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RESEARCH PAPER

Assessment, Analysis and Risk Management In the Production Process of Products with a Fuzzy Control Approach

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ABSTRACT
Today, one of the most important concerns of production units is the evaluation, analysis and risk management in the production process. In this research, based on the fuzzy control approach, a scientific and logical method for evaluating, analyzing and managing risk in the production process is presented. Based on the proposed method of this research, after identifying the risks in the production process of products, according to the three criteria of failure severity, probability of failure and detectability, as well as using the best - worst method, evaluation and determining the importance of these risks, is done. Then, with the fuzzy rules, fuzzy inference system is designed. The final result is the classification and prioritization of identified risks. Finally, the proposed research model for an applied sample is used and its final results are analyzed.

KEYWORDS: *Risk; Database of rules; Best-Worst method; Improvement priority; Fuzzy inference system.*

1. Introduction

Risk is present in all human activities and can be related to health and safety, have an economic impact or affect the environment. The purpose of risk management is to control, prevent or reduce mortality, disease or property damage and subsequent damage to the environment [1]. Risk must be analyzed before it can be effectively managed. The results of risk analysis can be used by decision makers to assist in judging the acceptability of risk and to assist in choosing between potential measures to reduce risk or avoid risk. The overall purpose of risk analysis is to provide a rational basis for risk decision making [2].

Risk management is a subsection of project management that aims to help project managers assess and better respond to risks. The main objective of risk management is to maximize the probability of success for the project which is achieved through identifying and systematically assessing the risks as well as finding solutions to avoid or remedy risks and maximize opportunities [3].

Failure modes, effects and analysis (FMEA) is a widely used methodology among the safety, reliability, and risk engineers in manufacturing industries [4], aerospace industries [5], process plants ([6], [7]), food industries [8], supply chain management [9], etc. According to AS/NZS IEC 60812:2020 "FMEA is a systematic method of evaluating an item or process to identify the ways in which it might potentially fail, and the effects of the mode of failure upon the performance of the item or process and on the surrounding environment and personnel". Often, the criticality of a failure mode is defined in terms of risk priority number (RPN) - a product of the crisp ratings (between 1–10) of three risk factors (RFs) (i.e., severity (S), occurrence (O), and detection (D)), provided by the cross-functional experts. After the risk ranking of the failure modes, organizations come up with different proactive strategies to mitigate their likelihood of occurrence.

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Multi-criteria decision making (MCDM) methods are frequently utilized in a context, where it is necessary to prioritize the feasible options/alternatives in best to worst order, by comparing them against a set of conflicting criteria. However, at the time of formation of the decision matrix, experts usually prefer to linguistically evaluate the alternatives with respect to the considered criteria, rather than providing their crisp judgments. To properly address the associated uncertainties of linguistic judgments, MCDM methods are often combined with fuzzy sets (FSs)/type-1 fuzzy sets (T1FSs), and its different extensions, such as Z-numbers [10], neutrosophic fuzzy sets [11], interval type-2 fuzzy sets (IT2FSs) [12], etc.

Organizations usually need a system that, in addition to evaluating their activities and processes, can guide them on the status of risk, determine tolerable risk criteria, and accurately identify risk, depending on the complexity of each organization's activities. Being able to get them to that goal is different.

The project risk management process consists of two levels: assessment and response to risks. Assessing risks is broken down into two parts; identifying and analyzing risks. Many techniques have been utilized to identify risks, each of which has their unique scenario [13]. At this level, the sources for risks that are halting a firm’s progress towards its goals are classified and their causes are recorded based on their impacts. This is a qualitative process which aims to identify and explain risks that impact a project’s goals. Identifying risks is not a fixed process and must be carried out regularly in all stages of the project. Risk identification is an iterative process. At first, the process is carried out by people in the project team or a risk management team and, later, iterations are made by the entire project team and subordinates [14]. Main tools in risk identification are brainstorming, reviewing records, Delphi technique, checklist analysis and assumptions analysis. Risk analysis is either qualitative or quantitative. Qualitative risk analysis consists of probability assessment, impact and probability-impact matrix, risk classification, Delphi technique, brainstorming, hypothesis analysis, checklist analysis and expert’s decision. On the other hand, quantitative risk analysis consists of sensitivity analysis, expected monetary value returned, decision trees based on utility theory, simulation, causal diagrams, penetration graphs, game theory, fuzzy theory, Rough analysis and analysis of error trees [13]. Software development project risk management is a set of steps taken to identify and eliminate areas that are either directly causing a risk to the production and development of software, or might end up becoming a risk later on [15].

Therefore, organizations should be able to choose the best method from a variety of risk assessment methods [16]. In this research, by presenting a step-by-step and logical method, a model of risk assessment, analysis and management in the production process of products with a fuzzy control approach is presented. In the second part of this article, a review of previous research related to the research topic is provided. In the third section, the proposed method of this research is presented to evaluate, analyze and manage the risks in the production of products. In the fourth section, a practical example is shown to explain how to calculate and implement the proposed model. In the fifth section, the sensitivity of the results of the proposed model is analyzed according to the changes of the main parameters, and finally in the sixth section, conclusions and suggestions for future studies are presented.

2. Review of Literature

Due to the various approaches and theories related to the field of risk assessment, analysis and management, a lot of research on the subject of research, has been done, which is briefly reviewed below.

In Kalathil et al. (2020), the authors adopted the Dempster-Shafer evidence theory for the FMEA analysis of a LNG storage facility. The major aim of this paper was to address the uncertainty associated with the input evaluations of the RFs [17]. Wang et al. (2021) proposed a cloud model based FMEA approach (CM-FMEA) for quantitative risk assessment of a process industry. The cloud weights of the RFs were calculated by interval AHP (analytic hierarchy process) and CM, and the risk ranking results of the failure modes were calculated by improved TOPSIS method [18].

