ANALYSIS

Vol. 15, January, 2018

ISSN 2319–7757
EISSN 2319–7765

Indian Journal of Engineering

Risk assessment of a tyre manufacturing industry plant: A comparative study of grey relational analysis and PROMETHEE approaches

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Article History
Received: 30 November 2017
Accepted: 06 January 2018
Published: January 2018

Citation

Emovon I. Risk assessment of a tyre manufacturing industry plant: A comparative study of grey relational analysis and PROMETHEE approaches. *Indian Journal of Engineering*, 2018, 15, 9-18

ABSTRACT

The key to sustainable growth in the tyre manufacturing industry is the reliable operation of tyre manufacturing plant equipment at minimum cost and these cannot only be attained through implementation of a sound maintenance management system. It means all the elements of the maintenance system must be optimised. One of such element is risk assessment which is generally performed with Failure Mode and Effect Analysis (FMEA). As result, different Multi-Criteria Decision Making (MCDM) enhanced FMEA have been developed and implemented. However, the purpose of this paper is to investigate the effectiveness of the implementation of two

MCDM tools; Grey Relational Analysis (GRA) and PROMETHEE methods,in order to determine the most suitable approach for analysing risk of failure of a tyre manufacturing plant. The comparative analysis was demonstrated with a case study of the boiler of a tyre manufacturing plant. The result of the analysis indicated that, GRA approach is a more suitable technique for risk assessment.

Keywords: Risk assessment, FMEA, GRA, PROMETHEE, tyre manufacturing, decision criteria

1. INTRODUCTION

The tyre manufacturing industry was established to produce inner tubes, pneumatic casings and cushion tyres for diverse vehicle type, farm equipment and airplane (Bradley 2000). The services that these mobility assets rendered will not have been possible without tyres and as such the importance of tyre in everyday human activities cannot be over-emphasized. In order to make the tyre manufacturing industry viable and sustainable there is the need for constant reliability and safety of the equipment used for manufacturing tyres and this can only be achieved through effective maintenance.

However, one of the key components of the maintenance management system is risk assessment because the maintenance policy suitable for maintenance of tyre manufacturing equipment depends largely on the level of risk of the equipment.Failure Mode and Effect Analysis (FMEA) is one of the commonly used approach for the assessment of risk of most manufacturing plant. The FMEA utilises Risk Priority Number (RPN) in estimating risk of failure and it is a product of the Occurrence of failure (O), the Severity of the failure (S) and Detectability of the failure (D). In most scenarios, experts assigned ratings to O, S and D using a pre-determined scale and an example can be found in the work of (Emovon et al. 2015).

Nevertheless, despite the popularity of the FMEA it has limitations which had hampered the efficiency in analysing risk of tyre manufacturing plant. To overcome these limitations, different MCDMtools have been integrated with the FMEA in order for it, to analysed risk more effectively.These have been the major concern of majority of researchers in the literature.Examples,Maheswaran and Loganathan, (2013) proposed the use of PROMETHEE method in enhancing FMEA for better risk analysis using a case study of boiler of a tyre manufacturing plant. Özveri and Kabak (2015) also utilised the PROMETHEE method in analysing risk of failure modes.

The GRA method is another popular MCDM tool and has been applied successfully to analysed different multi-criteria decision problem. Athawale and Chakraborty (2011) used GRA to analysed supplier selection problem in a manufacturing establishment. Ertugrul et al. (2016) applied the technique to compare performance of Turkish universities.

In this paper a comparative analysis of the use of GRA and PROMETHEE in prioritising risk, is executed in order to determine the most suitable approach for analysing failure modes risk in a tyre manufacturing industry and other engineering firms.

2. METHODOLOGY

2.1. GREY RELATIONAL ANALYSIS Method

The development of the Grey theory can be traced to Julong Deng (1982) and the technique was developed with the intention of making multi-criteria decision in a scenario of incomplete data.The GRA utilises relational grade which indicates the degree of proximity of a compared sequences with a reference sequence (Wei and Zhang 2011).The approach have been utilised in the literature to solve multi-criteria problem. (Wei and Zhang, P., 2011) applied the technique to study the impact of criteria such as dosage of cement and ratio of sand on the durability of high performance concrete. Hasani et al. (2012) used GRA to ascertain the best process parameters for spinning yarns.

