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AN APPLICATION FOR THE FAILURE MODE AND EFFECTS ANALYSIS INTEGRATED WITH THE GREY RELATIONAL ANALYSIS

Burak KURŞUN[1], Ünal KURT[2] , Salih GÜVERCİN[3], Korhan ÖKTEN[1], Simge AKGÜL[4] Aytaç YILDIZ[5*]

[1] *Department of Mechanical Engineering, Amasya University, Amasya-TURKEY*

[2] *Electric-Electronic Engineering, Amasya University, Amasya-TURKEY*

[3] *Machine Technology Program, Amasya University, Amasya-TURKEY*

[4] *Cumhuriyet University, Koyulhisar MYO, Sivas-TURKEY*

[5] *Department of Automotive Engineering, Amasya University, Amasya-TURKEY*

Abstract: Although the Failure Mode and Effects Analysis (FMEA) is a systematic method of analysis, it has some shortcomings and limitations since it is a method based on intuitionistic and subjective statements of the person that rate the failure modes. In order to eliminate these constraints, the use of the method in conjunction with the grey relational analysis, which is one of the multi criteria decision making methods, helps to eliminate intuitionistic situations and prioritize the failure modes that need corrections and precautions.

The classical FMEA and the FMEA integrated with the grey relational analysis approaches were applied, and their effectiveness was assessed in this study to identify and prioritize the failures and determine the measures to be taken in the wheat sieving machine production. For this purpose, first the Risk Priority Numbers (RPN) were calculated using the classical failure mode and effects analysis, then two separate grey RPNs were calculated on the assumptions that risk factors have either equal weight or different weight in the grey relational analysis-integrated FMEA approach, and the prioritization of the failures was performed. Three different RPN values obtained in the study were compared, and the priority optimizations to be made were recommended in order to prevent failures before reaching the customers as well as drawing the necessary conclusions accordingly.

Keywords: Failure Mode and Effects Analysis; grey relational analysis; multi criteria decision making

GRİ İLİŞKİSEL ANALİZİ İLE BÜTÜNLEŞTİRİLMİŞ HATA TÜRÜ VE ETKİLERİ ANALİZİ YAKLAŞIMI İÇİN BİR UYGULAMA

Özet: Hata Türü ve Etkileri Analizi (HTEA) sistematik bir analiz yöntemi de olsa hata türlerini değerlendiren kişilerin sübjektif ifadelerine dayanması sebebiyle aynı zamanda sezgisel de bir yöntemdir. Sezgilere dayanması ise uygulamada bazı eksikliklere ve kısıtlamalara yol açmaktadır. Bu problemleri ortadan kaldırabilmek için yöntemi çok kriterli karar verme yöntemlerinden biri olan gri ilişkisel analizi ile birlikte kullanmak, sezgisel durumları ortadan kaldırarak önlem alınmasını ve düzeltilmesi gereken hata türlerinin önceliklendirilmesini sağlamaktadır.

Bu çalışmada buğday eleme makinesi üretimindeki hataların tespit edilerek önceliklendirilmesi ve alınacak önlemlerin belirlenmesi için klasik HTEA ve gri ilişkisel analizi ile bütünleştirilmiş HTEA yaklaşımları uygulanarak yaklaşımların etkinliği değerlendirilmiştir. Bunun için ilk önce klasik HTEA ile Risk Öncelik Sayıları (RÖS) daha sonra ise gri ilişkisel analizi ile bütünleştirilmiş HTEA yaklaşımıyla risk faktörlerinin hem eşit ağırlığa hem de farklı ağırlıklara sahip olduğu varsayımıyla iki ayrı gri RÖS hesaplanarak hataların önceliklendirilmesi yapılmıştır. Çalışma sonunda elde edilen üç ayrı RÖS değerleri karşılaştırılmış ve buna göre hataların müşteriye ulaşmaması için öncelikle yapılması gereken iyileştirmeler önerilmiş ve gerekli değerlendirmeler yapılmıştır.