In Wang et al. (2020), the authors integrated an extended matter-element model and AHP for the risk ranking of the failure modes in a FMECA problem [19]. Lo et al. (2020) proposed an integrated MCDM approach to generate the aggregated risk ranking of the failure modes, obtained by different MCDM methods. Crisp-DEMATEL was used to calculate the weights of the RFs as well as their causal relationships. Then four MCDM methods: SAW (simple additive weighting), grey relation analysis (GRA), VIKOR (Vlse kriterijumska optimizacija kompromisno resenje), and COPRAS (COmplex PRoportional ASsessment) were used to rank the failure modes. Then the TOPSIS-based approach was used to generate a final risk result [20].

In Bashan et al. (2020), the authors integrated the concept of single valued neutrosophic sets and TOPSIS method for the risk prioritization of failure modes [21].

To deal with the associated vagueness with linguistic judgments in FMEA, He et al. (2020) introduced the concept of probabilistic linguistic term sets (PLTSs) and integrated it with ELECTRE – II approach for the risk prioritization of failure modes [22]. Similarly, Zhu et al. (2020) proposed a regret theory based PROMETHEE (Preference ranking organization method for enrichment evaluation) method and integrated it with linguistic neutrosophic sets in a FMEA case study [11].

In Huang et al. (2020) the authors extended the TOPSIS method and integrated with rough set theory and CM theory for the risk ranking of the failure modes under linguistic context [23]. Rathore et al. (2020) used fuzzy VIKOR method for evaluating and ranking the risks associated with the food grains supply chain [24]. Das et al. (2020) integrated the concept of Z-number with weighted VIKOR for the hazard prioritization associated with the virtual prototype based EOT crane operations [10].

Wu and Tang (2020) integrated the concept of grey relational projection method and Dempster-Shafer evidence theory for ranking the risk priorities of the failure modes [25]. In the work of Seiti et al. (2020), a modified R-number methodology is combined with SECA (Simultaneous Evaluation of Criteria and Alternative) and used to solve a FMEA case study related to centrifugal compressor of steel manufacturing plant [26]. In Fang et al. (2020) the authors proposed the concept of extended TOPSIS method, combining it with the variable precision rough number and prospect theory. The methodology was used for the FMEA case study of a steam valve system [27].

In Gopal and Panchal (2021), the authors used the fuzzy COPRAS method for identification of critical failure causes associated with different components of a curd unit in a milk processing industry [28]. Gul and Ak (2021) used the concept of an interval-valued spherical fuzzy sets-based TOPSIS method for the risk ranking of failure modes in a FMEA work of a marble manufacturing industry. Apart from the traditional S, O, and D, the other considered risk factors were cost, prevention, and effectiveness [29].

The weights of them were calculated by an interval-valued spherical weighted arithmetic mean operator. Luqman et al. (2021) integrated triangular Pythagorean fuzzy numbers and digraph and matrix techniques for risk prioritization in a FMEA case study of a steam valve system. Pythagorean fuzzy digraph was used to capture the interrelations among the risk factors and to calculate their weights. Then, failure mode priorities were calculated from the Pythagorean fuzzy risk matrices [30].

Pintelon et al. (2021) presented the applications of MCDM methods in a FMEA case study of a medical device. The Entropy method was used to calculate the weights of the risk factors, TOPSIS and GRA (Grey Relational Analysis) was used to calculate the interrelationships among the criteria and alternatives, and EDAS was used for risk prioritization of failure modes [31].

Chatterjee et al. (2019) studied software risks in its first stages to produce more reliable software because the necessary measures for reliability optimization with regard to time and cost have been set by developers. In this study, algorithms were used based on rules to produce the fuzzy rules for predicting the initial risks of the software's life cycle. The model uses fuzzy logic to combat uncertainty and 26 software projects' data were used to analyze the performance and accuracy of this model [32].

Nourian et al. (2019) proposed a hybrid fuzzy decision support system to decrease the risk in gas industries connected to gas transmission services. The advanced fuzzy expert system was programmed by C and CLIPS, and was joined with MATLAB for calling fuzzy membership functions. There are few number of studies as a case study in risk assessment techniques combined with fuzzy logic and proposed a model which was built using Mamdani algorithm and MATLAB's fuzzy logic toolbox. This could be implemented in many engineering problems as a smart risk assessment tool [33].

Sohag and Yiannis (2018) reviewed the applications of this technique in evaluating the safety and reliability of systems by reviewing the use of fuzzy sets [34].

Abdul Karim (2017) has reviewed a study entitled "Identification and evaluation of risk factors for construction projects" in which the impact of factors affecting the cost and possible time has been considered. Information and data were collected from sixteen construction companies in Egypt, and output charts and analysis pages were developed to develop a computer model [35].

Pimchangthong and Boonjing (2017) expanded those previous methods for risk management that had impacted information technology (IT) projects successfully. For this study, data were gathered from 200 project managers as well as managers and IT technicians of successful IT firms and analyzed using methods such as t-test, one-way ANOVA and linear variable analytics in a sample with 0.05 error. Results showed differences in firms and that their sizes affected their success in IT projects [36].

Samantra et al. (2017) conducted a study entitled Fuzzy Risk Assessment for Urban Construction. In this research, ranking for a source of risk expresses two parameters of probability of occurrence and consequence of occurrence of risk. The proposed method in the urban construction project is presented for a case study of the construction of an underground railway station and the risk matrix is used to classify different risk factors at different levels of intensity to create a plan of necessary measures [37].