The steps of the GRA are as follows (Kuoet al.2008):

Step 1. Establishment of decision problem: A decision problem example is illustrated in Table 1, which has m number of alternatives and n number of decision criteria.

Step 2. Grey relational generating: The unit of performance measurement of different decision criteria are not always the same and if the analysis is carried using different unit, incorrect results will be generated. To avoid such scenario,the decision problem in Table 1 are normalised. In GRA method, the process is refer to as grey relational generating. The technique utilised depends on whether the decision criteria is beneficial, non-beneficial and in-between.For beneficial and non-beneficial criteria grey relational generating is carried out using Eq. 1-2 respectively as follows:

$$R_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \; ; \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \qquad (1)$$

$$R_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \; ; \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \qquad (2)$$

Step 3. Evaluation of GRA coefficient

$$Y_{ij} = \frac{\min \Delta_{ij} + \delta(\max \Delta_{ij})}{\Delta_{ij} + \delta(\max \Delta_{ij})} \; ; \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \qquad (3)$$

$$\Delta_{ij} = \left| R_{oj} - R_{ij} \right| \qquad (4)$$

The distinguishing coefficient δ is set between 0 and 1. However, the value of 0.5 is commonly used in literature. Roj is the reference sequences for each decision criteria and is generally the best performance achievable among compared sequences. Δij is the deviation of the compared sequences from the reference sequence.

Step 4. Evaluation of GRA grade: The GRA grade is evaluated as follows:

$$G_i = \sum_{j=1}^{n} w_j \, . \, Y_{ij} \qquad (5)$$

Wj is the weight of jth criterion and one of the approach for evaluating it, is the Analytic Hierarchy Process (AHP).

The alternative with the highest value of GRA grade is taken as the optimum solution.

2.2. PROMETHEE Method

PROMETHEE is an abbreviation for Preference Ranking Organisation Method for Enrichment Evaluations. The technique was initially proposed by Brans in 1982 (Brans, 1986) and was extended by Brans and Vincke (Brans and Vincke, 1985). The method is an outranking technique utilised for resolving decision problem involving more than one criteria. PROMETHEE II is one of the seven versions of PROMETHEE method (Behzadian et al., 2010)and it is the most commonly used version.The approach have been implemented in solving diverse multiple criteria problem. Emovon (2016) applied the method to select the optimum inspection interval for mechanical/service system. Tomic et al. (2013) used PROMETHEE to analysed optimum pneumatic for dumper mine machine.

The basic steps involves in the PROMETHEE method are:

Step 1. Determination of the decision matrix:An example of the decision matrix is illustrated in Table 1.

Step 2. Definition of preference function: Alternatives *g* and hare compared for each criterion with regard to preference function, a scenario which convert the variance between the alternatives into [0, 1]. Alternative *g*preference over *h* for each criterion is evaluated as:

$$P_j(g, h) = F_j\{f_j(g) - f_j(h)\} \qquad (6)$$

Where F_j is a function of the deviation of alternative *g* from *h*. Six preference function types are generally applicable and can be found in the work of (Figueira et al., 2005).

Step 3. Evaluation of complete preference index,$\pi(g,h)$, of *g* over *h*: The complete preference index is evaluated as follows:

$$\pi(g,h) = \sum_{j=1}^{n} w_j P_j(g,h) \tag{7}$$

Where wj is the weights of decision criteria and one of the technique for determining weights is AHP.

Step 4. The alternative net flow determination: The net flow,, is the difference between the positive flow,$\emptyset^+$, and the negative flow,$\emptyset^-$,and is calculated as follows:

$$\phi = \emptyset^+ - \emptyset^- \tag{8}$$

Where

$$\emptyset^+ = \frac{1}{m-1}\sum_{h\neq g} \pi\,(g,h) \tag{9}$$

$$\emptyset^- = \frac{1}{m-1}\sum_{h\neq g} \pi\,(h,g) \tag{10}$$

The best alternative is the one with the highest value of net flow.