Anahtar Kelimeler: Hata Türü ve Etkileri Analizi; gri ilişkisel analizi; çok kriterli karar verme

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*Corresponding Author: Aytaç YILDIZ
Tel: +90 (358) 260 00 67, e-mail: aytac.yildiz@amasya.edu.tr

Introduction

Before the market launch of a new product, many problems arise in the design, pre-production planning, production, packaging, shipping, and the customer presentation stages. Identifying and resolving this problem in the relevant processes before the product reaches to the customer is of great importance for the company. Some failures can be determined easily, whereas some others cannot be detected, and remain hidden eventually. These hidden remaining failures can only be unearthed by monitoring and evaluating the process intensively as well as using various quality management techniques. The FMEA method is one of the most effective methods used for identifying the factors that may cause a problem in the process regarding the product. Although the FMEA method is a systematic method, there may be intuitive situations in the determination and evaluation of the failures. The integration of the method with mathematical models will reduce the emergence of intuitive situations (Down et al., 2008). For this purpose, both the classical FMEA and the FMEA integrated with the grey relational analysis approaches were applied in three separate models in order to prioritize the failure modes, with the assumptions that risk factors have either equal or different weights, and the effectiveness of three models were evaluated within the scope of detection and prioritization of the failures that may arise in the wheat sieving machine production, which is in the product range of a company that produces agricultural machinery in Turkey.

In the following second section of the study, the FMEA method is briefly described, in the third section, the grey relational analysis integrated with FMEA approach is described, the application on the company's case is performed in the fourth section, and the conclusions are drawn in the final section in accordance with the results obtained.

FMEA Method

The FMEA method was developed by the American army, and the first procedure prepared for this purpose is MIL-P-1629 (Military Procedure), dated November 9, 1949, titled as 'Procedures for Performing a Failure Mode, Effects, and Criticality Analysis'. The method was first used for the evaluation of system and equipment failures (Gulcicek and Sofyalioglu, 2014), then it was adapted in areas that produce safety-critical products that contain advanced electronic and mechanical equipment, in advanced manufacturing systems, such as automotive and aerospace systems (Baysal et al., 2002). In 1975, it has been implemented the manufacture of computers and in Japanese NEC company. It became widespread in the automobile industry, particularly Ford in 1977 and Fiat in 1985, and also applied by Chrysler, and General Motors as well (Aytac, 2011).

The definition of FMEA in MIL-STD-1629A (Procedures for Applying the Failure Mode and Effects Analysis) published in 1980, which is one of the first published standards on this topic, is given as "A procedure to analyze and classify each possible failure mode in the system according to their significance, and determining their outcomes and effects in the system." Stamatis (1995) expands the definition, and states that "FMEA is an engineering method that aims to detect, identify, and eliminate the known and/or potential failures, mistakes and problems in the design, process, systems and services before they reach the customer" (Buyuktuna, 2012; Kadıoglu, et al. 2009; Cevik and Aran, 2009). According to another definition, FMEA is an analytical method that is used to identify potential problems that may arise in the product or process development works and is the most explicit documentation of the information that is collected by cross-functional teams (Down et al., 2008). FMEA focuses on the potential failures that may occur in order to locate and eliminate the root causes of the product or process before they reach the customer. It improves the operational performance of the production cycle, reduces the risk by performing system analysis or collecting historical data (Scipioni et al., 2002; Omdahl, 1988). Potential risks and impacts of each failure in the plant equipment are listed in the order of criticality on the system. In other words, this method examines the equipment, malfunctioning situations, and potential impacts (Yucel, 2007; Dizdar and Kurt, 1996). With this method, the likelihood of failures is reduced, to produce quality products or services that can respond to customers' needs and expectations (Buyuktuna, 2012). In addition, FMEA helps the competitiveness of the company, improves company image, reduces product development time and cost, helps in the development of new production methods, and allows the reduction of scrap and waste (Eryurek and Tanyas, 2003). The FMEA method is divided into the system FMEA, design FMEA, process FMEA, and the service FMEA classifications (Chin et al., 2008).

In FMEA, the Risk Priority Number (RPN) is calculated first by multiplying three important factors (Eq.1). These factors are the occurrence (*O*), severity (S), and detection (*D*) respectively.

$$RPN = O \times S \times D \quad (1)$$

The occurrence refers to the frequency of the occurrence of the risk. The severity factor refers to the impact if that risk happens. The detection factor is a measure of the detectability of the risk before it occurs. The occurrence, severity, and detection values used in FMEA are presented in Tables 1, 2, and 3 respectively (Wang et al., 2009).

