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EVALUATION OF PC-FMEA USING NETWORK ANALYSIS

EDINA UNGVÁRI[1*], ISTVÁN GÁBOR GYURIKA[1]

1 Department of Mechanics, University of Pannonia, H-8200 Veszprém, Hungary

Abstract – PC-FMEA is a method that combines the pairwise comparison and basic FMEA (Failure Modes and Effects Analysis) methods. Using the pairwise comparison, which of the risks is more severe, common or noticeable can be determined. The results evaluated by the pairwise comparison can be modeled with networks, where the risks can be ranked according to the criteria using the PageRank and weighted in-degree values. Applying these two solutions together, a form of risk assessment can be created where risks are assessed by pairwise comparisons and the results analyzed using network research tools. The resulting method also provides two types of evaluations to rank the risks and also facilitates visualization. This study aimed to develop the application of PC-FMEA in network research.

Keywords: Network science, PC-FMEA, risk assessment, pairwise comparison

1. Introduction

Failure Modes and Effects Analysis (FMEA) is a method of identifying and fully understanding the potential causes as well as effects of failures on systems or end users with regard to a given product, process or project [1]. FMEA is a risk assessment method that is widely used in several fields [2], particularly in the automotive industry, to formalize a complete set of actions, thereby reducing the risk associated with a system or manufacturing and assembly process [3]. In FMEA, each failure is ranked in order of its Risk Priority Number (RPN), which is calculated by multiplying the values of the three risk factors for failure, namely severity, probability of occurrence and probability of detection before the effects of the failure are realized, moreover, is represented by numbers, generally between 1 (in the case of no or a negligible risk) and 10 (in the worst-case scenario) [4]. The new method is based on a reference table, which gives the most critical risk. The FMEA team takes into account previous FMEAs, test results of similar items, experience with comparable systems and sources of information. A subjective element of this ranking will over time arise as the FMEA always includes new parts and all sources of risk must be reexamined. However, the FMEA team should be as objective as possible by using the criteria from the scales to help determine the appropriate ranking. Therefore, the FMEA team defines the classification of the failure modes based on their experience and knowledge [5].

To eliminate subjectivity, an improved method has been developed in which the evaluation is carried out by a pairwise comparison. According to the three criteria, the risks are assessed by the pairwise comparison. The essence of the pairwise comparison can be grasped in the form of a prepared table, the output of which is the ranking of risks [6].

The results evaluated by the pairwise comparison can be further examined using the tools of network research. From the results of the pairwise comparison, a criticality network can be created in which the directed edges represent the direction of the preference and the weight of such edges can also be specified as the weight of the preference. Based on the criticality network, PageRank and weighted in-degree values can be used to determine which vertices have the most input edges that are also important or the most high-weight input edges [7]. Using the Pairwise Comparison-based FMEA (PC-FMEA) along with network research, a risk assessment method can be created where risks are evaluated by pairwise comparisons and the most severe risks extracted from the results of networks. The following section introduces this method.

2. Experimental

PC-FMEA is a method based on a pairwise comparison to improve the precision of a risk evaluation. The members of the FMEA team evaluate the risks in pairs based on a defined scale from 0-9, where 0 means equally critical and 9 means extremely critical. The scale was created from the fundamental scale of AHP (Analytic Hierarchy Process), which is a decision-making method

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*Correspondence: kulcsar.edina@mk.uni-pannon.hu

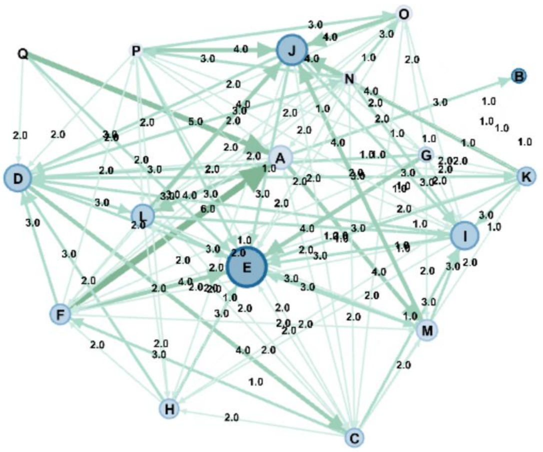

Figure 1. Individual criticality network. The sizes of the nodes show the results based on the weighted in-degree values and the colors of the nodes represent the results of the risk assessment based on the PageRank value

