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FMEA Based Fuzzy Topsis for Assessment of Quality Problems in Telescopic Platform Production

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Abstract

In order to increase process and product quality fast and least costly, it is very useful to focus on the process that causes the important quality problems. In this study, quality problems and related processes in a company that produces on-vehicle equipment in the automotive industry are examined. The purpose of this study is to provide a quality improvement perspective to reduce process and product defects. Fault Mode and Effects Analysis (FMEA) is applied to detect faults, determine their causes and prioritize them. Prioritization of critical quality errors is revealed using traditional FMEA and FMEA-based fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The FMEA-based fuzzy TOPSIS method has been proposed because of its ability to handle uncertainty arising from the subjective judgments of decision makers. The results are compared and the preventions are suggested to avoid from the most important process that causes the quality problem.

Keywords: FMEA, Failure, Fuzzy TOPSIS, On-vehicle equipment, Multicriteria decision making

Teleskopik Platform Üretiminde Kalite Sorunlarının Değerlendirilmesi için FMEA Tabanlı Bulanık Topsis

Öz

Proses ve ürün kalitesini hızlı ve en az maliyetli şekilde arttırmak için önemli kalite sorunlarına neden olan prosese odaklanmak oldukça faydalıdır. Bu çalışmada otomotiv sektöründe araç üstü ekipman üretimi yapan bir firmada kalite sorunları ve buna bağlı süreçler incelenmiştir. Bu çalışmanın amacı, süreç ve ürün hatalarını azaltmak için kalite iyileştirme perspektifi sağlamaktır. Arızaları tespit etmek, nedenlerini belirlemek ve önceliklendirmek için Hata Türü ve Etkileri Analizi (HTEA) uygulanmıştır. Kritik kalite hataları geleneksel HTEA ve HTEA tabanlı bulanık İdeal Çözüme Benzerliğe Göre Tercih Sıralama tekniği (TOPSIS) kullanılarak ortaya konulmuştur. HTEA tabanlı bulanık TOPSIS yöntemi,

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karar vericilerin öznel yargılarından kaynaklanan belirsizliği ele alma yeteneği nedeniyle önerilmiştir. Sonuçlar karşılaştırılmış ve kalite problemine neden olan en önemli proses hatası için önlemler sunulmuştur.

Anahtar Kelimeler: HTEA, Hata, Bulanık TOPSIS, Araç üstü ekipman, Çok kriterli karar verme

1. INTRODUCTION

Sustainable success in competitive production depends especially on the quality of the products. Quality is the most important factor for companies to be permanent in the local and global market. One of the factors that negatively affect the business in the market is variability in the product or service quality. The main reason for the market losses that businesses face with is the exceeding level of quality variability than the acceptable level.

In the automotive sector, quality variability is experienced more intensely for high variety of products than the other sectors. It has been still labor-intensive in many processes and the process flow consists of multiple tasks. Therefore, the production and process failures may occur. These failures may result in major changes in the quality of the product. The customer dissatisfaction caused by these changes results in large monetary losses to businesses. For this reason, businesses use scientific analysis to identify failures and take action. FMEA (Fault Mode and Effects Analysis) is a useful tool for businesses to classify and prioritize the failures. The major advantage of this method is its applicability to all kinds of sectors. Purpose of the FMEA is to define potential errors of systems, processes or products, and determine their importance levels to take appropriate actions for preventing failures and the quality losses.

In this study, we propose a more reasonable failure evaluation framework using the integration of FMEA and fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Firstly, the typical failure modes are obtained through brainstorming and the causes, effects and processes for the failure modes are determined. The experts are asked for the importance of failures and weights of FMEA components. As a result, the proposed FMEA based Fuzzy TOPSIS approach has been proved to be a more accurate tool than the traditional FMEA.

In the second section of this paper, a literature review on the application of FMEA and Fuzzy TOPSIS techniques are given. In the material and methodology section, the problem is defined, the methods are explained and the application of methods in the telescopic platform production process is proposed. Finally, the results and a brief discussion is given in the conclusion.

