[1.]Annamária KONCZ, [2.]Zsolt Csaba JOHANYÁK, [3.]László POKORÁDI

MULTIPLE CRITERIA DECISION MAKING METHOD SOLUTIONS BASED ON FAILURE MODE AND EFFECT ANALYSIS

[1,2.]John von Neumann University, GAMF Faculty of Engineering and Computer Science, Kecskemét, HUNGARY
[3]Óbuda University, Institute of Mechatronics and Vehicle Engineering, Budapest, HUNGARY

Abstract: Failure Mode and Effect Analysis (FMEA) is nowadays one of the most popular and recognized risk analysis methods. In practice, it is used as a mandatory requirement in the automotive industry, in some branches of industrial manufacturing, in chemical industry, etc. It is important to point out, that due to its flexibility, FMEA is developed by researchers and technological experts. With the applied modifications FMEA can fit specialized purposes. In our work we give a complex summary of the multiple criteria decision making solutions, which are based on the traditional Failure Mode and Effect Analysis. The developed methods are using fuzzy logic in common and have different field of usage. For each methodology described, we give an example of usage, and Fuzzy TOPSIS is defined in detail in our literature review.
Keywords: Risk Assessment methods, Failure Mode an Effect Analysis, Multiple Criteria Decision Making, Fuzzy MCDM, Fuzzy TOPSIS

1. INTRODUCTION

The aim of our work is to identify the developed fuzzy multiple criteria decision making methods based on the traditional FMEA method, starting from the wider view, to the exact examples. In the *Introduction* section we give a summary on the standardized risk analysis methods, which are listed and described in ISO/IEC 31010:2009[1].

In Section 2, we represent the collected developed fuzzy FMEA methods based on multiple criteria decision making, with the focus on the practical examples. In Section 3, we give an overview about the attributes of multiple criteria decision making methods, focusing on the fuzzy TOPSIS method. The results of our work are summarized in Section 4.

Since FMEA was invented in the 1940's, it has approximately 70 years of history to look back on. The method was developed by the US military (MIL-P-1629 military standard, 1943[2]), and was used and implemented by the NASA as well [3]. Since the second half of the 20th century FMEA gained importance in design and process analysis as well, and nowadays it is inevitable part of applied quality assurance/quality management systems.

The collection of applied risk analysis methods is summarized and detailed in the standard to ISO/IEC 31010:2009. The most relevant risk analysis methods are important to know, as they give a good overview about nowadays industrial practice.

Table 1. Traditional risk assessment methods according to ISO/IEC 31010:2009 [1]

	Risk assessment methods	Abbreviation
1	Brainstorming	-
2	Structured or semi-structured interviews	-
3	Delphi technique	-
4	Checklists	-
5	Preliminary hazard analysis	PHP
6	Hazard and operability studies	HAZOP
7	Hazard analysis and critical control points	HACCP
8	Toxicity assessment	-
9	Structured What-if technique	SWIFT
10	Scenario analysis	-
11	Business impact analysis	BIA
12	Root cause analysis	RCA
13	Failure modes and effects analysis, Failure modes and effects and critically analysis	FMEA, FMECA
14	Fault tree analysis	FTA
15	Event tree analysis	ETA
16	Cause-consequence analysis	-
17	Cause-and-effect analysis	-
18	Layers of protection analysis	LOPA
19	Decision tree analysis	-
20	Human reliability assessment	HRA
21	Bow tie analysis	-
22	Reliability centered maintenance	-

23	Sneak analysis, Sneak circuit analysis	SA, SCA
24	Markov- analysis	-
25	Monte Carlo simulation	MCS
26	Bayesian statistics and Bayes Nets	-
27	FN curves (*F* refers to events expected per year, *N* refers to the number harmed)	-
28	Risk indices	-
29	Consequence/probability matrix	-
30	Cost/benefit analysis	CBA
31	Multi-criteria decision analysis	MCDA

In Chapter 2, we describe the conventional FMEA, its types and barriers. In contrast to this, in Chapter 3 we introduce the main non-conventional FMEA types: FMEA based on Multi-Criteria Decision Method; on Mathematical Programming approaches; on Artificial Intelligence solutions and Integrated approaches.

2. INTRODUCTION OF MULTIPLE CRITERIA DECISION MAKING METHOD SOLUTIONS BASED ON FAILURE MODE AND EFFECT ANALYSIS

In terms of FMEA, there are multiple non-conventional approaches. According to Hu-Chen Liu et al [4] there are the following sub-group: Multiple Criteria Decision Making applications, Mathematical Programming methods, Artificial intelligence applications, integrated approaches and other (mixed) approaches.