[6]. This scale is based on the three evaluation factors, namely severity, occurrence and detection. The second step of the method is to calculate the importance weights based on a comparison matrix [8]. The presented method offers a new method for enhancing the visual evaluation of the importance weights.

2.1. Modelling risk assessments with networks

Since the network compiled from the results of the pairwise comparison is directed, the direction of criticality is shown. The degree of this criticality can also be specified. The edges are merged with the sum of the weights. A weighted network is C = {V, E, W}, where V denotes the set of vertices, E represents the set of edges and W refers to the weights of the edges. In the network, α_{ij} denotes the connection of node i to node j and each link (i, j) has a weight w_{ij}. The weighted in-degree w_1D_j is calculated as follows [9]:

$$w_1 D_j = \sum_{(v_i, v_j) \in E} w_{ij} \qquad (1)$$

The other indicator from a network that can be easily used for the evaluation of the weights of the risks is the PageRank value. PageRank is an algorithm that defines the importance of a node in a network. The algorithm is calculated from the data to determine how many connections the vertex has and how important they are.

3. Results

The methodology combines the techniques of PC-FMEA and network research. The evaluation is carried out by a pairwise comparison, which is evaluated by network modeling. The following subsections show how the method can be applied to individual and aggregate risk assessments. In both cases, the weighted in-degree and PageRank values are used for ranking. The weighted in-degree shows how many input edges a given node has and their weights [10]. The PageRank indicator also takes into account the role of these nodes in the network [11]. To demonstrate the method, data were generated randomly.

Table 1. Scale for the occurrence evaluation

Value	Occurrence
0	Equally frequent
1	Slightly more frequent
2	Moderately more frequent
3	More frequent
4	Strongly more frequent
5	Very strongly more frequent
6	Extremely more frequent
7	Extremely more (+) frequent

3.1. Individual criticality network

Risk assessments using the FMEA methodology are in most cases carried out by a team from different professions. Evaluation within the group can be modeled individually and in aggregate with networks. The modeling of an individual evaluation is shown in *Fig.1*, where the vertices indicate the risks and the directed edges between them indicate the preferential relationship. The sizes of the nodes show the weighted in-degree results. The larger the node, the more critical the risk is in that regard. The colors of the nodes illustrate the evaluation according to the PageRank indicator. The darker the node, the more critical the risk. At the edges, weights are visible on a scale of 1 to 7. The sizes of the edges show the extent of the preference. An example scale for the pairwise comparison of the risk according to the occurrence is shown in *Table 1*.

The results of the network model are presented in *Table 2* by the weighted in-degree and PageRank indexes, moreover, are ranked according to the criticality of the risks. It can be seen that the rankings are different based on the two ratings because PageRank also takes into account the role of neighboring nodes in the network.

Each node in the network is visualized in *Fig.2* to show the connected edges with their weights.

3.2. Aggregate criticality network

Aggregate criticality networks can be used to evaluate the risk assessment results produced by an FMEA team. If the evaluation is conducted by everyone individually, the aggregate result can be modeled with networks. Preferences in this case are summarized along with their weights. The results of the aggregate criticality network are shown in *Fig.3*. The visualization of the results is the same as in the individual network.

The results of the network model are presented in *Table 3* in terms of the weighted in-degree and PageRank indexes as well as ranked according to the criticality of the risks. The results of the evaluation are not completely the same in this case either.