2. LITERATURE REVIEW

Although FMEA is a very effective and reliable risk analysis technique, it is constantly criticized by researchers for some deficiencies in the calculation of the Risk Priority Numbers (RPN) [1-6]. It is quite difficult for an expert to decide on appropriate values for failure modes. Therefore, multi-criteria decision-making methods are used to make the analysis more objective. There are many multi-criteria decision-making methods integrated with FMEA in the literature. These methods are AHP (Analytic Hierarchy Process), VIKOR (Višekriterijumsko Kompromisno Rangiranje), ELECTRE (Elimination Et Choix Traduisant la Realité), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations), TOPSIS, etc. Among these methods, TOPSIS has been widely used that offers collective analysis and produces more realistic solutions within the framework of fuzzy logic. These approaches have been commonly used at various phases of the product life cycle in several industries such as semiconductor processing, food service, plastic power plant, software and healthcare [7]. Various researchers have used FMEA based Fuzzy TOPSIS to analyse manufacturing and assembly processes. FMEA is used to detect critical failures in processes for measuring the quality of products. A study of effects analysis for automotive industry was conducted by [8] using fuzzy TOPSIS and fuzzy AHP. Chang's fuzzy AHP approach was used to obtain the weights of the risk factors. Chen's fuzzy TOPSIS was utilized to obtain the closeness coefficients of processes. The AHP and fuzzy TOPSIS is used to assess the implementation of the lean and green supply chain in automotive industry [9]. A fuzzy TOPSIS approach for FMECA (Failure Mode, Effects and Criticality Analysis) was proposed in [1]. The fuzzy version of TOPSIS was applied allowing the traditional FMECA factors S, O, and D and their equally important weights to be evaluated using triangular fuzzy numbers. They applied this method for refrigerator production process. In [10], an industrial example regarding the manufacturing process of PCB (printed circuit board) was demonstrated. The failures causing the poor quality of the product were determined by FMEA. An optimization model for improving quality in a steel rolling mill is integrated to MCDM (Multi criteria decision making) in [11] to control the process parameters within the specified limits to improve the quality. An evaluation model based on FMEA used fuzzy AHP and fuzzy TOPSIS was used in assessing the risk priority of the critical process in the rolling industry. By applying fuzzy TOPSIS integrated with AHP for FMEA, a fuzzy methodology was considered that allows experts to use language variables to describe severity, occurrence, and detectability. Using fuzzy FMEA and FQFD (fuzzy quality function distribution), the interface was implemented for improvement of the process and product development. Other FMEA and fuzzy TOPSIS applications to steel sheet production and knitting process can be found in [12] and [13], respectively. The FMEA and TOPSIS technique applied for risk assessment in a steel production company in [14]. In [15], the potential failure modes of a subsea control module were identified. A variant of Fuzzy TOPSIS based FMEA method was applied to analyse and prioritize the most critical failure modes. A FMEA based fuzzy TOPSIS was used to analyse the risk of human error concerning user experience for in-vehicle equipment [16]. Another study was conducted as a part of an enterprise-wide cost improvement project in an international food company handling the problem of variability between the planned and the actual costs in [17].

The FMEA and FMEA based fuzzy TOPSIS methods have been used to assess the prioritization of many parameters in previous studies. In this study, the assessment of quality parameters related to processes and products is a new field of implementation of the methodology.

3. MATERIALS AND METHODS

The product is determined by Pareto analysis. The relative importance of the products is measured over their total sales value. The most sold products are in group A in Figure 1. These products are telescopic platform and garbage truck. The sales volume of the telescopic platform and the profit it provides to the company are higher than the other products. The quality of the product plays an important role in the customer satisfaction and the brand value of the company. For this reason, the failures that occur in the telescopic platform production are considered and FMEA is applied to investigate the quality causes.

3.1. Failure Mode and Effects Analysis (FMEA)

FMEA technique is used to answer the questions as in which level the failure affects the process, how often it occurs, and what the chance of detecting this failure. Three components are used to answer these questions mathematically. This value is the product of Severity (S), Occurrence (O) and Detectability (D) that are measurable in some scale. In this study, 1 to 10 scale is given at Table 1. The advantages of this scale are its acceptability of precision level and ease of use than other scales. The prioritization of the failures that are defined as quantitatively is articulated with the RPN (Risk Priority Number) value. RPN is calculated by (S) x (O) x (D). RPN below 40 means no need to take precautions while greater than 100 requires precautions. The values between 40 and 100 indicates to take precautions if it is useful.

Table 1. RPN components and associated degrees

Severity	**Occurrence**	**Detectability**	**Degree**
Dangerous	Very high	Absolute uncertainty	10
Warning		Very difficult	9
Very high	High	Difficult	8
High		Very low	7
Middle	Medium	Low	6
Low		Medium	5
Very low	Low	Medium high	4
Small		High	3
Very small	Very Low	Very high	2
No		Almost certain	1

3.2. FMEA Based Fuzzy TOPSIS

Chen's fuzzy TOPSIS method is used in this study. The importance weights of criteria and the ratings of alternatives are considered as linguistic variables in Table 2.

