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Comparative Study of the use of Arithmetic Mean and Geometric Mean for Data Aggregation in FMEA Analysis

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Abstract: Failure Mode and Effects Analysis (FMEA) is a commonly use approach for ranking risk of failure modes of most marine machinery system. However, the Risk Priority Number (RPN) use for evaluating risk within FMEA framework have several limitations and as such most researchers focus had been in the area of improvement of the tool without considering the effect of the aggregated data from multiple experts use as input into the decision making process. The purpose of this paper therefore, is to perform a comparative analysis of the aggregation techniques for combining multiple experts' ratings of failure modes in order to establish their degree of similarity and their effect on the output of the ranking tools. The commonly used aggregation techniques in the literature considered are; Arithmetic Mean (AM) and Geometric Mean (GM). The index for comparison of the AM and GM was based on the effect of their respective aggregated data on the rank produced by four well known ranking tools; RPN of FMEA, Compromise Programming (CP), Vlsekriterijumska Optimizacija Ikompromisno Resenje, meaning: Multicriteria Optimization and Compromise Solution (VIKOR), Weighted Sum Model (WSM) and Weighted Product Model (WPM). A case study of fuel oil system of marine diesel engine of ship system was utilised to demonstrate the effectiveness of the two techniques.

Keyword: Arithmetic Mean, Geometric Mean, Failure modes, Aggregation techniques, MCDM, FMEA

1. Introduction

One of the major element of any maintenance system is risk assessment, this is because generally the maintenance strategy that need to be implemented for plant system maintenance will depend on it degree of risk. Failure Mode and Effect Analysis (FMEA) is popular technique for evaluating risk of failure modes of most industrial system. FMEA fundamentally carried out three functions. These are (Ben-Daya 2009): (1) to identify potential failures together with their causes and effects, (2) to estimate and rank identified failure modes and (3) to recommend actions to either mitigate or probably eliminate the chance of the potential failures from occurring. FMEA utilises RPN in estimating risk of failure and RPN is a product of three decision criteria; Occurrence of failure (O), Severity of the failure (S) and Detectability of the failure (D).

The application of the technique in evaluating risk have been reported in literature. Souza and Alvares (2008) proposed FMEA in conjunction with Fault Tree Analysis (FTA) as a risk assessment tool for application within the framework of Reliability Centred Maintenance (RCM). Cicek and Celik (2013) applied the FMEA in prioritising risk of crankcase failures of ship main engine. Cicek et al., (2010) used the approach to estimate risk of fuel oil system of marine diesel engine. Sankar and Prabhu (2000) applied FMEA to prioritise risk of failure of a cooling sub-system in an off-shore plant.

However, the conventional FMEA had been criticised in the literature to have several limitations such as the inability to utilise more than three decision criteria in determining risk. On the basis of the limitations different enhanced FMEA approaches were developed and reported in the literature. For example, the Multi-Criteria Decision Making (MCDM) tool such as COPRAS, VOKOR and WSM had been applied in enhancing FMEA in the literature. Vahdani, (2015) utilised TOPSIS in enhancing FMEA for effective ranking of failure modes. Emovon et al., (2015) proposed the use of VIKOR technique for prioritising risk of failure modes of marine machinery system. In a similar research, Emovon (2016) applied integrated Dempster Shafer Theory and ELECTRE method for estimating risk of various equipment items of a marine diesel engine. Braglia, (2000) utilised AHP methodology in prioritising risk of failure modes. Sachdeva et al. (2009) used an integrated Shannon's entropy and TOPSIS techniques for risk assessment of a digester of a paper manufacturing plant in India. Zhao et al., (2017) proposed the use of MULTIMOORA combined with entropy for the ranking of failure modes.

Researchers have been much concerned about continuous improvement of ranking tools for effective risk prioritisation without considering the effectiveness of tools applied for aggregating data used as input into the ranking tools. There are basically two aggregating techniques commonly applied for aggregating failure modes ratings obtained from multiple experts. They are; Arithmetic Mean (AM) and Geometric Mean (GM) techniques. In this paper a comparative analysis of the aforementioned methods is carried out in order to establish how they compare and their effects on the output of the ranking tools.