Table 2. Example of Fuzzy MCDM related applications used for FMEA and other approaches [4], [5]

Method	Author/year	Practical approaches/Practical FMEA applications
Fuzzy ME-MCDM	Franceschini and Galetto, 2001[6]	risk analysis/Several design and manufacturing purposes
Fuzzy evidence theory	Guo et al.,2007 [7] Li and Liao,2007 [8] Wang et al., 2006 [9] Xu et al., 2006 [10] Yang et al.,2006 [11]	comparison of technical products (cars) corporate risk analysis environmental impact assessment personal performance assessment car ranking
Fuzzy AHP/ANP	Hu et al., 2009 [12] Boral et al.,2009 [5]	component risk analysis / Fuzzy FMEA of components manufacturing risk analysis / Fuzzy Process FMEA
Fuzzy TOPSIS	Boran et al.,2009 [13] Taylan et al.,2015 [14] Dagdeviren et al.,2009 [15] Braglia et al.,2003 [16]	supplier selection (automotive, etc.) risk assessment of construction projects weapon selection production risk analysis / Fuzzy Production FMEA
Fuzzy Grey theory	Zhou and Thai, 2016 [17] Shi and Fei,2019 [18] Geum et al.,2011 [19]	failure analysis / Fuzzy FMEA for tanker equipment failure prediction failure analysis / Combined Fuzzy FMEA method for medical service process failure analysis / Service specific Fuzzy FMEA (hospital service)
Fuzzy DEMATEL	Seyed et al. ,2006 [20] Govindan and Chaudhuri,2016 [21]	failure analysis / Product specific Fuzzy FMEA (turbocharger product FMEA) risk analysis of third-party logistics service
VIKOR	Liu et al.,2012 [22] Mete et al, 2019 [23]	failure analysis / Fuzzy FMEA for medical processes occupational risk assessment of a natural gas pipeline construction
COPRAS	Roozbahani et al.,2020 [24]	water transfer planning
SWARA/COPRAS	Zarbakhshnia et al., 2018 [25]	risk analysis of third-party logistics service
ELECTRE (-TRI)	Certa et al., 2017 [26] Liu and Ming (2019) [27]	Fuzzy FMEA / Alternative failure mode classification Fuzzy FMECA / Fuzzy FMECA for smart product service
MULTIMOORA	Liu et al. (2014) [4]	Evaluation of failure modes / Fuzzy MULTIMOORA FMEA

3. ATTRIBUTES OF MULTIPLE CRITERIA DECISION MAKING APPLICATIONS

According to Massam [28] Multiple Criteria Decision Making applications (MCDM) are related to several decision making applications, as the following: Multi-Attribute Decision Making (MADM), Multi-Attribute Utility Theory (MAUT), Multi-Objective Decision Making (MODM) and Public Choice Theory (PCT).

The before mentioned applications can be used for planning processes, if multiple decision alternatives are applicable [28], or at FMEA processes if multiple choices are applicable for each factor categories.

MADM is applied if there are finite feasible sets of alternatives and the aim is to choose the best solution, in case of planning problems. MODM is used if the objective is to define finite number of possible alternatives for a given problem (the problem is typically solved with mathematical programming). MADM and MODM are applied in case of single decision makers or unified opinions [28].

In case of MAUT approaches the task is to evaluate the utilities of the given alternatives. As a result, the highest utility value is considered as the best possibility (in planning processes). PCT is applied if consensus is needed [28] in a certain decision situation, as well in a case of a risk category selection.

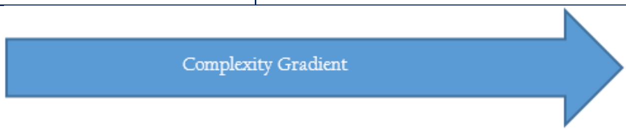
In general, it can be stated that the MCDM method consists of three areas, which were previously isolated. These are the following: Solution generation via search, Solution selection via preference aggregation and tradeoff, and Interactive visualization [29].

According to the tree fields mentioned, the MCDM methods cover these main solutions of planning problems: well-distributed Pareto sets (Solution generation via search), Bayesian and Fuzzy decision-making techniques (Solution selection via preference aggregation and tradeoff, and Interactive visualization) [29].

According to Bonissone et al. [29] MCDM attributes (Figure 1.) can be categorized according to their complexity.