3. CASE STUDY

In order to carry out the comparative analysis of the GRA and PROMETHEE methods, a case study of boiler of a tyre manufacturing plant was taken from the work of Maheswaran and Loganathan (2013).Ten failure modes were identified by the authors with the aid of "What –if analysis" technique. The ten failure modes were rated based on four criteria; Occurrence (O),Severity(S), Detection (D) and Protection (P) by multiple experts and the average ratings are presented in Table 2.

3.1. Grey Relational Analysis

After the formation of the decision problem, the next step is the grey relational generating process and the aim is to transform the data in the decision matrix in Table 1 into compared sequences. The O and S are taken as non-beneficial criteria while the D and P is taken as beneficial criteria. Eq. 2 is therefore applied to transform O and S while Eq. 1is used to transform D and P into compared sequences. The results are indicated in Table 3.This is followed by the determination of the grey relational coefficient using Eq. 3. However, prior to this, the deviation of compared sequences from the reference sequence are evaluated using Eq. 4. For example:

$$\Delta_{11} = |1-0| = 1,$$

The detail results together with themax Δii and min Δij values are shown in Table 4. The application of Eq. 3 is demonstrated with failure mode 1, criterion O (Y_{11}) as follows:

$$\max\Delta_{i1} = 1, \min\Delta_{i1} = 0\,, \Delta_{11} = 1, \delta = 0.5 \text{ then} Y_{11} = \frac{0+0.5(1)}{1+0.5(1)} = 0.3333$$

The results obtained for all the failure modes are shown in Table 5

Applying Eq. 5 on the grey relational coefficient values in Table 5 and the weights of the decision criteria also in Table 5, grey relational grade for each failure mode were obtained and the result are shown in Figure 1. Based on the grey relational grades, failure modes were ranked and the ranking order is also indicated in Figure 1.

From Figure 1, F2 having the highest grey relational grade is the most critical failure mode of the boiler while the least critical is F5 having the lowest grey relational grade.

The effect of the distinguishing coefficient on the grey grade and rank of failure modes was investigated and the results are shown in Table 6 and Figure 2.

From Table 6 and Figure 2, it is glaring that for the different value of distinguishing coefficient ranging from 0.1 to 1, the ranking order of the failure modes almost completely remain unchanged. For example, the most critical and least critical failure mode; F2 and F5 remain unaffected in rank for all values of distinguishing coefficient.