Table 2. Results of the individual criticality network model based on the weighted in-degree and PageRank values

ID	Weighted in-degree	ID	PageRank
E	38	B	0.124224
J	27	E	0.113282
I	24	J	0.092585
D	23	D	0.073775
A	19	I	0.072988
L	18	L	0.070678
M	16	K	0.065196
F	15	F	0.063325
H	14	C	0.058084
C	13	H	0.053769
K	13	M	0.044907
O	10	G	0.044183
G	9	A	0.040232
B	8	N	0.029640
N	7	O	0.023272
P	7	P	0.021036
Q	0	Q	0.008824

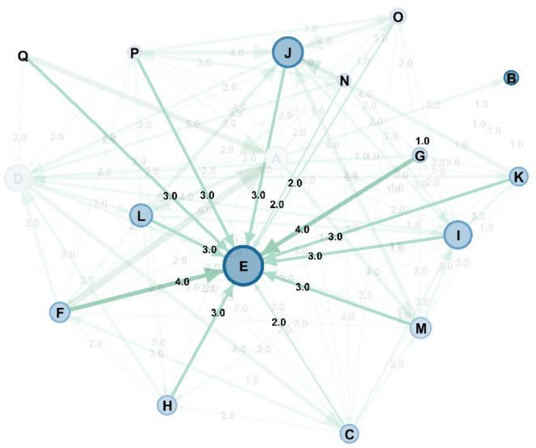

Figure 2. Visualization of the connection between a vertex in the network and the weights of the preference

Each node in the network can be visualized to show the connected edges along with their weights as presented in *Fig.4*.

The results of the modeling show that the transformation of the result concerning the pairwise comparison of a risk assessment could yield a new method of evaluation. Severity, Occurrence and Detection values can be evaluated with the weighted in-degree and PageRank values. In a traditional FMEA, the members of the team assess the risks together and try to come to a common understanding. However, the members could have different opinions and comprehend the criticality of the risks in various ways based on their fields of expertise. To eliminate subjectivity within the team, individual criticality networks can be used. An aggregated criticality network can evaluate the overall opinion of the team.

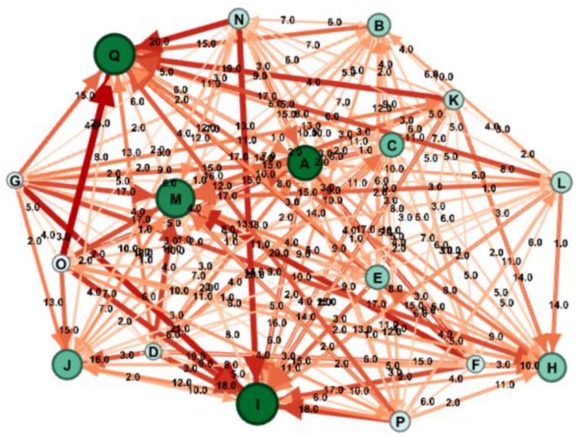

Figure 3. Aggregate criticality network. The sizes of the nodes represent the results based on the weighted in-degree value and the colors of the nodes show the results of the risk assessment based on the PageRank value

Table 3. Results of the aggregated criticality network model based on the weighted in-degree and PageRank values

ID	Weighted in-degree	ID	PageRank
I	227	A	0.111017
Q	221	I	0.111016
M	205	Q	0.106530
A	176	M	0.096950
J	141	J	0.070793
H	134	C	0.067337
C	98	H	0.058812
E	97	E	0.055613
B	90	B	0.049083
L	74	L	0.043342
N	69	K	0.040657
P	69	N	0.038440
K	65	D	0.036829
O	48	F	0.032958
F	47	P	0.030556
D	40	G	0.026501
G	36	O	0.023568

4. Conclusions

In this study, how the risks assessed by pairwise comparisons can be modeled by networks was demonstrated. The combination of PC-FMEA and the network research toolkit based on pairwise comparisons provides a new method for implementing risk assessment. Risks can be assessed individually and in aggregate based on two indicators. This modeling can be