Table 3. Framework to describe Multi Criteria Decision Making Problems [29]

Multiple Criteria Decision-Making ATTRIBUTES			
1. Deployment Requirements	Batch (Off-board)	Real-time (On-board)	
2. Deployment Architecture	Centralized	Distributed	
3. Response Evaluation	Deterministic Models	Stochastic Models Functional Approximation (data driven models)	Fuzzy models Qualitative evaluation
4. Search Method	Simple EMOO (Evolutionary Multi Objective Optimization)	Knowledge enhanced, hybrid EMOO (Evolutionary Multi Objective Optimization)	Fusion of multiple search methods
5. Objectives & Constraints Complexity	Few objectives; Convex regions	High -dimensional objectives; Non-convex regions	
6. Uncertainty Management	Uncertainty measures implicity captured in objectives	Explicit externally driven uncertainty management (e.g.: fusion on multiple models)	
7. Leveraging Domain Knowledge	Customized data structures &operators in evolutionary search	Meta-heuristics to guide evolutionary search; fuzzy rule-based preference aggregation functions	Self-tuning fuzzy rule-based functions; context-dependent (Case-based) visualization config management
8. Preferences	Complete ordering (numerical, ordinal or cardinal)	Partial Ordering (Imprecise, fuzzy, linguistic, preferences assigned to objective subsets)	
9. Decision-making Requirements & Methods	Automated decisions-making via constraints and weights	Interactive graphical with human in loop	
10. Update Requirements for Solution fidelity	Implicit via update of problem descriptors in database	Explicit via periodic retraining of data-driven models, or other adaptation mechanisms	Explicit via autonomous retraining of data-driven models, or other adaptation mechanisms



According to Suganthi [30] MCDM methods can be grouped differently, according to their purpose:

- in the energy sector (assessment of sustainability of cogeneration with similar sustainability index according to Lipošćak et al. [31], 2006 and Jovanovic et al, [32]): fuzzy-set theory, ASPID method (Analysis and Synthesis Parameters under Information Deficiency) [30];
- in manufacturing organizations: fuzzy VIKOR method [30];
- in business (optimization of economic and environmental criteria) sustainability index [30];
- in urban sustainability assessment: data envelopment analysis, IFPPSI (Improved full permutation polygon synthetic indicator) [30];
- in city sustainability evaluation: fuzzy logic [30];
- in smart city models: fuzzy logic, ANP and DEMATEL methods, AHP method [30]
- renewable industry: fuzzy AHP DEA [30];
- petrochemical industries [30].

According to Suganthi [7] MCDM methods are used for certain purposes. For pairwise comparison AHP (Analytic Hierarchy Process), ANP (Analytic Network Process) and DEMATEL (Decision Making Trial and Evaluation Laboratory) methods can be used. For evaluation of alternatives ASPID (Analysis and Synthesis of

Parameters under Information), IFFPPSI, ELECTRE (Elimination et Choix Traduisant la Realité, Elimination and Choice Expressing Reality), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), VIKOR and DEA can be used.