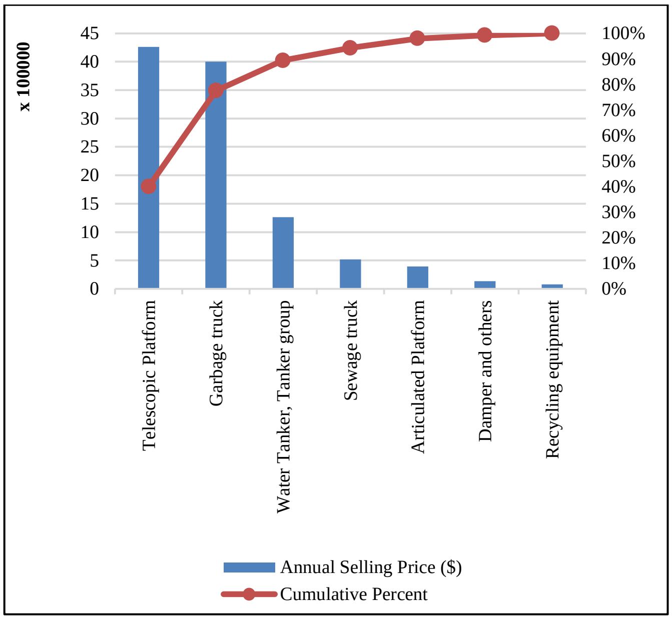

Figure 1. Pareto analysis of products

Table 2. Linguistic variables

For importance weight of each criterion		**For importance weight of each alternative**	
Very low (VL)	(0;0;0.1)	Very poor (VP)	(0;0;1)
Low (L)	(0;0.1;0.3)	Poor (P)	(0;1;3)
Medium low (ML)	(0.1;0.3;0.5)	Medium poor (MP)	(1;3;5)
Medium (M)	(0.3;0.5;0.7)	Fair (F)	(3;5;7)
Medium high (MH)	(0.5;0.7;0.9)	Medium good (MG)	(5;7;9)
High (H)	(0.7;0.9;1)	Good (G)	(7;9;10)
Very high (VH)	(0.9;1;1)	Very good (VG)	(9;10;10)

The importance weight of all j^{th} criterion $\widetilde{w}_{ij}$ and the weight of alternatives $\tilde{X}_{ij}$ with respect to each criterion are calculated by Equations 1 and 2.

$$\widetilde{w}_{ij} = \frac{1}{k}[\widetilde{w}_j^1(+)\widetilde{w}_j^2(+)\ldots(+)\widetilde{w}_j^k] \qquad (1)$$

$$\tilde{X}_{ij} = \frac{1}{k}[\tilde{x}_j^1(+)\tilde{x}_j^2(+)\ldots(+)\tilde{x}_j^k] \qquad (2)$$

where $\widetilde{w}_j^k$ and $\tilde{x}_j^k$ are the importance weight and the rating of the *k*th decision maker.

Obtaining weights of the criteria ($\widetilde{w}$) and the ratings of alternatives ($\tilde{x}$) with respect to each criterion, a fuzzy decision matrix ($\widetilde{D}$) can be expressed in matrix format for *m* alternatives and *n* criteria as follows:

$$\widetilde{D} = \begin{bmatrix} \widetilde{x_{11}} & \cdots & \widetilde{x_{1n}} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \widetilde{x_{mn}} \end{bmatrix}$$

The normalization method is used to ensure the normalized triangular fuzzy numbers are in the [0,1] interval. The normalized fuzzy decision matrix shown by $\widetilde{R}$ and calculated by Equation 3.

$$\tilde{R} = [\widetilde{r_{ij}}]_{mxn} \quad i = 1, 2\ldots, m \qquad j = 1,2,\ldots,n$$

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \qquad (3)$$

c_j^* = max c_{ij}, for the benefit criteria

The elements of the weighted fuzzy normalized decision matrix ($\widetilde{v_{ij}}$) are calculated by Equation 4.

$$\widetilde{v_{ij}} = \widetilde{r_{ij}} w_j \quad i = 1,2\ldots, m \text{ and } j = 1,2\ldots, n \qquad (4)$$

The fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) are defined according to the weighted normalized fuzzy decision matrix. It is known that triangular fuzzy numbers belong to the closed interval [0,1]. FPIS denoted as A^* and FNIS denoted as A^- are defined as (Equation 5).

$$A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*\},\ A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\} \qquad (5)$$

where $\tilde{v}_j^* = (1,1,1)$ and $\tilde{v}_j^- = (0,0,0)$, j=1, 2…, n

The distances (d_i^* and d_i^-) of each alternative A^* and A^- can be calculated by the vertex method which is defined to calculate the distance between two triangular fuzzy numbers. Let $\tilde{a}$ = (a_1, a_2, a_3) and $\tilde{b}$= (b_1, b_2, b_3) be two triangular fuzzy numbers, then the formulas are given below (Equations 6, 7 and 8):

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]} \qquad (6)$$

$$d_i^* = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \widetilde{v_j^*}), \qquad i = 1,2\ldots, m \qquad (7)$$

$$d_i^- = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \widetilde{v_j^-}), \qquad i = 1, 2\ldots, m \qquad (8)$$

A closeness coefficient (CC_i) is defined to determine the ranking the order of alternatives once the d_i^* and d_i^- of each alternative have been calculated (Equation 9).

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1,2\ldots, m \qquad (9)$$

Finally, failure modes are ranked according to CC_i values.

3.3. Application of FMEA and Fuzzy TOPSIS

The processes that are responsible for the failures in products are selected from entire process activities after consulting with the engineers and experts working in the field. Three decision makers are quality engineer, process chief and design engineer. The modes of the failures to corresponding processes are given by their explanations in Table 3. The experts evaluated the failures based on the scale of RPN components.

Table 3. The failure modes and related processes

Process mode	**Process**	**Explanation of modes (Failure mode)**
M1	Receiving raw material	Incorrect determination of raw material type (M11)
M2	Pre-assembly	Incorrect assembly of the tower on the chassis (M21)
M3	Assembly	Spot welding the boom without centring the tower (M31) Improper fix of brackets and bolts (M32) Unbalanced basket (M33) Contact of hydraulic hoses under the basket with the vehicle body (M34) Wrong adjustment of the boom and chain (M35) Jolting in the basket while the platform is running (M36) Missing profile welding in the chassis (M37) Swinging booms too much during operation (M38)
M4	Hydraulic	Leaks in front right leg notching roller (M41) Hydraulic hoses touching sharp edges, no weather strip (M42)
M5	Coating	Lack of paint touch-ups and final cleaning (M51)
M6	Labelling	Attached wrong type label on the vehicle (M61) Lack of labelling of leg control valves (M62) Lack of labelling reflector that should be on the basket (M63)
M7	Accessory	Hydraulic control levers getting stuck in the control plate (M71) Not opening the rain holes of the basket and tool box (M72) Limitations used in right and left turns do not work (M73)
M8	Delivery	The platform to be sent is hard to fit in the truck (M81)

FMEA is applied to prioritize the 20 failure modes classified under 8 different processes. RPN values are calculated and given at Table 4. The ranking of RPN values of the failure modes is M38 > M32 > M81 = M42 > M41 = M11 > M36 > M37 > M51 > M33 > M31 > M34 > M61 > M35 > M21 > M73 > M62 = M72 > M71 > M63 and given in Table 4.

As a result of the analysis, the RPN values of some failure modes are equal. Thus, the maximum ranking is 17. Decision makers cannot pinpoint precisely which of the failures are more important. This equality is the concern of unreliable FMEA results.

The shortcomings of traditional FMEA are eliminated by this method. The experts are prioritized the criteria (severity, occurrence, detectability) and alternatives (quality failures) based on the linguistic variables and these terms are converted to fuzzy numbers. The weights of criteria matrix of three decision makers and fuzzy decision matrix are given in Table 5 and Table 6, respectively.