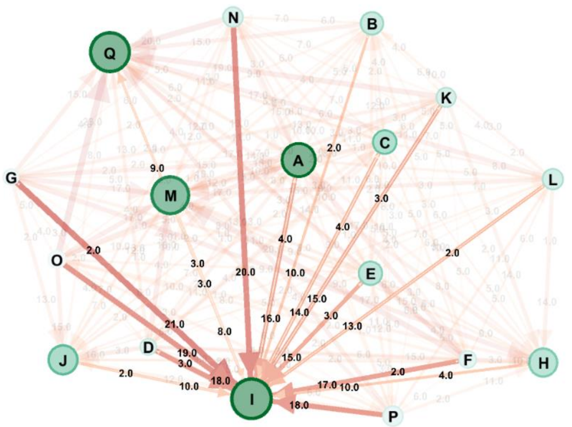

Figure 4. Visualization of the connection between a vertex in the network and the aggregated weights of the preference

applied to all three bases and additional risk factors. Of the two indicators, the FMEA team can choose which one they prefer. Evaluation is not time-consuming and the use of a pairwise comparison and network research reduces the level of subjectivity. The results are less liable to manipulation by participants than in the traditional FMEA, where assessment is added individually to the risks. The results do not match the scales used by the FMEA. Deriving results from scales could be another research direction. Another advantage of this method is that it visualizes the relationship between the risks, which can greatly support their presentation.

REFERENCES

[1] Stamatis, D.H.: Failure mode and effect analysis: FMEA from theory to execution (ASQ Quality Press), 2003, ISBN: 9780873893008

[2] Sharma, K.D.; Srivastava, S.K.: Failure mode and effect analysis (FMEA) implementation: A literature review, *J. Adv. Res. Aeronaut. Space Sci.*, 2018, **5**(1-2), 1–17, ISSN: 2454-8669

[3] Ambekar, S.B.; Edlabadkar, A.; Shrouty, V.: A review: implementation of failure mode and effect analysis, *Int. J. Eng. Innov. Technol.*, 2013, **2**(8), 37–41, ISSN: 2277-3754

[4] Spreafico, C.; Russo, D.; Rizzi, C.: A state-of-the-art review of FMEA/FMECA including patents, *Comput., Sci. Rev.*, 2017, **25**, 19–28, DOI: 10.1016/j.cosrev.2017.05.002

[5] Banghart, M.; Babski-Reeves, K.; Bian, L.; Strawderman, L.: Subjectivity in failure mode effects analysis (FMEA) severity classification within a reliability centered maintenance (RCM) context, *Int. J. Aviat. Aeronaut. Aerosp.*, 2018, **5**(1), 2, DOI: 10.15394/ijaaa.2018.1191

[6] Kulcsár, E.; Csiszér, T.; Abonyi, J.: Pairwise comparison based failure mode and effects analysis (FMEA), *Methodsx*, 2020, **7**, 101007, DOI: 10.1016/j.mex.2020.101007

[7] Kulcsár, E; Gyurika, I.G.; Csiszér, T.: Application of network science to extend the AHP and QFD methods, *Proc. 6th World Congress Mech. Chem. Mat. Eng.*, 2020, DOI: 10.11159/icmie20.137

[8] Sebestyén, V.; Somogyi, V.; Szőke, S.; Utasi, A.: Adapting the SDEWES index to two Hungarian cities, *Hung. J. Ind. Chem.*, 2017, **45**(1), 49–59, DOI: 10.1515/hjic-2017-0008

[9] Kulcsár, E.; Gyurika, I.G.; Csiszér, T.: Network-based – quality function deployment (NB-QFD): The combination of traditional QFD with network science approach and techniques, *Comput. Ind.*, 2022, **136**, 103592, DOI: 10.1016/j.compind.2021.103592

[10] Barabási, A.L.: Network science, (Cambridge University Press), 2016, ISBN: 9781107076266

[11] Abbas, M.; Inayat, I.; Jan, N.; Saadatmand, M.; Enoiu, E.P.; Sundmark, D.: MBRP: Model-based requirements prioritization using PageRank algorithm, *26th Asia-Pacific Software Engineering Conference, Putrajaya, Malaysia*, (IEEE), 2019, pp. 31–38, DOI: 10.1109/APSEC48747.2019.00014