**1.00**

	Normalized values				Importance level (weight)
	L_1	L_2	L_1	L_2	
L_1	1.00	5.00	0.83	0.83	**0.83**
L_2	0.20	1.00	0.17	0.17	**0.17**
Total	1.20	6.00	1.00	1.00	**1.00**

	Normalized values						Importance level (weight)
	P_1	P_2	P_3	P_1	P_2	P_3	
P_1	1.00	2.20	7.40	0.63	0.66	0.47	**0.59**
P_2	0.45	1.00	7.40	0.29	0.30	0.47	**0.35**
P_3	0.14	0.14	1.00	0.09	0.04	0.06	**0.06**
Total	1.59	3.34	15.80	1.00	1.00	1.00	**1.00**

	Normalized values						Importance level (weight)
	O_1	O_2	O_3	O_1	O_2	O_3	
O_1	1.00	8.20	6.20	0.78	0.87	0.53	**0.73**
O_2	0.12	1.00	4.60	0.10	0.11	0.39	**0.20**
O_3	0.16	0.22	1.00	0.13	0.02	0.08	**0.08**
Total	1.28	9.42	11.80	1.00	1.00	1.00	**1.00**

	Normalized values		Importance level (weight)
	D_1	D_1	
D_1	1.00	1.00	**1.00**
Total	1.00	1.00	1.00

Bold values indicate the weights of importance for each criterion.

RPDSF model, now, the success factors of that process should be considered.

Together with company experts (using the literature research), six success factors affecting the product development process were determined: ensuring customer satisfaction (SF_1), quality production (SF_2), timely production (SF_3), targeted sales value (SF_4), targeted profit level (SF_5), and ensuring staff satisfaction (SF_6).

The AHP method calculates the importance of determining the product development success factors. Similar to calculating the importance levels of the risks, the weighted average of the paired comparisons made by

Table 7: Determining the importance level (weight) of internal risks

	Normalized values						Importance level (weight)
	M_1	M_2	M_3	M_1	M_2	M_3	
M_1	1.00	9.00	6.60	0.79	0.89	0.44	**0.71**
M_2	0.11	1.00	7.40	0.09	0.10	0.49	**0.23**
M_3	0.15	0.14	1.00	0.12	0.01	0.07	**0.07**
Total	1.26	10.14	15.00	1.00	1.00	1.00	1.00

	Normalized values						Importance level (weight)
	B_1	B_2	B_3	B_1	B_2	B_3	
B_1	1.00	1.40	2.20	0.46	0.54	0.24	**0.42**
B_2	0.71	1.00	5.80	0.33	0.39	0.64	**0.45**
B_3	0.45	0.17	1.00	0.21	0.07	0.11	**0.13**
Total	2.17	2.57	9.00	1.00	1.00	1.00	1.00

	Normalized values		Importance level (weight)
	FA_1	FA_1	
FA_1	1.00	1.00	**1.00**
Total	1.00	1.00	1.00

	Normalized values						Importance level (weight)
	DE_1	DE_2	DE_3	DE_1	DE_2	DE_3	
DE_1	1.00	6.60	5.00	0.74	0.85	0.40	**0.66**
DE_2	0.15	1.00	6.60	0.11	0.13	0.52	**0.25**
DE_3	0.20	0.15	1.00	0.15	0.02	0.08	**0.08**
Total	1.35	7.75	12.60	1.00	1.00	1.00	1.00

	Normalized values						Importance level (weight)
	T_1	T_2	T_3	T_1	T_2	T_3	
T_1	1.00	1.00	1.00	0.33	0.47	0.10	**0.30**
T_2	1.00	1.00	8.20	0.33	0.47	0.80	**0.54**
T_3	1.00	0.12	1.00	0.33	0.06	0.10	**0.16**
Total	3.00	2.12	10.20	1.00	1.00	1.00	1.00

	Normalized values						Importance level (weight)
	PE_1	PE_2	PE_3	PE_1	PE_2	PE_3	
PE_1	1.00	4.60	5.80	0.72	0.80	0.42	**0.65**
PE_2	0.22	1.00	7.00	0.16	0.17	0.51	**0.28**
PE_3	0.17	0.14	1.00	0.12	0.02	0.07	**0.07**
Total	1.39	5.74	13.80	1.00	1.00	1.00	1.00

	Normalized values				Importance level (weight)
	CO_1	CO_2	CO_1	CO_2	
CO_1	1.00	5.00	0.83	0.83	**0.83**
CO_2	0.20	1.00	0.17	0.17	**0.17**
Total	1.20	6.00	1.00	1.00	1.00