Table 4. FMEA results

Failure mode	S	O	D	RPN	Rank
M11	5.67	2.67	2.67	40	4
M21	8.67	1.33	1.33	15	13
M31	8.67	1.67	1.67	24	9
M32	7.67	2.33	3.33	60	2
M33	4.33	3.67	1.67	26	8
M34	6.00	1.67	2.33	23	10
M35	6.00	2.00	1.33	16	12
M36	6.00	2.67	2.33	37	5
M37	5.33	2.67	2.33	33	6
M38	7.00	6.00	1.67	70	1
M61	3.67	2.00	2.33	17	11
M41	5.67	2.67	2.67	40	4
M42	6.00	3.00	2.67	48	3
M51	4.67	2.33	2.67	29	7
M62	3.33	2.00	1.67	11	15
M63	2.33	1.33	2.67	8	17
M71	3.67	1.33	2.00	10	16
M72	4.00	1.67	1.67	11	15
M73	5.33	1.33	1.67	12	14
M81	8.00	6.00	1.00	48	3

Table 5. Criteria weights of decision makers based on the linguistic variables

Criteria	DM 1	DM 2	DM 3	Weight
Severity (S)	(0.9,1,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.767,0.933,1)
Occurrence (O)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.433,0.633,0.833)
Detectability(D)	(0.7,0.9,1)	(0,0.1,0.3)	(0.5,0.7,0.9)	(0.4,0.567,0.733)

Table 6. Fuzzy decision matrix

Failure modes	Severity(S)			Occurrence (O)			Detectability(D)		
M11	3.333	4.667	6.000	0.333	1.333	3.000	0.333	1.333	3.000
M21	5.667	7.667	9.333	0.000	0.333	1.667	0.000	0.333	1.667
M31	5.667	7.333	8.667	0.000	0.667	2.333	0.000	0.333	1.667
M32	6.000	7.000	7.667	0.000	1.000	3.000	1.000	2.333	4.333
M33	1.667	3.000	5.000	1.000	2.333	4.333	0.000	0.667	2.333
M34	4.000	5.333	6.667	0.000	0.667	2.333	0.000	0.667	2.333
M35	3.333	5.000	7.000	0.000	0.667	2.333	0.000	0.333	1.667
M36	2.667	4.333	6.333	0.000	1.000	3.000	0.333	1.333	3.000
M37	2.667	4.000	5.667	1.000	2.000	3.667	0.333	1.333	3.000
M38	4.667	6.000	7.333	3.000	5.000	7.000	0.000	0.667	2.333
M41	2.667	4.333	6.000	0.333	1.667	3.667	0.333	1.333	3.000
M42	3.000	5.000	6.667	0.667	2.000	3.667	0.333	1.000	2.333
M51	1.333	3.000	5.000	0.000	1.000	3.000	0.000	1.000	3.000
M61	1.000	2.333	4.333	0.000	0.667	2.333	0.000	0.667	2.333
M62	0.333	1.667	3.667	0.000	0.667	2.333	0.000	0.333	1.667
M63	0.333	1.333	3.000	0.000	0.333	1.667	0.333	1.333	3.000
M71	1.000	2.333	4.333	0.000	0.333	1.667	0.000	0.667	2.333
M72	1.333	2.667	4.333	0.000	0.333	1.667	0.000	0.667	2.333
M73	2.000	3.667	5.667	0.000	0.333	1.667	0.000	0.667	2.333
M81	5.000	6.667	8.000	3.000	5.000	7.000	0.000	0.000	1.000

The linear normalization for benefit criteria is applied and related equations are used to construct normalized fuzzy decision and weighted fuzzy normalized decision matrices. Finally, the results of FMEA integrated fuzzy TOPSIS method are given in Table 7. M38 > M81 > M32 > M42 > M31 > M37 > M41 > M21 >M11 > M36 > M33 > M34> M35 > M51 > M73 > M61 > M72 > M71 > M63> M62. The ranking order of all the alternatives closeness coefficient shows that the failure mode M38 has the highest priority, followed by the failure mode M81**.** There are no same priorities for failure modes like in FMEA.