2. Methodology

2.1 Experts ratings aggregation methods

Averaging is the most frequently applied technique for combining inputs and it is regularly use in statistical analysis, multi-criteria decision making among others (Beliakov et al., 2016). In this paper, two most commonly used averaging function are considered for the aggregation of group experts ratings of failure modes (alternatives) in a group multi-criteria decision making process. They are; Arithmetic Mean (AM) and Geometric Mean (GM).

The ratings assigned by multiple experts which are tagged for aggregation are usually represented in the form of a decision matrix. The decision matrix formed as a result of z experts' ratings of failure modes i with respect to criteria j is expressed as:

$$P_{ij}^{k} = \left(p_{ij}^{k}\right)_{m,n}, \quad k = 1,2,\ldots,z \;\; i = 1,2,\ldots,m; \;\; j = 1,2,\ldots,n \qquad (1)$$

2.1.1 Arithmetic Mean (AM)

AM of the ratings assigned to alternative i based on certain criteria j by z number of experts can be expressed as:

$$x_{ij} = \frac{1}{z}\sum_{k=1}^{z} p_{ij}^{k} \qquad (2)$$

2.1. 2 Geometric Mean (GM)

GM of the assigned ratings to alternative i with respect to criteria j by z number of experts can be expressed as follows:

$$x_{ij} = \prod_{k=1}^{z} p_{ij}^{k} \qquad (3)$$

2.2 Ranking tools

2.2.1 FMEA

CEIEN 60812 Standard (2006) define FMEA as a methodology for industrial system analysis in order to identify potential failure modes and their corresponding effects on the performance of the system. FMEA uses RPN to estimate the risk contribution of each failure modes to the system and it is expressed as a product of probability of failure Occurrence (O), Severity of failure (S) and Detection of failure probability (D)

$$RPN = O \times S \times D \qquad (4)$$

The ratings to O, S and D are commonly assigned by experts based on their judgement using a pre-determined scale. See an example in the work of Cicek and Celik (2013).

2.2.2 MCDM method

The most regularly used method for making decision involving more than one criteria is the Multi-Criteria Decision Making (MCDM) tool. There are many variant of the MCDM which include among others; VIKOR, TOPSIS, CP, WSM and WPS. The different types of MCDM tools have been applied in the literature in the modelling and solving diverse multi-criteria problems in various fields of human endeavour. In this paper; CP, VIKOR, WSM and WPM are applied as alternative to RPN of the FMEA in prioritising risk of failure modes.

2.2.2.1 Compromise Programming (CP)

In the year 1973 the CP method was proposed by Po-lung Yu and Milan Zeleny (Zeleny, 1982). The approach has since by applied in the literature in addressing different multi-criteria decision problem. The aim is to obtain a solution that is closest to the 'ideal' solution. This can be achieve by comparing distances of different alternatives at various points to a particular reference point refer to as the ideal point. The alternative with the shortest distance to the reference point is the optimal solution. Diaz-Balteiro et al. (2011) proposed the use of CP technique for the ranking of seventeen European countries based on the sustainability of their paper industries. Amiri et al., (2011) used the approach for selection of portfolio based on 35 stock indices of Iranian stock market. Phua and Minowa (2005) applied the technique for forest conservation planning.

The steps involved in the CP analysis are as follows:

Step 1. The best and worst values evaluation for each criterion.

The best and worst values for each criterion are evaluated as follows:

$$x_{ij}^{+} = \max_{i} x_{ij}, \quad x_{ij}^{-} = \min_{i} x_{ij} \qquad (5)$$

Where

x_{ij}^{+} is the best value for jth criterion, and

x_{ij}^{-} is the worst value for the jth criterion.

Step 2. Evaluation of the performance index c_{pi}

The performance index is evaluated using the best and worst values as follows:

$$c_{pi} = \left[\sum_{j}^{n} w_j^p \left| \frac{x_{ij}^{+} - x_{ij}}{x_{ij}^{+} - x_{ij}^{-}} \right|^p \right]^{\frac{1}{p}} \qquad (6)$$

Subject to $1 \leq p \leq \infty$

In this paper, the value of p was denoted as 2 because this is the value generally applied in the literature (Phua and Minowa, 2005; Zeleny, 1982).