Toth and Sebestyen (2015), in their articles, assessed the various risks of construction projects. The main goal was to reduce and eliminate the risk of change by monitoring risk. Based on the results of this study, if necessary, operational plans may be planned to prevent accidents and casualties. As a result, in a construction project, a continuous assessment is proposed to maintain the risk management process [38].

According to the explanations provided, choosing an appropriate and efficient model for evaluation to evaluate, analyze and manage risk in the production process of products, has a great impact on increasing production efficiency and also, customer satisfaction. Therefore, it is necessary to provide a scientific and logical solution to achieve this goal, which in this research, has tried to achieve this goal by presenting a new and practical evaluation model.

3. Research Methodology

In the proposed method of this research, based on scientific and practical methods, an appropriate solution has been tried to answer one of the most important issues of production units, based on risk assessment, analysis and management in the production process, to finally, with priority Define improvement projects and defined remedial measures, determine appropriate strategies to increase productivity and profitability of production.

According to the proposed method of this research, first, the members of the expert team for safety and risk assessment are determined that the selected members must have sufficient work experience and expertise in the field of research. Then, according to the review of activities related to the production process, the identification and analysis of risks associated with these activities are performed and based on the opinions of experts, the relevant risks are identified. Then, a questionnaire related to risk assessment is developed according to the best-worst (BWM) approach, in which the risk assessment is considered in the context of three criteria of failure intensity, failure probability and detectability. After distributing the questionnaires and conducting risk assessments by experts according to the three criteria, the weight of all risks from the perspective of each criterion is determined using the BWM method.

In the next step, the fuzzy inference system related to the proposed research is designed in which the final results are proposed by considering the desired fuzzy rules and the identified risks are categorized and prioritized.

Finally, according to the targeting of the organization based on acceptable levels of risk, if there are risks with undesirable and critical levels, improvement priorities are determined, and by defining the relevant corrective measures and implementing them, the risk assessment process is performed again. This process is repeated until the target level of the target organization is reached.

This paper proposed a framework is shown in Fig. 1.

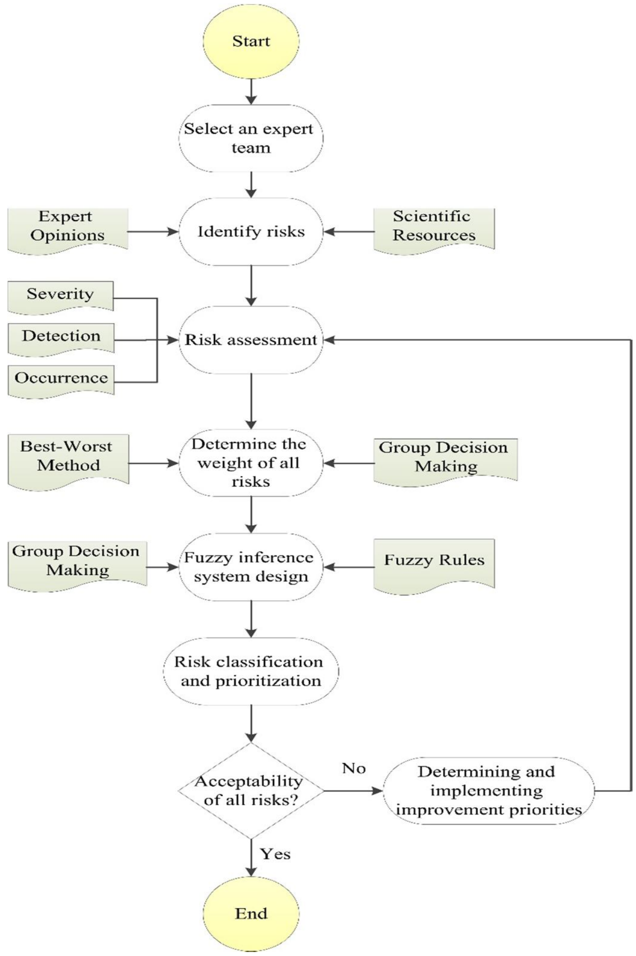

Fig. 1. Proposed framework of this paper

3. 1. Identifying and evaluating the risks in the production process

In order to identify the risks in the production process, the risk assessment experts must first be identified. The experts, who are 3 or 5 people, are experienced people with useful experience in the production process of the desired product, who have sufficient skills and expertise and have passed the required training courses in a desirable way.

In the next step, the risks of each process and the risks associated with it are identified separately. In this research, the combined use of interview methods and questionnaires by experts in the field of product production process has been suggested.

After identifying the risks in the production process of the product in question, the risk assessment criteria are determined. In this study, the criteria of failure severity, failure probability and detectability have been considered. The severity of the failure indicates the extent of the damage and loss that will occur if the failure actually occurs. The probability factor of failure indicates the possibility of a failure occurring in a certain period of time. Detection is also an assessment of the extent to which an ability exists to identify a cause or mechanism of failure.

In this research, it is proposed to evaluate the risks in the production process using the Best-Worst-Method (BWM) method. Because this method is one of the newest and most effective multi-criteria decision making techniques that is used to weight decision factors and criteria [39]. In the next step, a questionnaire of pairwise comparisons between the risks is developed. This questionnaire is based on the logic of the best-worst method and should be prepared to assess the identified risks from the perspective of each of the criteria of "failure rate", "failure probability" and "detectability".

According to the developed questionnaire, the evaluation of the desired risks is done by selected experts, who use a group of experts to evaluate the desired risks on a scale of 1-9 using verbal variables. After determining the evaluation matrix of each of the experts in the field of measuring the identified risks in terms of "failure severity", "failure probability" and "detectability" criteria, the importance (weight) of each risk is determined based on the BWM method. The following steps are performed to extract the weight of identified risks using the BWM method. It is necessary to mention that in the beginning, pairwise comparisons with the criterion of severity of failure should be done:

Step 1- Selecting the best and worst risks: In this step, the evaluator determines the best and worst risks (in his opinion).