	Normalized values								Importance level (weight)
	PP_1	PP_2	PP_3	PP_4	PP_1	PP_2	PP_3	PP_4	
PP_1	1.00	3.40	1.40	1.80	0.39	0.64	0.27	0.16	**0.36**
PP_2	0.29	1.00	2.60	1.80	0.11	0.19	0.50	0.16	**0.24**

(*Continued*)

Table 7: *Continued*

	Normalized values								Importance level (weight)
	PP_1	PP_2	PP_3	PP_4	PP_1	PP_2	PP_3	PP_4	
PP_3	0.71	0.38	1.00	6.60	0.28	0.07	0.19	0.59	**0.28**
PP_4	0.56	0.56	0.15	1.00	0.22	0.10	0.03	0.09	**0.11**
Total	2.56	5.34	5.15	11.20	1.00	1.00	1.00	1.00	1.00

Bold values indicate the weights of importance for each criterion.

Table 8: Calculating the importance levels of success factors

							Normalized values						Importance level (weight)
	SF_1	SF_2	SF_3	SF_4	SF_5	SF_6	SF_1	SF_2	SF_3	SF_4	SF_5	SF_6	
SF_1	1.00	6.20	4.60	3.40	3.80	8.20	0.49	0.79	0.35	0.22	0.18	0.20	0.37
SF_2	0.16	1.00	7.00	5.80	5.40	7.80	0.08	0.13	0.53	0.37	0.26	0.19	0.26
SF_3	0.22	0.14	1.00	5.00	5.80	8.20	0.11	0.02	0.08	0.32	0.27	0.20	0.17
SF_4	0.29	0.17	0.20	1.00	5.00	7.40	0.14	0.02	0.02	0.06	0.24	0.18	0.11
SF_5	0.26	0.19	0.17	0.20	1.00	9.00	0.13	0.02	0.01	0.01	0.05	0.22	0.07
SF_6	0.12	0.13	0.12	0.14	0.11	1.00	0.06	0.02	0.01	0.01	0.01	0.02	0.02
Total	2.06	7.83	13.09	15.54	21.11	41.60	1.00	1.00	1.00	1.00	1.00	1.00	1.00

the company experts for success factors was taken while calculating the importance levels of success factors. (While calculating the weighted average, since the decision makers do not have an equal amount of experience, the weight of the first and second decision maker with almost equal work experience was calculated as 2, and the weight of the third decision maker with less work experience was calculated as 1.)

Table 9: Calculation of total scores of risks

External risks		Product development success factors						Total score
		SF_1 (**0.37**)	SF_2 (**0.26**)	SF_3 (**0.17**)	SF_4 (**0.11**)	SF_5 (**0.07**)	SF_6 (**0.02**)	
Financial risks	F_1				0.11	0.07		0.18
	F_2				0.11	0.07		0.18
Competition risks	C_1				0.11	0.07		0.18
	C_2				0.11	0.07		0.18
	C_3				0.11	0.07		0.18
Supplier risks	S_1	0.37		0.17	0.11			0.65
	S_2	0.37		0.17	0.11			0.65
	S_3	0.37		0.17				0.54
	S_4	0.37	0.26	0.17	0.11			0.91
Legal and regulatory risks	L_1	0.37	0.26					0.63
	L_2	0.37	0.26					0.63
Political risks	P_1			0.17				0.17
	P_2					0.07		0.07
	P_3	0.37	0.26	0.17	0.11	0.07	0.02	1
Organizational risks (R&D organization that made the design)	O_1		0.26	0.17				0.43
	O_2		0.26	0.17			0.02	0.45
	O_3						0.02	0.02
Natural disaster risks	D_1	0.37	0.26	0.17	0.11	0.07	0.02	1

(*Continued*)

Table 9: *Continued*

		Product development success factors						Total score
Internal risks		**SF_1 (0.37)**	**SF_2 (0.26)**	**SF_3 (0.17)**	**SF_4 (0.11)**	**SF_5 (0.07)**	**SF_6 (0.02)**	
Managerial risks	M_1						0.02	0.02
	M_2						0.02	0.02
	M_3	0.37		0.17				0.54
Budget risks	B_1					0.07		0.07
	B_2					0.07		0.07
	B_3					0.07		0.07
Facility risks	FA_1			0.17				0.17
Design risks	DE_1	0.37	0.26		0.11	0.07		0.81
	DE_2			0.17				0.17
	DE_3		0.26					0.26
Technical risks	T_1	0.37						0.37
	T_2		0.26	0.17				0.43
	T_3		0.26	0.17				0.43
Personnel risks	PE_1		0.26	0.17				0.43
	PE_2		0.26	0.17			0.02	0.45
	PE_3						0.02	0.02
Contract risks	CO_1				0.11			0.11
	CO_2				0.11			0.11
Planning and programming risks	PP_1			0.17	0.11			0.28
	PP_2				0.11	0.07		0.18
	PP_3			0.17	0.11	0.07		0.35
	PP_4		0.26	0.17			0.02	0.45

Calculation of the importance levels of six success factors is shown in Table 8.