Table 1. Crisp Ratings for Occurrence of a Failure (Wang et al., 2009).

Rating	Probability of occurrence	Failure probability
10	Very high: failure is almost inevitable	>1 in 2
9		1 in 3
8	High: repeated failures	1 in 8
7		1 in 20
6	Moderate: occasional failures	1 in 80
5		1 in 400
4		1 in 2000
3	Low: relatively few failures	1 in 15.000
2		1 in 150.000
1	Remote: failure is unlikely	<1 in 1.500.000

Table 2. Crisp Ratings for Severity of a Failure (Wang et al., 2009).

Rating	Effect	Severity of effect
10	Hazardous without warning	Very high severity ranking when a potential failure mode effects safe system operation without warning
9	Hazardous with warning	Very high severity ranking when a potential failure mode effects safe system operation with warning
8	Very high	System inoperable with destructive failure without compromising safety
7	High	System inoperable with equipment damage
6	Moderate	System inoperable with minor damage
5	Low	System inoperable without damage
4	Very low	System operable with significant degradation of performance
3	Minor	System operable with some degradation of performance
2	Very minor	System operable with minimal interference
1	None	No effect

Table 3. Crisp Ratings for Detection of a Failure (Wang et al., 2009).

Rating	Detection	Likelihood of detection
10	Absolute uncertainty	Design control cannot detect potential failure mode
9	Very remote	Very remote chance, the design control will detect potential failure mode
8	Remote	Remote chance, the design control will detect potential failure mode
7	Very low	Very low chance, the design control will detect potential failure mode
6	Low	Low chance, the design control will detect potential failure mode
5	Moderate	Moderate chance, the design control will detect potential failure mode
4	Moderately high	Moderately high chance, the design control will detect potential failure mode
3	High	High chance, the design control will detect potential failure mode
2	Very high	Very high chance, the design control will detect potential failure mode
1	Almost certain	Design control will detect potential failure mode

The flow of the FMEA process is shown in Figure 1.

The FMEA approach integrated with the grey relational analysis

The grey theory, which has been developed by Julong Deng in 1982 for the first time, is widely used to solve problems of uncertainty under missing or incomplete information. In addition, the grey theory is a popular method that is used in decision making in multi-criteria cases as well as analyzing various relationships between discrete data sets (Sofyalioglu, 2011).

The results based on the original data, simple and easily understandable calculations, and being the best method for decision making are the main advantages of this method (Wu, 2002).

Chang et al. (2001) have suggested that the grey theory can be applied to FMEA, since the risk factors in classical FMEA have the characteristics mentioned above. Grey relational analysis is one of the subheadings of the grey theory. This analysis technique is used to determine the degree of relationship between the series of reference factors and each factor in a grey system. Each factor is defined as a series (rows or columns), and the degree of effect between factors is called as the grey relational degree (Sofyalioglu, 2011).