Step 2 - Determining the degree of superiority of the best risk: In this step, according to the best risk determined (according to step 1), the degree of superiority of this risk over other risks, using the numbers 1 to 9, is determined by the assessor.

Step 3- Determining the degree of superiority of risks over the worst risk: In this step, according to the worst risk determined (according to step 1), the degree of superiority of other risks over this risk is determined by the assessor.

Step 4 - Determining the optimal weights: If the weight of the best (B), worst (W) and "j" risks are indicated by the criterion of failure intensity, with the symbols W_{SB}, W_{SW} and W_{Sj}, respectively, to determine the optimal weight of the risks, , Linear programming model (1), be solved [39]:

$$\begin{aligned} &\text{Min } \xi S \\ &\text{S.t.} \\ &\left|W_{SB} - a_{SBj}W_{Sj}\right| \le \xi S\ , \quad j = 1,2,\dots,n. \\ &\left|W_{Sj} - a_{jWS}W_{wS}\right| \le \xi S\ , \quad j = 1,2,\dots,n. \\ &\sum_{j=1}^{n} W_{Sj} = 1 \\ &W_{Sj} \ge 0\ , \quad j = 1,2,\dots,n. \end{aligned} \tag{1}$$

Step 5 - Determining the final weight: According to the optimal weights of the failure severity criterion, the final weight of the risks are calculated by considering the failure severity criterion, based on Equation (2):

$$W^*_{Si} = L_S \times \frac{W_{Si}}{\max_i (W_{Si})}\ , \qquad i = 1,2,\dots,n. \tag{2}$$

After calculating the optimal weights of risks identified by each of the evaluating experts, according to the principles of group decision-making and the importance of the opinions of each of the experts, the geometric average of all weights (which is the number of evaluating experts) should be calculated. The five steps are also performed for the criteria of occurrence and detectability (indicated by the symbols O and D, respectively), and finally, the risk weight j of the production process with the criteria of probability of failure, according to Equation (3) and The risk weight of the product production process is determined by the criterion of detectability, according to Equation (4).

$$W^*_{Oj} = (W^*_{Oj1})^{\lambda_1} \times \dots \times (W^*_{Oji})^{\lambda_i} \times \dots (W^*_{Ojk})^{\lambda_k} \tag{3}$$

$$W^*_{Dj} = (W^*_{Dj1})^{\lambda_1} \times \dots \times (W^*_{Dji})^{\lambda_i} \times \dots (W^*_{Djk})^{\lambda_k} \tag{4}$$

3.2. Fuzzy inference system design

Fuzzy inference system (FIS) based on a combination of component rules: membership functions of input and output variables (fuzzy), fuzzy rules (rules base), mechanism inference (combination of rules with fuzzy input) and output characteristics and system results (non-fuzzy) Is. One of the common methods for fuzzy reasoning is to use the Mamdani method. In this method, the logical condition "if A, then B" is used. The inputs considered in this study are the obtained weights for failure intensity, failure probability and detection that have been calculated in the previous step. However, in order to design a fuzzy inference system for risk analysis, relevant fuzzy rules must be established. For this purpose, the verbal variables assessing the severity of failure, probability occurrence and detectability, which are used to quantify the relevant variables, triangular fuzzy numbers are used, according to Table (1).

Tab. 1. Triangular fuzzy quantities for different failure levels

Severity of Failure			Probability of Failure			Ability to Detection		
Type of severity	Symbol	Fuzzy quantity	Probability occurrence	Symbol	Fuzzy quantity	Probability of detection	Symbol	Fuzzy quantity
Catastrophic	Z	(8,8,9)	Repetitious	A	(7,8,9)	Low	S	(7,8,9)
Critical	H	(6,7,8)	Possible	B	(4,6,7)	Medium	T	(2,5,7)

Severity of Failure			Probability of Failure			Ability to Detection		
Type of severity	Symbol	Fuzzy quantity	Probability occurrence	Symbol	Fuzzy quantity	Probability of detection	Symbol	Fuzzy quantity
Medium	M	(4,5,6)	Low	C	(2,3,4)	High	U	(1,2,2)
Low	L	(2,3,4)	Very Low	D	(1,2,2)			
Negligible	N	(1,1,2)						

After determining the different levels of severity, failure probability and detectability, fuzzy rules should be developed. These rules are determined by the opinions of experts and the method of brainstorming. In this research, the rules related to determining the final output (risk acceptance level) are as described in Table (2).