The alternatives are ranked based on the performance index and the smaller the value the better the alternative.

2.2.2.2 VIKOR method

The VIKOR technique is an MCDM tool which select a compromise solution using an index based on a measure of closeness to the positive ideal solution (Opricovic and Tzeng, 2004). The alternatives with the highest and lowest values with regard to risk criteria are the positive and negative ideal solutions respectively (Chu et al., 2007) while the optimum or compromise solution is the alternative farthest to the negative ideal solution. The application of the VIKOR technique in addressing different multi-criteria decision problems have been reported in the literature. Pamucar et al., (2017) applied the method to select the best location of a logistical center. Hsu et al., (2012) used the approach in the selection of vendors. Anojkumar et al., (2014) applied the technique in material selection problem.

The steps in the VIKOR analysis are as follows (Çalişkan et al., 2013):

Step 1. Determination of the utility measure and regret measure.

The best and worst values, determined using Equation 4 are applied as input data to determine utility and regret measures as follows:

$$t_i = \sum_{j=1}^{n} w_j (x_{ij}^{+} - x_{ij}) / (x_{ij}^{+} - x_{ij}^{-}) \qquad (7)$$

$$y_i = \max_{j} \text{ of } \left[w_j (x_{ij}^{+} - x_{ij}) / (x_{ij}^{+} - x_{ij}^{-}) \right] \qquad (8)$$

Where

w_j is the weight of jth criterion s

t_i is the utility measure

y_i is the regret measure

Step 2. Evaluation of the performance index Q_i,

The performance index is expressed as:

$$Q_i = v(t_i - t^+)/(t^- - t^+) + (1-v)(y_i - y^+)/(y^- - y^+) \quad (9)$$

$$t^+ = \max_i[(t_i), \quad i = 1,2,\dots,m]$$

$$t^- = \min_i[(t_i), \quad i = 1,2,\dots,m]$$

$$y^+ = \max_i[(y_i), \quad i = 1,2,\dots,m]$$

$$y^- = \min_i[(y_i), \quad i = 1,2,\dots,m]$$

Where v can be any value from 0 to 1 and is generally set at 0.5 (Çalişkan et al., 2013). The ranking of the alternative is based on the performance index and the smaller the value the better the alternative.

2.2.2.3 Weighted Sum Model (WSM)

The WSM is the simplest form of MCDM technique and it utilises a linear relationship in the decision making process (Zardari et al., 2015). The approach have been applied in the literature in addressing various decision problem involving conflicting decision criteria. For example, Triantaphyllou and Mann, (1989) demonstrate the effectiveness of the approach using a numerical example.

The steps involves in the WSM analysis are (Chakraborty and Zavadskas, 2014):

Step 1: Normalisation of decision

The normalisation method depend on the type of criteria which is either beneficial or non-beneficial. The normalisation of the beneficial criteria is carried out using the following expression:

$$z_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \quad j = 1,2,\dots,n, \quad i = 1,2,\dots,m \quad (10)$$

While the non-beneficial criteria normalisation is performed as follows:

$$z_{ij} = \frac{x_{ij}}{\min_i x_{ij}}, \quad j = 1,2,\dots,n, \quad i = 1,2,\dots,m \quad (11)$$

Step 2: Performance index evaluation

The performance index of alternative ith using WSM is evaluated as follows:

$$sQ_i = \sum_{j=1}^{n} z_{ij} w_j \quad (12)$$

The alternatives are ranked based on the evaluated performance index and the higher the value the better the alternative.

2.2.2.4 Weighted Product Model (WPM)

The WPM is a modified WSM designed in a way to avoid some of its limitations (Triantaphyllou and Mann, 1989).

The WPM begin with normalisation of the decision matrix using either Equations 9 or 10. The performance of alternative ith is then evaluated as follows (Chakraborty and Zavadskas, 2014):

$$pQ_i = \prod_{j=1}^{n} (z_{ij})^{w_j} \quad (13)$$

The alternatives are ranked with respect to the performance index, pQi, and the optimal solution is the one with the highest value of pQi.