4.4 Determination of success factors affected by risks and calculation of risk total score from success factors

After determining the importance of success factors in the product development, a study was conducted with company experts to determine which success factor(s) was affected by risks. Table 9 shows the success factors affected by the risks. The importance levels of the success factors (are expressed in parentheses next to success factors) used in Table 9 are the values obtained by the calculation in Table 8. Thus, the total score column of Table 9 is obtained by the sum of the importance levels of success factors affected by the relevant risk. Not every risk can affect every success factor; risks only take the importance levels of the success factors they affect. For example, F_1 financial subrisk only affects the targeted sales value and targeted profit level success factors. Accordingly, the total score (obtained from the success factors) of the F_1 risk is 0.18.

4.5 Risk assessment according to RPDSF model

Although risk matrices generally formed in the form of 5 × 5, they will be created in 10 × 10 to make a more detailed analysis in this study. For this reason, the values of likelihood and severity components are given over 10. Then, according to the RPDSF Model, since the scores of the risks from other components (importance level of risk and total scores obtained from the success factors) are over 100, each likelihood and severity value are normalized by dividing by 100. Finally, the calculation of risk sizes and determination of risk priorities according to the calculation method of the RPDSF Model shown in equation (3) are shown in Table 10.

Table 10: Calculating risk sizes and determining risk priorities according to the RPDSF model

External risks		P	S	IL	RSF	RSDSF	RPR
Financial risks	F_1	0.5	0.7	0.87	0.18	0.05481	7
	F_2	0.5	0.6	0.13	0.18	0.00702	15
Competition risks	C_1	0.6	0.8	0.59	0.18	0.050976	8
	C_2	0.5	0.5	0.31	0.18	0.01395	11
	C_3	0.7	0.9	0.1	0.18	0.01134	13
Supplier risks	S_1	0.6	0.8	0.57	0.65	0.17784	2
	S_2	0.6	0.7	0.23	0.65	0.06279	5
	S_3	0.4	0.6	0.14	0.54	0.018144	10
	S_4	0.5	0.9	0.16	0.91	0.06552	4
Legal and regulatory risks	L_1	0.3	0.4	0.83	0.63	0.062748	6
	L_2	0.2	0.6	0.17	0.63	0.012852	12
Political risks	P_1	0.3	0.2	0.59	0.17	0.006018	16
	P_2	0.4	0.8	0.35	0.07	0.00784	14
	P_3	0.3	0.1	0.06	1	0.0018	17
Organizational risks (R&D organization that made the design)	O_1	0.4	0.6	0.73	0.43	0.075336	3
	O_2	0.3	0.7	0.2	0.45	0.0189	9
	O_3	0.5	0.5	0.08	0.02	0.0004	18
Natural disaster risks	D_1	0.4	0.8	1	1	0.32	1
Internal risks		**P**	**S**	**IL**	**RSF**	**RSDSF**	**RPR**
Managerial risks	M_1	0.4	0.7	0.71	0.02	0.003976	16
	M_2	0.6	0.8	0.23	0.02	0.002208	18
	M_3	0.3	0.8	0.07	0.54	0.009072	11
Budget risks	B_1	0.2	0.5	0.42	0.07	0.00294	17
	B_2	0.3	0.5	0.45	0.07	0.004725	15
	B3	0.2	0.3	0.13	0.07	0.000546	21
Facility risks	FA_1	0.2	0.5	1	0.17	0.017	7
Design risks	DE_1	0.2	0.7	0.66	0.81	0.074844	1
	DE_2	0.2	0.6	0.25	0.17	0.0051	14
	DE_3	0.2	0.4	0.08	0.26	0.001664	20
Technical risks	T_1	0.7	0.6	0.3	0.37	0.04662	3
	T_2	0.4	0.4	0.54	0.43	0.037152	4
	T_3	0.4	0.5	0.16	0.43	0.01376	9
Personnel risks	PE_1	0.4	0.6	0.65	0.43	0.06708	2
	PE_2	0.3	0.7	0.28	0.45	0.02646	5
	PE_3	0.5	0.5	0.07	0.02	0.00035	22
Contract risks	CO_1	0.3	0.4	0.83	0.11	0.010956	10
	CO_2	0.2	0.5	0.17	0.11	0.00187	19
Planning and programming risks	PP_1	0.2	0.7	0.36	0.28	0.014112	8
	PP_2	0.3	0.4	0.24	0.18	0.005184	13
	PP_3	0.3	0.8	0.28	0.35	0.02352	6
	PP_4	0.2	0.6	0.11	0.45	0.00594	12

RSDSF, risk size driven by success factors; *P*, likelihood value of risk; *S*, severity value of risk; IL, importance level calculated with AHP (weight); RSF, the total score the risk gets from the success factors (which the risk affects); RPR, risk priority ranking with risk prioritization model driven by success factor.