Tab. 2. Fuzzy reasoning rules for risk acceptance level

Rule number	if Severity	and Occurrence	and Detection	then Level of risk acceptance	Symbol of risk acceptance
1	Z	A	S	Unacceptable	I
2	Z	A	T	Unacceptable	I
3	Z	A	U	Undesirable	II
4	Z	B	S	Unacceptable	I
5	Z	B	T	Undesirable	II
6	Z	B	U	Undesirable	II
7	Z	C	S	Unacceptable	I
8	Z	C	T	Undesirable	II
9	Z	C	U	Acceptable by review	III
10	Z	D	S	Undesirable	II
11	Z	D	T	Acceptable by review	III
12	Z	D	U	Acceptable without review	IV
13	H	A	S	Unacceptable	I
14	H	A	T	Unacceptable	I
15	H	A	U	Undesirable	II
16	H	B	S	Undesirable	II
17	H	B	T	Undesirable	II
18	H	B	U	Acceptable by review	III
19	H	C	S	Undesirable	II
20	H	C	T	Acceptable by review	III
21	H	C	U	Acceptable without review	IV
22	H	D	S	Acceptable by review	III
23	H	D	T	Acceptable without review	IV
24	H	D	U	Acceptable without review	IV
25	M	A	S	Unacceptable	I
26	M	A	T	Undesirable	II
27	M	A	U	Acceptable by review	III
28	M	B	S	Undesirable	II
29	M	B	T	Acceptable by review	III
30	M	B	U	Acceptable without review	IV
31	M	C	S	Undesirable	II
32	M	C	T	Acceptable by review	III
33	M	C	U	Acceptable without review	IV
34	M	D	S	Acceptable without review	IV
35	M	D	T	Acceptable without review	IV
36	M	D	U	Acceptable without review	IV
37	L	A	S	Undesirable	II
38	L	A	T	Acceptable by review	III
39	L	A	U	Acceptable without review	IV
40	L	B	S	Acceptable by review	III
41	L	B	T	Acceptable by review	III
42	L	B	U	Acceptable without review	IV
43	L	C	S	Acceptable by review	III

Rule number	if Severity	and Occurrence	and Detection	then Level of risk acceptance	Symbol of risk acceptance
44	L	C	T	Acceptable without review	IV
45	L	C	U	Acceptable without review	IV
46	L	D	S	Acceptable without review	IV
47	L	D	T	Acceptable without review	IV
48	L	D	U	Acceptable without review	IV
49	N	A	S	Acceptable by review	III
50	N	A	T	Acceptable without review	IV
51	N	A	U	Acceptable without review	IV
52	N	B	S	Acceptable by review	III
53	N	B	T	Acceptable without review	IV
54	N	B	U	Acceptable without review	IV
55	N	C	S	Acceptable without review	IV
56	N	C	T	Acceptable without review	IV
57	N	C	U	Acceptable without review	IV
58	N	D	S	Acceptable without review	IV
59	N	D	T	Acceptable without review	IV
60	N	D	U	Acceptable without review	IV

Finally, the fuzzy output obtained in the previous step must be converted to a non-fuzzy number. In this study, according to the levels of final risk acceptance, the final decision to determine the priorities for improving the risks in the production process is as follows:

- Group (priority) one: risks assessed with risk acceptance levels equal to or less than 25;
- Group (priority) two: assessed risks with risk acceptance levels between 25 and 55;
- Group (Priority) Three: Risks assessed with risk acceptance levels between 55 and 75.

Also, the intra-group prioritization of each of the three groups is based on the ascending order of risk acceptance numbers.

After prioritizing the desired risks, corrective actions to improve the level of risk acceptance are defined and the risk assessment process is repeated, and this process continues until the level of risk acceptance of the organization is reached.

4. Case study

In this section, a practical example is provided to show how to use the proposed model and analyze the relevant results. Assume that in the seamless steel production process, 6 main risks have been identified, which are:

- ✓ Unfavorable cutting
- ✓ Defects in the heating process
- ✓ Improper drilling
- ✓ Problems in the sphericalization process
- ✓ Improper traction
- ✓ Lack of desirability of the cooling process

The assessment of the mentioned risks by experts 1, 2 and 3 is in the form of tables (3) to (5):

Tab. 3. Assessment of risks in the seamless steel production process by an expert 1

Severity	r_1	r_2	r_3	r_4	r_5	r_6	Occurrence	r_1	r_2	r_3	r_4	r_5	r_6	Detection	r_1	r_2	r_3	r_4	r_5	r_6
BO	4	5	1	3	3	2	BO	5	1	4	2	3	4	BO	1	3	2	5	2	2
OW	3	1	5	1	3	2	OW	1	5	2	3	2	2	OW	5	2	3	1	3	3

Tab. 4. Assessment of risks in the seamless steel production process by an expert 2

Severity	r_1	r_2	r_3	r_4	r_5	r_6	Occurrence	r_1	r_2	r_3	r_4	r_5	r_6	Detection	r_1	r_2	r_3	r_4	r_5	r_6
BO	3	1	2	2	1	4	BO	1	3	4	2	5	2	BO	5	3	1	4	2	3
OW	1	1	2	3	4	1	OW	5	2	2	3	1	3	OW	1	2	5	2	3	2

Tab. 5. Assessment of risks in the seamless steel production process by an expert 3

Severity	r_1	r_2	r_3	r_4	r_5	r_6	Occurrence	r_1	r_2	r_3	r_4	r_5	r_6	Detection	r_1	r_2	r_3	r_4	r_5	r_6
BO	4	3	1	5	3	4	BO	5	1	3	2	4	3	BO	3	5	2	4	3	1
OW	2	3	5	1	4	3	OW	1	5	2	3	2	2	OW	2	1	3	2	3	5

Following the evaluations, linear programming model (1), should be developed for the evaluations of each expert. The results of the planning model related to the evaluation of experts 1, 2 and 3 are determined in the form of tables (6) to (8) (using Lingo software).