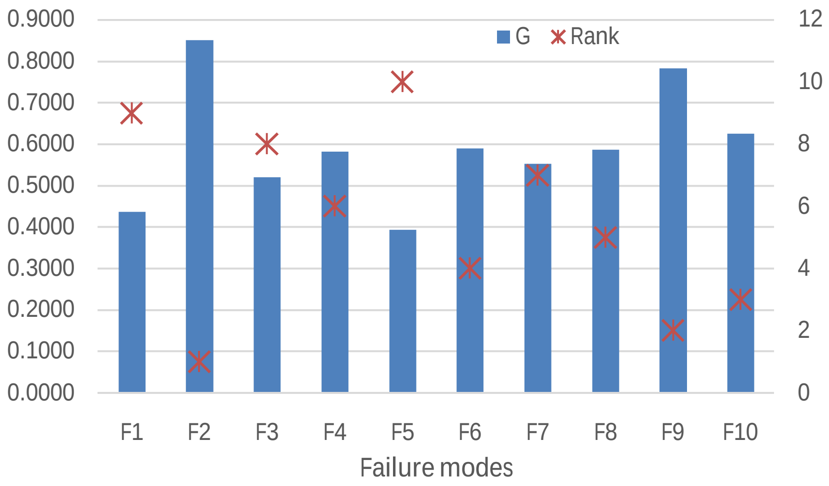

Figure 1 Failure modes grey relational grades and rank

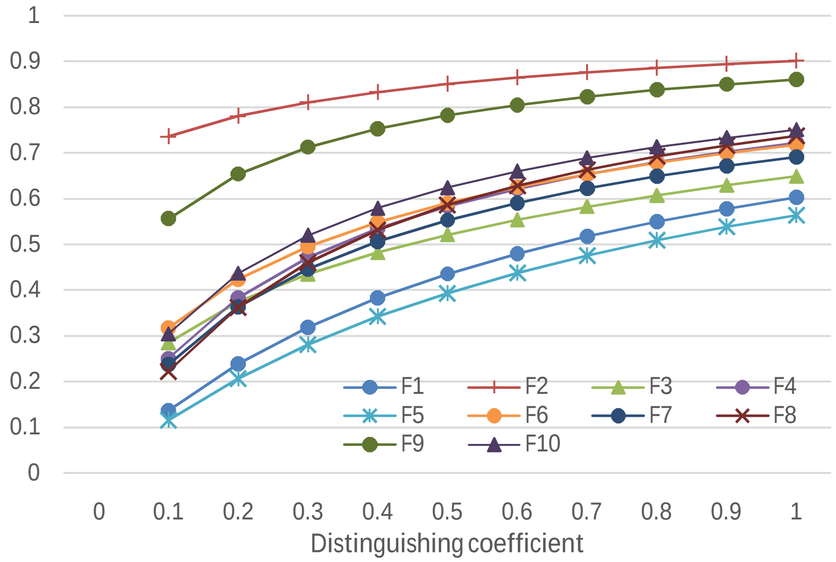

Figure 2 Effect of distinguishing coefficient on grey relational grade of failure modes

Table 1 Decision matrix

Alternatives (Fi)	Decision criteria (Cj)					
	C1	C2	C3	-	-	Cn
F_1	x_{11}	x_{12}	x_{13}	-	-	x_{1n}
F_2	x_{21}	x_{22}	x_{23}	-	-	x_{2n}
F_3	x_{31}	x_{32}	x_{33}	-	-	x_{3n}
-	-	-	-	-	-	-
-	-	-	-	-	-	-
F_m	x_{m1}	x_{m2}	x_{m3}	-	-	x_{mn}

Where xij is the rating of alternative i with regard to criterion j

Table 2 Decision matrix (Maheswaran and Loganathan, 2013)

S/N	Failure modes	O	S	D	P
F1	Induced Draft fan get tripped	7.4	7.0	4.2	3.4
F2	Feed water pump get failed	4.4	5.8	7.4	7.8
F3	Safety valve fail to act	1.8	8.2	1.4	3.8
F4	Nozzle failure at the fuel supply system	5.4	6.2	2.2	3.4
F5	Low temperature of the furnace oil	5.8	7.8	4.6	3.0
F6	Safety door fail to act	1.8	7.0	1.4	1.8
F7	Electrode rod failure at the ignition system	6.6	6.2	2.2	1.8
F8	Failure of water level controller	3.6	6.6	3.4	5.8
F9	Failure of water pipe gets ruptured	1.6	6.2	7.8	2.6
F10	Failure occurs in the steam separator	2.0	6.6	1.8	1.8

Table 3 Compared sequences and reference sequence

Failure modes	O	S	D	P
F1	0.0000	0.5000	0.4375	0.2667
F2	0.5172	**1.0000**	0.9375	**1.0000**
F3	0.9655	0.0000	0.0000	0.3333
F4	0.3448	0.8333	0.1250	0.2667
F5	0.2759	0.1667	0.5000	0.2000
F6	0.9655	0.5000	0.0000	0.0000
F7	0.1379	0.8333	0.1250	0.0000
F8	0.6552	0.6667	0.3125	0.6667
F9	**1.0000**	0.8333	**1.0000**	0.1333
F10	0.9310	0.6667	0.0625	0.0000
Reference sequence	1	1	1	1

Table 4 Deviation of the compared sequences from the reference sequence (Δij)

Failure modes	O	S	D	P
F1	1.0000	0.5000	0.5625	0.7333
F2	0.4828	0.0000	0.0625	0.0000
F3	0.0345	1.0000	1.0000	0.6667
F4	0.6552	0.1667	0.8750	0.7333
F5	0.7241	0.8333	0.5000	0.8000
F6	0.0345	0.5000	1.0000	1.0000
F7	0.8621	0.1667	0.8750	1.0000
F8	0.3448	0.3333	0.6875	0.3333
F9	0.0000	0.1667	0.0000	0.8667
F10	0.0690	0.3333	0.9375	1.0000
Max Δij	1	1	1	1
Min Δij	0	0	0	0