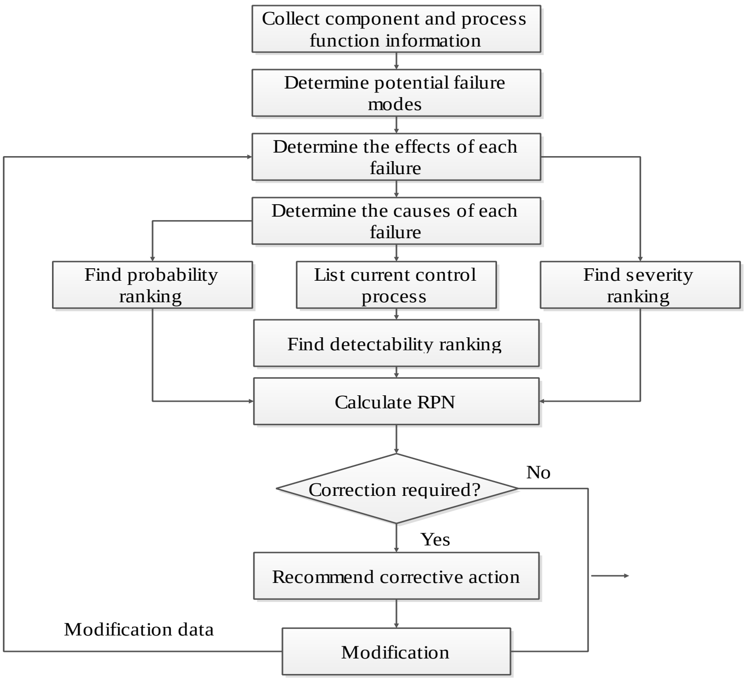

Figure 1. The FMEA process (Pillay and Wang, 2003).

The FMEA Approach Integrated with the grey Relational Analysis is performed with the following steps (Chang et al., 2001):

Step 1. Determination of standard (reference) series: target series, known as the standard series, of length k is as follows

$$X_0=\{X_0(1), X_0(2),\dots,X_0(k)\} \tag{2}$$

Since small scores indicate smaller risks, standard series are determined by taking the smallest values of all risk factors.

$$X_0=\{X_0(1), X_0(2),\dots,X_0(k)\}=\{1, 1,\dots,1\} \tag{3}$$

Step 2. Determination of comparative series: m information series related to the occurrence, severity, and detection of the failure can be expressed as in the following.

$$X_i=\{X_i(1), X_i(2),\dots,X_i(k)\} \quad i = 1,2,\dots,m \tag{4}$$

$X_i(k)$; shows the kth factor of X_i. If it is possible to compare all information series, n information series can be defined as in the following matrix.

$$X=\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} X_1(1) & X_1(2) & \dots & X_1(k) \\ X_2(1) & X_2(2) & & X_2(k) \\ \vdots & & \ddots & \vdots \\ X_n(1) & X_n(2) & \cdots & X_n(k) \end{bmatrix} \tag{5}$$

Step 3. Obtaining the difference between comparative series and standard series, and calculating the coefficient value: the difference between the decision factor point. Standard series model is determined to reveal the degree of fuzzy relation. All three risk factors are compared with the standard series for each failure series, and the relation coefficient is defined by the following equation;

$$\gamma\left(X_0(k),X_j(k)\right)=\frac{\Delta_{min}+(\zeta\Delta_{max})}{\Delta_{0j}(k)+(\zeta\Delta_{max})} \quad (6)$$

Here $j=1,\ldots,m$ and $k=1,\ldots,n$ $X_0(k)$; standard series. $X_j(k)$: comparative series

$$\Delta_{min}=\min_{\forall j\in i}\min_{\forall k}\left\|X_0(k)-X_j(k)\right\| \quad (7)$$

$$\Delta_{max}=\max_{\forall j\in i}\max_{\forall k}\left\|X_0(k)-X_j(k)\right\| \quad (8)$$

ζ is defined as a coefficient between $(0, 1)$. In order to reduce the effect of the maximum value on the relationship coefficient, this coefficient is taken as $\zeta = 0.5$ usually. The purpose of this coefficient is to adjust the difference between "$\Delta_{0j}(k)$" and "Δ_{max}". Studies show that ζ value does not affect the order obtained as a result of the grey relational degree.

Step 4. Determination of the grey relational degree: the grey relationship degree is a measure of the geometric similarity between comparative series and standard (reference) series. The degree of the relationship indicates that there is a strong relationship between the comparative and standard series.

If the compared two series are the same, then the grey relationship degree is found as 1. The grey relationship degree shows the extent of similarity between compared and standard series.

$$\tau(X_0,X_j)=\frac{1}{n}\sum_{k=1}^{n}\gamma\left(X_0(k),X_j(k)\right) \quad (9)$$

n is the decision factor number.

If the weights of each criteria are given, the grey relationship degree can be found by multiplying the weight values of the degree significance of the criterion and grey relationship coefficient of the criterion.

$$\tau(X_0,X_j)=\sum_{k=1}^{n}\gamma\left(X_0(k),X_j(k)\right)W_k \quad (10)$$

Here W_k is the weighting coefficient of the factors, and

$$\sum_{k=1}^{n}W_k=1 \quad (11)$$

In the classical FMEA, the occurrence, severity, and detectability of the failures cannot be assigned appropriately to reflect the real world. The grey approach in FMEA, however, allows engineers to assign relative weights to the decision factors based on research and production strategies.