Tab. 6. Final weight of each risk by the expert 1

	Severity						Occurrence						Detection					
Title	r_1	r_2	r_3	r_4	r_5	r_6	r_1	r_2	r_3	r_4	r_5	r_6	r_1	r_2	r_3	r_4	r_5	r_6
Symbol	WS11	WS21	WS31	WS41	WS51	WS61	WO11	WO21	WO31	WO41	WO51	WO61	WD11	WD21	WD31	WD41	WD51	WD61
Amount	0.109	0.06	0.368	0.129	0.146	0.189	0.069	0.379	0.103	0.207	0.138	0.103	0.321	0.112	0.168	0.061	0.168	0.168
Final weight	2.68	1.46	9	3.16	3.57	4.62	1.45	8	2.18	4.36	2.91	2.18	8	2.79	4.19	1.52	4.19	4.19

Tab. 7. Final weight of each risk by the expert 2

	Severity						Occurrence						Detection					
Title	r_1	r_2	r_3	r_4	r_5	r_6	r_1	r_2	r_3	r_4	r_5	r_6	r_1	r_2	r_3	r_4	r_5	r_6
Symbol	WS21	WS22	WS32	WS42	WS52	WS62	WO21	WO22	WO32	WO42	WO52	WO62	WD21	WD22	WD32	WD42	WD52	WD62
Amount	0.10	0.19	0.16	0.16	0.31	0.08	0.34	0.13	0.09	0.19	0.06	0.19	0.07	0.13	0.37	0.10	0.20	0.13
Final weight	2.67	5.00	4.00	4.00	8.00	2.00	8.00	2.91	2.18	4.36	1.45	4.36	1.09	2.18	6.00	1.64	3.27	2.18

Tab. 8. Final weight of each risk by the expert 3

	Severity						Occurrence						Detection					
Title	r_1	r_2	r_3	r_4	r_5	r_6	r_1	r_2	r_3	r_4	r_5	r_6	r_1	r_2	r_3	r_4	r_5	r_6
Symbol	WS13	WS23	WS33	WS43	WS53	WS63	WO13	WO23	WO33	WO43	WO53	WO63	WD13	WD23	WD33	WD43	WD53	WD63
Amount	0.12	0.16	0.39	0.06	0.16	0.12	0.07	0.37	0.13	0.20	0.10	0.13	0.14	0.06	0.20	0.10	0.14	0.36
Final weight	2.74	3.66	9.00	1.41	3.66	2.74	1.27	7.00	2.55	3.82	1.91	2.55	2.66	1.21	3.98	1.99	2.66	7.00

In the next step, the fuzzy inference system of this research is performed. The diagram in Figure (1) shows the levels created between the variables of failure intensity and probability of failure.

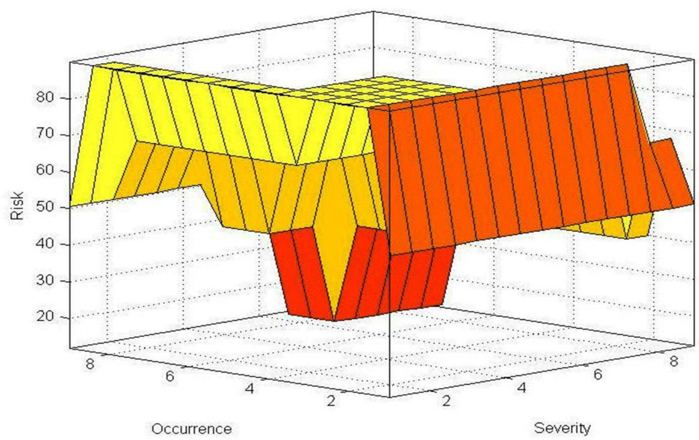

Fig. 2. Levels created between failure intensity and failure probability variables

Finally, based on the designed fuzzy inference system, the final results of the risk levels are the final decision to determine the priorities for improving the risks in the production process, as described in Table (9).

Tab. 9. Priorities for improving the risks in the seamless steel production process

Risk title	Symbol	Risk level number	Grouping	Priority
Unfavorable cutting	r_1	90	-	
Defects in the heating process	r_2	67.3	3	1
Improper drilling	r_3	67.5	3	3
Problems in the sphericalization process	r_4	89.9	-	
Improper traction	r_5	67.4	3	2
Lack of desirability of the cooling process	r_6	90	-	

The proposed research model can be analyzed in different contexts. In this research, the sensitivity of the proposed model to the proposed method and method of evaluation has been analyzed. If the desired level of risk is determined in the traditional way and according to the product of the severity of failure, probability of failure and detectability (such as the method used by the source), the relevant final results can be compared and analyzed with the results of the proposed research method. Contract analysis. The diagram in Figure (3) shows the ranking changes of the risks identified in both traditional and proposed methods of this research.

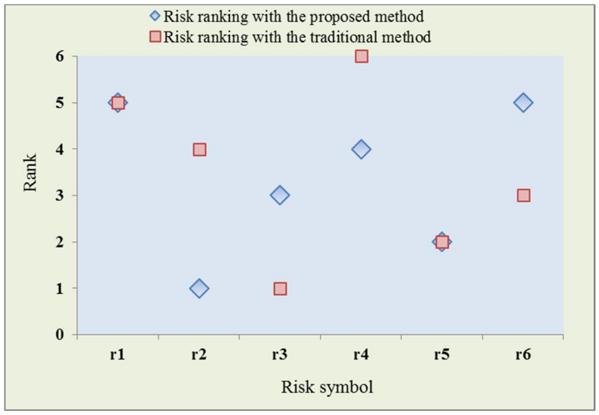

Fig. 3. Changes in the ranking of identified risks in both traditional and proposed methods

5. Conclusion

Risk management in the production of products is one of the most prominent challenges in the field of production management and all processes and decisions in the business environment depend on uncertainty. Therefore, uncertainty must be constantly monitored and managed through a logical process, because when it occurs, it will have important effects. In this research, based on the fuzzy control approach, a scientific and logical method for evaluating, analyzing and managing risk in the production process was presented. According to the method presented in this research, first, the risks related to the production process of the desired product were identified by an expert team of safety and risk assessment. Then, the risk assessment was performed by experts, according to the best-worst (BWM) approach, in which the risk assessment was considered in terms of three criteria of severity, occurrence and detectability. Then, the weight of all risks was determined using the BWM method.