Table 5 Grey relational coefficient

Failure modes	O	S	D	P
F1	0.3333	0.6667	0.6400	0.5769
F2	0.6744	1.0000	0.9412	1.0000
F3	0.9667	0.5000	0.5000	0.6000
F4	0.6042	0.8571	0.5333	0.5769
F5	0.5800	0.5455	0.6667	0.5556
F6	0.9667	0.6667	0.5000	0.5000
F7	0.5370	0.8571	0.5333	0.5000
F8	0.7436	0.7500	0.5926	0.7500
F9	1.0000	0.8571	1.0000	0.5357
F10	0.9355	0.7500	0.5161	0.5000
Criteria weights	0.2884	0.4996	0.0655	0.1465

The weight of decision was taken from (Maheswaran and Loganathan, 2013)

Table 6 Effect of distinguishing coefficient on grey relational grade and rank of failure modes

Failure mode		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	G	0.1370	0.2394	0.3192	0.3834	0.4361	0.4804	0.5180	0.5505	0.5788	0.6037
F1	Rank	9	9	9	9	9	9	9	9	9	9

F2	G	0.7359	0.7805	0.8108	0.8334	0.8511	0.8652	0.8769	0.8867	0.8951	0.9022
	Rank	1	1	1	1	1	1	1	1	1	1
F3	G	0.2849	0.3740	0.4345	0.4819	0.5209	0.5540	0.5826	0.6075	0.6296	0.6492
	Rank	5	6	8	8	8	8	8	8	8	8
F4	G	0.2498	0.3835	0.4710	0.5342	0.5827	0.6214	0.6532	0.6797	0.7024	0.7219
	Rank	6	5	5	5	6	6	6	5	5	5
F5	G	0.1157	0.2071	0.2812	0.3426	0.3942	0.4383	0.4764	0.5096	0.5389	0.5648
	Rank	10	10	10	10	10	10	10	10	10	10
F6	G	0.3170	0.4241	0.4949	0.5481	0.5903	0.6247	0.6536	0.6782	0.6994	0.7179
	Rank	3	4	4	4	4	5	5	6	6	6
F7	G	0.2374	0.3634	0.4462	0.5065	0.5532	0.5909	0.6222	0.6487	0.6714	0.6913
	Rank	7	7	7	7	7	7	7	7	7	7
F8	G	0.2223	0.3629	0.4601	0.5314	0.5859	0.6290	0.6639	0.6928	0.7171	0.7378
	Rank	8	8	6	6	5	4	4	4	4	4
F9	G	0.5564	0.6539	0.7127	0.7528	0.7822	0.8048	0.8229	0.8377	0.8501	0.8606
	Rank	2	2	2	2	2	2	2	2	2	2
F10	G	0.3056	0.4377	0.5208	0.5799	0.6248	0.6603	0.6893	0.7134	0.7339	0.7516
	Rank	4	3	3	3	3	3	3	3	3	3

Table 7 Failure mode net flow and rank

Failure modes	Net flow	Rank
F1	-0.2381	9
F2	0.3613	1
F3	-0.2274	8
F4	0.0346	5
F5	-0.3408	10
F6	-0.0039	6
F7	-0.0750	7
F8	0.1203	3
F9	0.2868	2
F10	0.0821	4

3.2. PROMETHEE Method Analysis

The use of PROMETHEE for the analysis of the failure modes of the boiler have been carried out by Maheswaran and Loganathan (2013) and the results are shown in Table 7. From Table 7, F2 is the most critical failure mode having the highest value of net flow while the least critical is F5 having the lowest net flow value.

3.3. Comparison of Grey Relational Analysis and PROMETHEE Methods

The ranking of failure modes obtained using GRA and PROMETHEE methods are compared with that of Emovon et al., (2015) Compromise Programming (CP) in order to determine the performance of GRA and PROMETHEE methods. The comparative results are shown in Figure 3.