Table 7. The distance of each failure to FPIS and FNIS, closeness coefficient

Failure mode	FPIS			d_i^+	FNIS			d_i^-	CC_i	Rank
	S	**O**	**D**		**S**	**O**	**D**			
M11	0.337	0.912	0.900	2.148	0.776	0.140	0.165	1.080	0.335	9
M21	0.347	0.871	0.900	2.118	0.734	0.199	0.165	1.098	0.341	8
M31	0.355	0.832	0.678	1.865	0.685	0.259	0.462	1.406	0.430	5
M32	0.757	0.871	0.856	2.484	0.304	0.199	0.233	0.736	0.229	3
M33	0.594	0.766	0.788	2.148	0.465	0.329	0.310	1.105	0.340	11
M34	0.560	0.802	0.788	2.150	0.485	0.269	0.310	1.064	0.331	12
M35	0.695	0.686	0.856	2.238	0.363	0.405	0.233	1.002	0.309	13
M36	0.707	0.832	0.816	2.355	0.360	0.259	0.303	0.922	0.281	10
M37	0.400	0.433	0.947	1.779	0.670	0.719	0.098	1.487	0.455	6
M38	0.818	0.871	0.900	2.589	0.247	0.199	0.165	0.611	0.191	1
M41	0.500	0.871	0.856	2.227	0.549	0.199	0.233	0.981	0.306	7
M42	0.848	0.912	0.788	2.548	0.202	0.140	0.310	0.652	0.204	4
M51	0.529	0.871	0.900	2.300	0.544	0.199	0.165	0.908	0.283	14
M61	0.587	0.832	0.788	2.208	0.482	0.259	0.310	1.051	0.323	16
M62	0.548	0.736	0.829	2.112	0.523	0.342	0.241	1.106	0.344	20
M63	0.757	0.912	0.856	2.525	0.304	0.140	0.233	0.677	0.211	19
M71	0.734	0.912	0.856	2.502	0.316	0.140	0.233	0.689	0.216	18
M72	0.647	0.912	0.856	2.415	0.420	0.140	0.233	0.794	0.247	17
M73	0.612	0.721	0.788	2.121	0.438	0.345	0.310	1.094	0.340	15
M81	0.442	0.433	0.856	1.731	0.612	0.719	0.233	1.565	0.475	2

The comparison of the rankings obtained by FMEA and FMEA based fuzzy TOPSIS method is depicted in Figure 2 The rankings for FMEA and FMEA-based fuzzy TOPSIS methods are illustrated with bold dashed lines and grey lines, respectively. The number on the lines shows the ranking of the corresponding failure modes on the x-axis. However, the rankings of modes that cannot be distinguished by FMEA for 3,4 and 15.

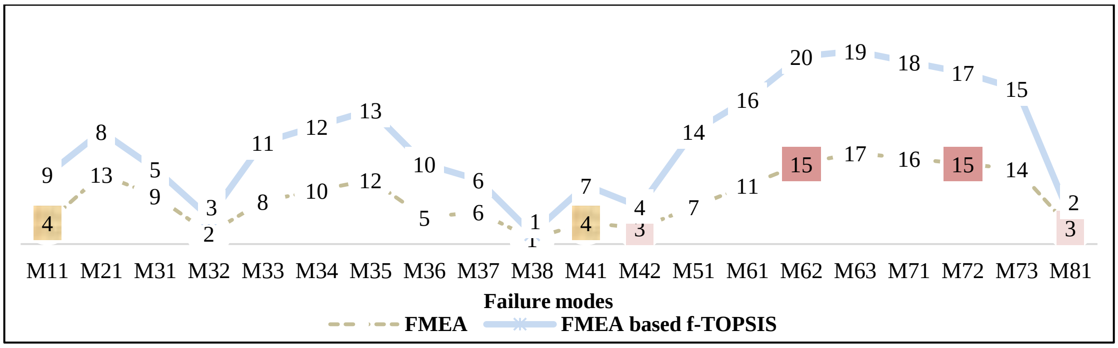

Figure 2. Comparison of rankings of both methods

Both methods indicate the main fault as swinging booms. After analysing the process, it is determined that the failure occur during the interlocking step of the main boom and primary boom. During this process, improper assembly of the booms and failures in the bending of the booms cause excessive swinging of the vehicle.

4. CONCLUSION

In this study, the quality problems are investigated due to the several causes in the telescopic platform production. FMEA and multi criteria decision making methods are used to reveal the critical failures. Traditional FMEA is used to evaluate the alternative failures according to severity, occurrence and detectability. However, the weakness of FMEA in distinguishing between failures that have the same RPN values is tried to be overcome with FMEA based fuzzy TOPSIS method.

As a result of the study, failure mode pairs M11& M41, M42&M81 and M62&M72 have the same rankings in FMEA, fortunately the similar rankings are distinguished by FMEA based fuzzy TOPSIS method. On the other side, the most important failure modes are M38 for both FMEA and FMEA based fuzzy TOPSIS method. According to the experts, these failures arise from the lack of the equipment in the loading platform, wrong calculations of dimensions for fitting in the truck and improper methods used while interlocking the booms. After meetings with decision makers, it is concluded that common quality problems occur due to unstandardized work tasks and unplanned assignment of works to workers.

Furthermore, some quantitative analysis can be done to analyse quality problems in depth, as well as the evaluation of the decision makers. Thus, some concrete improvements can be put forward by exploring the quality problems and quantifying the process improvement.

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