Step 5. Rating the risk priorities: in decision making problems, when the standard (reference) series is selected as the ideal series, then the grey relationship degree, which is calculated between the compared series and reference series, will be an indicator of the degree of detectability of the criteria. In other words, the factor series with the highest grey relational degree indicate the best alternative in decision making problems (Sofyalioglu, 2011). That is if $\gamma(X_0, X_i)\geq\gamma(X_0, X_j)$ we can say that the relationship between X_i and X_0 is greater than the relationship between X_j and X_0 . For FMEA, this shows the relationship between the scores of potential causes and optimal values of decision factors. Greater degree of relationship indicates the lesser effect of the source of failure. Therefore, gradually increasing the degree of relationship shows the decrease in risk priorities of the potential causes to be improved (Sofyalioglu, 2011; Chang et al., 2001).

The case study

The study was conducted with the data obtained from a company, operating in the manufacturing sector in Turkey that produces agricultural machinery. The wheat sieve machine, which is one of the products of the company, is a machine having 4 sieves used to sieve wheat. The company wants to reduce costs and increase customer satisfaction by determining the failures, arisen during the design and production of the machine before they reach the customers. For this reason, the grey relational analysis-integrated FMEA and the classical FMEA methods that detect, prioritize and allow to taking precautions were implemented to this company.

Classical FMEA Application

In the first part of the study, the classical FMEA approach was applied to detect, prioritize, and eliminate failures that occur in the design and production of the wheat sieving machine. In the first phase of implementation, a team of 4 people was established with individuals from the design, production, quality control and marketing departments of the company in order to determine the potential failure modes, causes, and effects of these failures. This team has determined the potential failures, effects, and causes of the failures given in Table 4 through brainstorming and using cause-and effect diagrams, and the RPN values were calculated with the help of Eq.1.

When we examine Table 4, it is seen that the failure numbers 1, 2, and 3 have RPN values 640, 600, and 480 respectively, indicating the priority failures that need to addressed first.

Table 4. Results of evaluation of classical FMEA.

Identifying the Design and Production Failure Modes of a Four-Sieve Wheat Sieving Machine Using the FMEA Method								
CURRENT SITUATION								
Failure No	**Potential Failure**	**Effect of Potential Failure**	**Severity**	**Potential Causes of the Failure**	**Occurrence**	**Preventive Control in the Present Process**	**Detectability**	**RPN**
1	Failure of suction fan	Inability to perform a complete cleaning	8	Insufficient hood	8	High amounts of air pressure	10	640
2	Frequent breakdown and breakage of the parts due to vibrations	Inoperative machinery	10	Welding defects and thin pieces used	6	Replacement or re-welding of the broken parts	10	600
3	Breakage of the brush arms	Inoperative brushes	6	Random bending of the brush arms	8	Replacement of the brush arms	10	480
4	Wood hangers used in the assembly of sieves	Inoperative machinery	3	Wooden hanger	10	Replacement of the broken part	10	300
5	Loosening of the fixing screws due to poor floor of customer's site and high vibration of the machine	Excessive vibration, malfunctioning and stopping of the machine as a result of the loosening of the screws	10	Poor floor at the installation site	4	When loosen, they have screwed again until it's not possible to screw further, then liquid concrete is poured and fixed again.	10	400
6	The holes do not align since the protection covers are pre-drilled before the installation.	Increased cost and waste of time during installation	3	Pre-drilled holes of the cover before installation	8	New ones are made with larger holes	10	240

Application of the FMEA Approach Integrated with the Grey Relational Analysis

In this approach, the RPN values calculated above using the classic FMEA method are converted to grey RPN values by using the grey relational analysis and re-prioritized. According to this new order of priority, the priority failures are determined, and the problems that cause these failures are eliminated. The calculation of grey RPN values of the failure modes, calculated by applying the steps of the grey-relational analysis integrated FMEA approach, and the prioritization of failures are as follows.