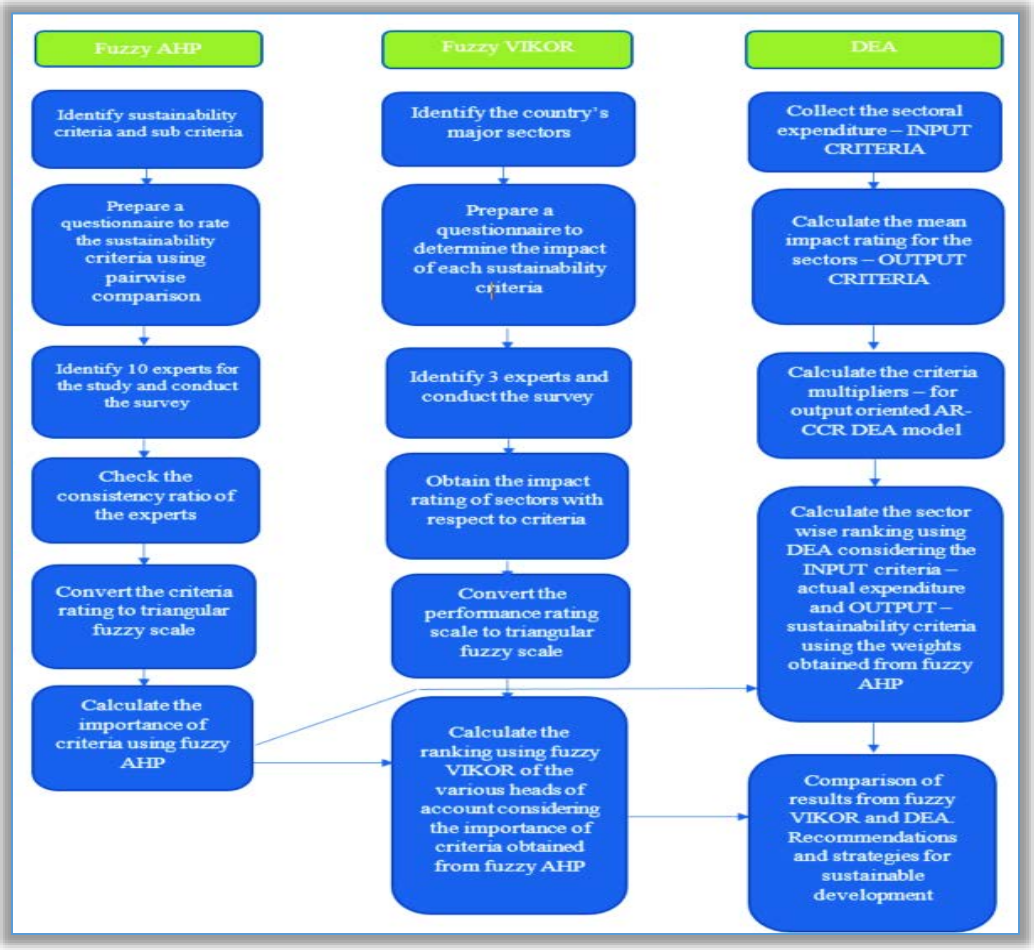


Figure 1. Comparison between MCDM methodologies [30]

4. FUZZY TOPSIS METHOD FOR FMEA

For our example description we have chosen the fuzzy TOPSIS method. This developed version of the traditional FMEA is used in several fields e.g.: supplier selection (automotive, etc.), risk assessment of construction projects, weapon selection projects and production risk analysis (described in Chapter 2).

According to Braglia et al. [33] the best solution is the nearest to the ideal solution, and the farthest from the worst (negative-ideal solution).

The fuzzy TOPSIS method starts with building a decision matrix, in which each criterion is characterized by a weight W_j. W_j is defined previously by the FMECA decision makers. (The risk factors are considered as criteria.)

$$\sum_{j=1}^{g} W_j = 1m$$

With the normalization of the judgement matrix $X=[x_{ij}]$, the elements (x_{ij}) are transformed with the following equation:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}^2}$$

Afterwards each element (rij) is weighed (with the corresponding weight W_j):

$$v_{ij} = r_{ij} W_j$$

In the following, Braglia et al. [33] assume, that A^+ represents the ideal solution, and A^- the negative one:

$$A^+ = \{(\max_i v_{ij} \mid j \in J), (\min_i v_{ij} \mid j \in J')\} = \{v_1^+, v_2^+, \dots, v_n^+\}$$

$$A^- = \{(\min_i v_{ij} \mid j \in J), (\max_i v_{ij} \mid j \in J')\} = \{v_1^-, v_2^-, \dots, v_n^-\}$$

$$J = \{j = 1,2, \dots, g \mid j \text{ associated with the benefit criteria}\}$$

$$J' = \{j = 1,2, \dots, g \mid j \text{ associated with the benefit criteria}\}$$

Calculation of the g-Euclidean distance from each alternative A^+ and A^-:

$$S_i^+ = \sqrt{\sum (v_{ij} - v_j^+)^2} \quad \text{for } i = 1,2, \dots, n$$

$$S_i^- = \sqrt{\sum (v_{ij} - v_j^+)^2} \quad \text{for } i = 1,2, \dots, n$$

The final ranking of alternatives is linked to the relative closeness:

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-}, \text{ where}$$

$$0 \le C_i^+ \le 1 \text{ and } i = 1,2, \dots, n$$

The ideal solution is considered as the shortest distance to the ideal solution. The method can be fuzzified with introducing linguistic terms to the three factors.

According to Hung and Chen [34], [35] the TOPSIS method has the following advantages:

- TOPSIS is simple and rational and has a comprehensible concept,
- TOPSIS uses an intuitive and clear logic (according to rational human choice),
- TOPSIS is easy to compute, and has good computational efficiency,
- TOPSIS uses a simple mathematical form,
- TOPSIS is possible to visualize.

5. CONSLUSIONS

In our work we have made a complex literature review of multiple criteria decision making method solutions based on Failure Mode and Effect Analysis. The wide range of fuzzified FMEA methods makes the developed FMEA method suitable for multiple purposes, from weapon selection to production process analysis. The detailed explanation of the TOPSIS application highlights that although the fuzzified methods are more complicated than the traditional FMEA, but from computing side they are easy to handle.

In our future work, we plan to make a developed fuzzy FMEA method for Lithium-ion battery standardized test analysis considering the extension of legacy fuzzy FMEA by signatures [35] and other ideas from fuzzy control [36], cognitive maps [37], and fuzzy rule interpolation methods [38].

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