In the next step, the fuzzy inference system related to the proposed research was introduced, in which, after determining the different levels of failure severity, Probability of occurrence and detectability, the relevant fuzzy rules were developed according to experts' opinions and brainstorming method. Finally, after determining the final output of the fuzzy inference system, according to the desired organizational policies and the views of senior managers, in terms of risk acceptance levels, priorities for improving the identified risks were determined.

In general, the proposed research is a new method for risk assessment, analysis and management in the production process of products, and according to the obtained results, the following can be expressed as research innovations:

- Development of the best-worst method for assessing identified risks;
- Design a fuzzy inference system to determine improvement priorities;
- Provide a scientific and logical solution for evaluating, analyzing and managing risk in the production process of products.

Sensitivity analysis of the proposed research model indicates the logical conclusion that prioritizing the identified risks in the production process, using the proposed method of this research, has significant changes compared to the proposed prioritization based on traditional methods. Therefore, according to the model used in the method of this research, it is suggested to use the proposed method of this research to prioritize product improvement projects according to the ranking of risks in the production process.

In order to conduct further studies on the subject of research, other methods of risk assessment can be presented and the final results can be compared with the findings of the present study. For future research, it is proposed to provide a model for assessing the risks in the production process, despite the dependence between the risks.

References

[1] Basseta, M.A., Gunasekaranb, M., Naveenchilamkurtic, M., "A framework for risk assessment, management and evaluation," *Economic tool for quantifying risks in supply chain*, Vol. 90, No. 2, (2019), pp. 489-502.

[2] Pourjavad, E., & Shahin, A., "The application of Mamdani fuzzy inference system in evaluating green supply chain management performance," *International Journal of Fuzzy Systems*, Vol. 20, No. 6, (2018), pp. 901-912.

[3] Chatterjee, S., Maji, B., & Pham, H., "A fuzzy rule based generation algorithm in interval type-2 fuzzy logic system for fault prediction in the early phase of software development," *Journal of Experimental & Theoretical Artificial Intelligence*, Vol. 31, No. 3, (2019), pp. 369-391.

[4] Li, Z., Chen, L., "A novel evidential FMEA method by integrating fuzzy belief structure and grey relational projection method," *Eng. Appl. Artif. Intell*, Vol. 77, No. 1, (2019), pp. 136-147.

[5] Wang, L.-E., Liu, H.-C., Quan, M.-Y., "Evaluating the risk of failure modes with a hybrid MCDM model under interval-valued intuitionistic fuzzy environments," *Comput.Ind. Eng*. Vol. 102, No. 1, (2016), pp. 175-185.

[6] Gugaliya, A., Boral, S., Naikan, V., "A hybrid decision making framework for modified failure mode effects and criticality analysis: a case study on process plant induction motors," *Int. J. Qual. Reliab. Manag*. Vol. 36, No. 8, (2019), pp. 1266-1283.

[7] Boral, Soumava, Howard, I., Chaturvedi, S.K., McKee, K., Naikan, V., "A novel hybrid multi-criteria group decision making approach for failure mode and effect analysis: an essential requirement for sustainable manufacturing," *Sustain. Prod. Consum*, Vol. 21, No. 1, (2020), pp. 14-32.

[8] Rezaee, M.J., Yousefi, S., Valipour, M., Dehdar, M.M., "Risk analysis of sequential processes in food industry integrating multi-stage fuzzy cognitive map and process failure mode and effects analysis," *Comput. Ind. Eng*, Vol. 123, No. 1, (2018), pp. 325-337.

[9] Arabsheybani, A., Paydar, M.M., Safaei, A.S., "An integrated fuzzy MOORA method and FMEA technique for sustainable supplier selection considering quantity discounts and supplier's risk," *J. Clean. Prod*, Vol. 190, No. 1, (2018), pp. 577-591.

[10] Das, S., Dhalmahapatra, K., Maiti, J., "Z-number integrated weighted VIKOR technique for hazard prioritization and its application in virtual prototype based EOT crane operations," *Appl. Soft Comput*, Vol. 94, No. 1, (2020), pp. 14-32.

[11] Zhu, J., Shuai, B., Li, G., Chin, K.-S., Wang, R., "Failure mode and effect analysis using regret theory and PROMETHEE under linguistic neutrosophic context," *J. Loss Prev. Process Ind*, Vol. 64, No. 1, (2020), pp. 104-118

[12] Qin, J., Xi, Y., Pedrycz, W., "Failure mode and effects analysis (FMEA) for risk assessment based on interval type-2 fuzzy evidential reasoning method," *Appl. Soft Comput*, Vol. 89, No. 1, (2020), pp. 106-134.

[13] Lee, E., Park, Y., & Shin, J. G., "Large engineering project risk management using a Bayesian belief network," *Expert Systems with Applications*, Vol. 36, No. 3, (2009), pp. 5880-5887.

[14] Kumar, A., Garg, R., &and Garg, D., "Critical Success Factors of implementing E-Supply chain in Indian Mechanical Sector," *International*

Journal of Advanced Science & Technology, Vol. 29, No. 7, (2019), pp. 11603-11628.

[15] Boehm, B., "Software risk management. In European Software Engineering Conference," *Springer, Berlin, Heidelberg*, (1989), pp. 1-19.

[16] Jinsheng, J., Sha, W., Cuiying, Z., Zuping, C., Yang, W., "FOSM-based shear reliability analysis of CSGR dams using strength theory," *Computers and Geotechnics*, Vol. 97, No. 2, (2018), pp. 52-61.

[17] Kalathil, M.J., Renjith, V., Augustine, N.R., "Failure mode effect and criticality analysis using Dempster Shafer theory and its comparison with fuzzy failure mode effect and criticality analysis: a case study applied to LNG storage facility," *Process Saf. Environ. Prot,* Vol. 138, No. 1, (2020), pp. 337-348.