5 Conclusions

Due to the complex nature of production activities, the subjective probability and impact values of risks, and the different degrees of importance of risks, the classical DMRA method may be insufficient to measure the risks thoroughly. In addition to the DMRA method, many different methods were applied for different applications [91–98]. This study aims to develop a method to eliminate these insufficiencies in risk assessment. The risk prioritization model driven by success factor has been developed for this purpose. With the RPDSF model, the size of the risks will be determined more effectively by including the importance of the risks and the success factors that affect the risk assessment process and the classical likelihood and severity values of the risks in the calculation of the risk size. Thus, a more detailed, sufficient risk assessment will be made. The allocation of resources allocated for risk prevention/reduction activities will be determined more efficiently by making more realistic risk prioritization. In the study, it was discussed that a textile manufacturing company would consider the increase in the use of surgical masks that came with the Covid-19 pandemic as an opportunity and want to switch to the production of surgical masks and therefore make a risk assessment in the product development process. Within the scope of the study, primarily with the interviews with company experts and the support of the literature, the risks affecting the product development process (seven external risks (consisting of eighteen sub-risks) and eight internal risks (consisting of twenty-two sub-risks)) and the six success factors of the product development process) were determined. To increase the sensitivity of the assessment, since the importance of each risk and each success factor is not the same, the importance levels of both risks and success factors were calculated with the AHP method. In addition, the risk prioritization model driven by success factor, which will be used for the first time in the literature to determine the risk size, has been proposed. The risk size score was calculated according to the proposed model; unlike the classical DMRA method, it was calculated by multiplying the importance level of risks and the score obtained from the success factors affected by the risk, in addition to the multiplication of the risk components (likelihood and the severity of risk).

According to the RPDSF model, the top three risks in external risks are "earthquake, fire, pandemic, etc. (D_1)"

with a risk size of 0.32, “prolongation of delivery time (S_1)” with a risk size of 0.1778, and “the number of personnel of the R&D organization is not sufficient (O_1)” with a risk size of 0.0753. When external risks are prioritized according to the classical DMRA method, the first three risks are “decrease in market share (C_3)” with a risk size of 0.63, “increase in competitors (C_1)” with a risk size of 0.48, and “prolongation of delivery time (S_1)” with a risk size of 0.48. Nowadays, where the effects of the Covid-19 pandemic are seen in all areas, it is pretty standard that the pandemic risk is the primary risk of the external origin. Furthermore, since the prolongation of the delivery time of the raw material coming from the supplier will delay the production and the insufficient number of personnel of the organization that will conduct R&D will delay the preparation of the surgical mask design project and again delay the production, it is pretty normal to determine it as a priority.

In the comparison of internal risks according to the risk prioritization model driven by success factor and the classical DMRA method; according to the RPDSF model, the top three risks are “deficiencies in the project design (DE_1)” with a risk size of 0.0748, “insufficient number of production personnel (PE_1)” with a risk size of 0.0670, and “failure to read technical instructions (T_1)” with a risk size of 0.0466. Conversely, according to the DMRA method, the most critical risks are as follows: the risks of “lack of communication between the manager and staff (M_2)” with a risk size of 0.48, “failure to read technical instructions (T_1)” with a risk size of 0.42, and “insufficient experience of the manager (M_1)” with a risk size of 0.28. Since problems such as deficiencies in project design, insufficiency of production personnel, and failure to read technical instructions will delay production in the company (that wants to start the production as soon as possible to evaluate the “increase in surgical mask sales” brought about by the Covid-19 pandemic as an opportunity), it is pretty normal to identify these as the primary risk.

According to the RPDSF, both the priority order of the risks and the risk sizes have changed. (e.g., The risk of “failure to read technical instructions (T_1)” ranks second in the classical DMRA method and third in the RPDSF. In addition, while the risk size is 0.42 according to the DMRA method, it is 0.0466 in the RPDSF.) It is also aimed to make a more detailed, more realistic, and perhaps different decision about the resource allocation to eliminate or reduce the risk with the change in the risk size in the proposed RPDSF. Results in the proposed RPDSF are better than classical methods. The use of the RPDSF is simple. Determining the success factors and risks can be easily applied to every process in the company, and the decisions about the processes can be made better.

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