First, the following information series matrix is obtained by using the RPN values given in Table 4 in order to determine the comparative series.

$$\begin{bmatrix} X_1(1) & X_1(2) & X_1(3) \\ X_2(1) & X_2(2) & X_2(3) \\ X_3(1) & X_3(2) & X_3(3) \\ X_4(1) & X_4(2) & X_4(3) \\ X_5(1) & X_5(2) & X_5(3) \\ X_6(1) & X_6(2) & X_6(3) \end{bmatrix} = \begin{bmatrix} 8 & 8 & 10 \\ 10 & 6 & 10 \\ 6 & 8 & 10 \\ 3 & 10 & 10 \\ 10 & 4 & 10 \\ 3 & 8 & 10 \end{bmatrix}$$

Then, the information series matrix is used to calculate the following difference matrix.

$$\begin{bmatrix} \Delta_1(1) & \Delta_1(2) & \Delta_1(3) \\ \Delta_2(1) & \Delta_2(2) & \Delta_2(3) \\ \Delta_3(1) & \Delta_3(2) & \Delta_3(3) \\ \Delta_4(1) & \Delta_4(2) & \Delta_4(3) \\ \Delta_5(1) & \Delta_5(2) & \Delta_5(3) \\ \Delta_6(1) & \Delta_6(2) & \Delta_6(3) \end{bmatrix} = \begin{bmatrix} 7 & 7 & 9 \\ 9 & 5 & 9 \\ 5 & 7 & 9 \\ 2 & 9 & 9 \\ 9 & 3 & 9 \\ 2 & 7 & 9 \end{bmatrix}$$

According to the values of the difference matrix, $\Delta_{min}=2$, $\Delta_{max}=9$ was defined, and the determination coefficient (ζ) was accepted as 0.5. After obtaining the difference matrix, the grey relationship coefficients were calculated according to Equation 6. For $\Delta_1(1)$;

$$\gamma\big(X_0(k),X_i(k)\big)=\frac{\Delta_{min}+(\zeta\Delta_{max})}{\Delta_{01}(1)+(\zeta\Delta_{max})}=\frac{2+(0.5x9)}{7+(0.5x9)}=0.565 \qquad (12)$$

was calculated. The same procedure was performed for the others to find the grey relationship coefficients in the following matrix.

$$\begin{bmatrix} \gamma_1(1) & \gamma_1(2) & \gamma_1(3) \\ \gamma_2(1) & \gamma_2(2) & \gamma_2(3) \\ \gamma_3(1) & \gamma_3(2) & \gamma_3(3) \\ \gamma_4(1) & \gamma_4(2) & \gamma_4(3) \\ \gamma_5(1) & \gamma_5(2) & \gamma_5(3) \\ \gamma_6(1) & \gamma_6(2) & \gamma_6(3) \end{bmatrix} = \begin{bmatrix} 0.565 & 0.565 & 0.481 \\ 0.481 & 0.684 & 0.481 \\ 0.684 & 0.565 & 0.481 \\ 1.000 & 0.481 & 0.481 \\ 0.481 & 0.867 & 0.481 \\ 1.000 & 0.565 & 0.481 \end{bmatrix}$$

In the final stage, grey relationship degree (grey RPN) of each failure mode was calculated for determining the risk priorities. At this stage, first of all, the grey relationship degrees were calculated using Equation 9, under the assumption that all three risk factors have equal weights. For example, the grey relationship degree in relation to 1st failure mode was calculated as;

$$\tau(X_1, X_3)=\frac{1}{3}(0.565+0.565+0.481)=0.537 \qquad (13)$$

The same process was applied to other failure modes to obtain;

$$\text{Grey RPN} = \begin{bmatrix} 0,537 \\ 0,549 \\ 0,577 \\ 0,654 \\ 0,609 \\ 0,682 \end{bmatrix}$$

Then, the grey relationship degrees of the failure modes were re-calculated using Equation 10 under the assumption that the risk factors have different weights. By taking $\sum_{k=1}^{n} W_k=1$, the weight coefficients for the occurrence, detectability, and severity of the failure were taken $W_O=0,4$, $W_D=0,2$ *ve* $W_S=0,4$ respectively. For example, the grey relationship degree in relation to 1st failure mode was calculated as;

$$\tau(X_1, X_3)=(0.565x0.4+0.565x0.2+0.481x0.4)=0.531 \qquad (14)$$

The same process was applied to other failure modes to obtain;

$$\text{Grey RPN} = \begin{bmatrix} 0,531 \\ 0,520 \\ 0,578 \\ 0,688 \\ 0,557 \\ 0,705 \end{bmatrix}$$

At the end of the application, RPNs, grey RPNs for the risk factors having the same and different weight for the failure modes, and the priority ranks of the failure modes are shown in Table 5.