[18] Wang, L., Yan, F., Wang, F., Li, Z., "FMEA-CM based quantitative risk assessment for process industries—a case study of coal-to-methanol plant in China," *Process Saf. Environ. Prot*, Vol. 149, No. 1, (2021), pp. 299-311.

[19] Wang, Z., Ran, Y., Chen, Y., Yu, H., Zhang, G., "Failure mode and effects analysis using extended matter-element model and AHP," *Comput. Ind. Eng*, Vol. 40, No. 1, (2020), pp. 106-113.

[20] Lo, H.-W., Shiue, W., Liou, J.J., Tzeng, G.-H., "A hybrid MCDM-based FMEA model for identification of critical failure modes in manufacturing," *Soft Comput*, Vol. 24, No. 1, (2020), pp. 15733-15745.

[21] Bashan, V., Demirel, H., Gul, M., "An FMEA-based TOPSIS approach under single valued neutrosophic sets for maritime risk evaluation: the case of ship navigation safety," *Soft Comput*, Vol. 24, No. 1, (2020), pp. 18749-18764.

[22] He, S.-S., Wang, Y.-T., Wang, J.-Q., Cheng, P.-F., Li, L., "A novel risk assessment model based on failure mode and effect analysis and probabilistic linguistic ELECTRE II method," *J. Intell. Fuzzy Syst*, Vol. 38, No. 4, (2020), pp. 4675-4691.

[23] Huang, G., Xiao, L., Zhang, W., Li, J., Zhang, G., Ran, Y., "An improving approach for failure mode and effect analysis under uncertainty environment: a case study of critical function component," *Qual. Reliab. Eng. Int*, Vol. 36, No. 1, (2020), pp. 2119-2145.

[24] Rathore, R., Thakkar, J., Jha, J., "Evaluation of risks in foodgrains supply chain using failure mode effect analysis and fuzzy VIKOR," *Int. J. Qual. Reliab. Manag*, Vol. 38, No. 2, (2020), pp. 551-580.

[25] Wu, D., Tang, Y., "An improved failure mode and effects analysis method based on uncertainty measure in the evidence theory," *Qual. Reliab. Eng. Int*, Vol. 36, No. 1, (2020), pp. 1786-1807.

[26] Seiti, H., Fathi, M., Hafezalkotob, A., Herrera-Viedma, E., Hameed, I.A., "Developing the modified R-numbers for risk-based fuzzy information fusion and its application to failure modes, effects, and system resilience analysis (FMESRA)," *ISA Trans*, (2020), http://dx.doi.org/10.1016/j.isatra.2020.01.015.

[27] Fang, H., Li, J., Song, W., "Failure mode and effects analysis: an integrated approach based on rough set theory and prospect theory," *Soft Comput*, Vol. 24, No. 1, (2020), pp. 6673-6685.

[28] Gopal, N., Panchal, D., "A structured framework for reliability and risk evaluation in the milk process industry under fuzzy environment," *Facta Univ. Ser. Mech. Eng,* (2021), http://dx.doi.org/10.22190/FUME201123004G, ISSN: ISSN 2335-0164.

[29] Gul, M., Ak, M.F., "A modified failure modes and effects analysis using interval-valued spherical fuzzy extension of TOPSIS method: case study in a marble

manufacturing facility," *Soft Comput*, (2021), pp. 1-22.

[30] Luqman, A., Akram, M., Alcantud, J.C.R., "Digraph and matrix approach for risk evaluations under Pythagorean fuzzy information," *Expert Syst. Appl*, Vol. 170, No. 1, (2021), pp. 114-128.

[31] Pintelon, L., Di Nardo, M., Murino, T., Pileggi, G., Vander Poorten, E., "A new hybrid MCDM approach for RPN evaluation for a medical device prototype," *Qual. Reliab. Eng. Int.*, (2021), pp. 1-25.

[32] Chatterjee, S., Maji, B., & Pham, H., "A fuzzy rulebased generation algorithm in interval type-2 fuzzy logic system for fault prediction in the early phase of software development," *Journal of Experimental & Theoretical Artificial Intelligence*, Vol. 31, No. 3, (2019), pp. 369-391.

[33] Nourian, R., Mousavi, S. M., and Raissi, S., "A fuzzy expert system for mitigation of risks and effective control of gas pressure reduction stations with a real application," *Journal of Loss Prevention in the Process Industries*, Vol. 59, No. 2, (2019), pp. 77-90.

[34] Sohag, K., Yiannis. P., "A review of applications of fuzzy sets to safety and reliability engineering," *International Journal of Approximate Reasoning*, Vol. 100, No. 3, (2018), pp. 29-55.

[35] Abd El-Karim. MS., "Identification and assessment of risk factors affecting construction projects," *HBRC Journal*. Vol. 13, No. 2, (2017), pp. 202-216.

[36] Pimchangthong, D., & Boonjing, V., "Effects of Risk Management Practice on the Success of IT Project," *Procedia Engineering*, Vol. 182, (2017), pp. 579-586.

[37] Samantra. Ch., Datta. S., Mahapatra. SS., "Fuzzy based risk assessment module for metropolitan construction project: An empirical study," *Engineering Applications of Artificial Intelligence*, Vol. 65, No. 2, (2017), pp. 449-464.

[38] Toth. T., Sebestyen. Z., "Time-varying Risks of Construction Projects.," *Procedia Engineering*, Vol. 123, No. 1, (2015), pp. 565-573.

[39] Rezaei, J., "Best-worst multi-criteria decision-making method: Some properties and a linear model," *Omega*, Vol. 64, No. 2, (2016), pp. 126-130.

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