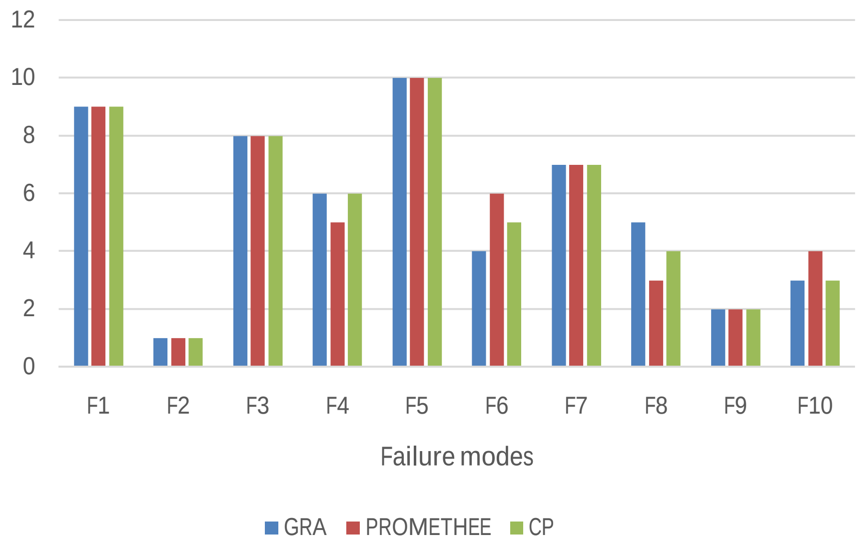

Figure 3 Comparison of methods

From Figure 3, GRA and PROMETHEE methods produced similar ranking order of failure modes with F1, F2, F3, F5, F7 and F9 having the same rank while the remaining failure modes having a rank difference of either one or two in between them.To establish the technique that perform more effectively, the two methods are compared with the CP method. From Figure 3, GRA and CP produces same ranking for seven among the ten failure modes with only three failure modes having a rank difference of one in between. However, PROMETHEE and CP have same ranking for six failure modes out of the ten failure modes.Furthermore, the best rank first three failure mode are the same for GRA and CP methods while only the best rank first two failure modes are the same for PROMETHEE and CP. From the comparative analysis, it is evident that GRA method is a more effective tool than the PROMETHEE in the ranking of failure modes of a tyre manufacturing plant equipment.

Apart from being less effective, the PROMETHEE method analytical process is more complex than the GRA method because of the following reasons: (1) difficulty of determining the most appropriate preference function for each of the decision criteria in the PROMETHEE method (2) the PROMETHEE technique involves more analytical steps than the GRA method.

Based on this comparative analysis, the GRA method is recommended for use in analysing risk of failure mode of tyre manufacturing plant.

4. CONCLUSION

This paper presented a comparative study of two MCDM methods; GRA and PROMETHEE, in order to establish which of the two techniques is more effective for analysing risk of failure modes of a tyre manufacturing plant. To demonstrate the effectiveness of the two methods, a case study of a boiler of a tyre manufacturing plant was applied. The data was analysed in this paper with the GRA method and compared with the result of PROMETHEE obtained by (Maheswaran and Loganathan, 2013). The comparative analysis revealed that both techniques produces similar results with six out of the ten failure mode having the same rank. To determine the most effective tool for analysing risk of failure, the GRA and PROMETHEE were compared with the CP method. The analysis revealed that, GRA and CP produced same ranking for 70 % of the total failure modes with only 30% failure modes having a rank difference of one in between them. However, PROMETHEE and CP produced same ranking for 60% of the entire failure modes. Furthermore, the best rank first three failure mode are the same for GRA and CP methods while only the best first two failure modes are the same for PROMETHEE and CP. The comparative analysis showed that the GRA method is a more effective tool than the PROMETHEE for the ranking of failure modes of a tyre manufacturing plant equipment. Furthermore, the GRA method is recommended because ofits effectiveness and simplicity with regard to analysis and implementation.

DISCLOSURE STATEMENT

There is no special financial support for this research work from the funding agency.

AKNOWLEDGMENT

The author wish to express his gratefulness to the Federal University of Petroleum Resources, Effurun, Nigeria for providing a serene atmosphere for conducting the research.

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