When we examine Table 5, it is seen that priority ranks of the failure modes calculated with the classical FMEA, and grey relational analysis-integrated FMEA with and without equal weights of risk factors were the same. In either case, the most significant two failures that need to be addressed were "Failure of suction fan", and "Frequent breakdown and breakage of the parts due to vibrations" respectively. The two most significant failure modes in the other two cases (classical FMEA and grey RPN that risk factors have equal weight) have exchanged ranks here, and the "Frequent breakdown and breakage of the parts due to vibrations" now became the most significant failure mode that needs to be addressed.

After these comparisons and findings, the improvements in relation to failure modes in Table 6 were proposed to the company, and the company has addressed these recommendations to keep failures from reaching the customer.

Table 5. RPN values.

Failure Modes	RPN	Ranking	Grey RPN (Risk factors have equal weight)	Ranking	Grey RPN (Risk factors have different weight)	Ranking
1	640	1	0.537	1	0.531	2
2	600	2	0.549	2	0.520	1
3	480	3	0.577	3	0.578	4
4	300	5	0.654	5	0.688	5
5	400	4	0.609	4	0.557	3
6	240	6	0.682	6	0.705	6

Table 6. Improvements on failure modes.

Proposed Improvements	**Authorized Person**	**Actual Improvements**	**Severity**	**Occurrence**	**Detectability**	**RPN**
Changing hood design to have wider holes	Assembler	Large air holes were designed.	2	2	3	12
Making the thin machine parts 2 mm thicker	Welder, designer	2 mm thicker parts were produced to replace the broken parts.	3	2	3	18
Performing the brush arm bending in certain molds.	Designer, producer	A custom mold was made for brush arms.	3	4	2	24
Use of metal hanger in the assembly of sieves	Designer, producer	The metal hanger was used.	3	3	3	27
Improving the quality of the concrete for mounting the machine at the customer	Customer, designer	The quality of the ground was improved.	4	2	3	24
Not drilling the holes of machine protection covers before installation	Designer, assembler	Protective covers were drilled after the installation of the machine	2	2	2	8

Conclusions

The FMEA method aims at preventing failures from reaching the customer by taking corrective measures and detecting the failures in the design, and production of a product or service. However, the classical FMEA may not provide reliable results in the prioritization of the failures since it is open to subjective assessments in the determination of risk factors as well as in the detection, occurrence, and severity of the failures. Therefore, the grey relational analysis-integrated FMEA approach was implemented in order to eliminate the disadvantages of the classical FMEA method, and compared with the results obtained from the classical FMEA method.

The priority ranks of the failure modes were the same in the classic FMEA method and the grey relational analysis-integrated FMEA approach applied under the assumption that the risk factors have equal weights. However, when we assumed that the risk factors do not have equal weights in accordance with the opinions of the team established in the company, four of the failure modes changed ranks. What is important here is the change in the ranking of the first two failure modes that need to be addressed. Considering the failure modes under the assumption that risk factors have different weights, the "Frequent breakdown and breakage of the parts due to vibrations" failure mode was found to be more critical since it affects operation of the machine, whereas the "Failure of suction fan" failure mode was only affecting the complete cleaning, hence it was determined that failure in the operation of the machine is more significant failure and needs immediate precaution. As understood from this result, the classical FMEA and the assumption that risk factors have equal weight may give erroneous results in the priority rankings due to the restrictions previously described. However, in situations where risk factors have different weights gave more meaningful results, and this result is in line with the study by Sofyalioglu (2011).

In future studies, grey RPN values can be calculated on the assumption that risk factors have different weights and using the improvement data obtained by the classical FMEA to compare the results.

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