3. Case Study

To demonstrate the effectiveness of AM and GM techniques as tool for aggregating multi experts ratings of alternatives, comparative analysis was conducted in search for better solution using a case study of fuel oil system of marine diesel engine of a ship system. Ten failure modes of the fuel oil system were identified for some equipment items of the system. The failure modes together with the failure causes, effects of the failure and failure detection scheme of the system are presented in Table 1

Table 1 Failure modes of fuel oil system

FM #	Failure modes	Equipment items	Failure cause	Local effects	Global effects	Detection system
1	pipe leakage/ rupture, sludge in fuel line	Fuel system- pipes, filter	deposits, low quality fuel oil	Hot spot , fuel oil spill	Stop engine, fire probable	Visual, high temperature deviation ,
2	Clogged fuel filter	Fuel system- pipes, filter	Contaminants, Lack of maintenance	Restriction in fuel flow (low fuel pressure), erratic cylinder firing	Engine speed drop, stop engine	Differential pressure alarm
3	Low supply pressure	High pressure fuel pump	Suction valve opens too early or late	Engine operates erratically	Reduced engine performance, stop engine	Low pressure alarm
4	Running without oil	Transfer/ supply/Booster pump	Wear-out gear	Low supply pressure	Reduce output from engine	,,
5	Abnormal sound	Transfer/ supply/Booster pump	Bearing defective/ shaft displacement	Overloading of electric motor	Reduce output from engine	,,
6	Fuel valve leaked	Fuel valve	Erosion, deposits	Excessive temperature after individual unit dropped	Reduce output from engine, hot spot	High exhaust temperature alarm
7	Seizure of injection valve spindle in open position	Fuel valve	Control system failure	Excessive fuel injected into the affected cylinder, high exhaust temperature, black smoke	Reduced engine performance, environmental damage	High exhaust temperature alarm

8	Fuel valve nozzle obstructed	Fuel valve	Inadequate maintenance, incorrect fuel temperature, contaminants, poor fuel quality	Poor combustion, discolored exhaust	Reduced engine performance, followed by engine failure	High exhaust temperature alarm
9	Early opening of fuel valve	Fuel valve	Low service pressure	Rough running, loss of compression and poor starting	Reduced engine performance	Low pressure alarm
10	Dripping	Fuel valve	Oversized injection mechanisms	Sticking of piston rings in their groove	Reduced engine performance, engine damage	High exhaust temperature alarm

For each of the failure modes, ratings assigned by three experts are presented in Table 2. Expert 1 rating in Table 2 were an agreed consensus rating of the ten failure modes from multiple experts obtained from the work of Emovon (2016). Expert 2 and 3 ratings were generated to be within close range of Expert 1 ratings.

Table 2 Failure Mode Ratings

Failure modes	Expert 1			Expert 2			Expert 3		
	O	S	D	O	S	D	S	O	D
1	6	7	2	8	6	3	6	8	4
2	6	7	2	7	6	4	5	9	3
3	5	8	5	4	7	3	4	7	3
4	5	8	5	7	7	5	7	6	5
5	6	7	4	5	9	6	8	9	3
6	5	7	2	4	8	3	6	7	2
7	4	9	2	6	7	2	3	6	4
8	5	8	2	4	6	4	8	9	2
9	6	7	6	8	8	5	8	7	5
10	4	8	2	2	9	2	6	6	4

4. Case Study Analysis

4.1 Experts ratings aggregation

The experts' 1, 2 and 3 ratings in Table 2 are aggregated using Equations 2 and 3 to obtain AM and GM ratings of failure modes respectively and the results are shown in Table 3.

Table 3 AM and GM values of failure modes

Failure modes	AM			GM		
	O	**S**	**D**	**O**	**S**	**D**
1	6.6667	7.0000	3.0000	6.6039	6.9521	2.8845
2	6.0000	7.3333	3.0000	5.9439	7.2304	2.8845
3	4.3333	7.3333	3.6667	4.3089	7.3186	3.5569
4	6.3333	7.0000	5.0000	6.2573	6.9521	5.0000
5	6.3333	8.3333	4.3333	6.2145	8.2768	4.1602
6	5.0000	7.3333	2.3333	4.9324	7.3186	2.2894
7	4.3333	7.3333	2.6667	4.1602	7.2304	2.5198
8	5.6667	7.6667	2.6667	5.4288	7.5595	2.5198
9	7.3333	7.3333	5.3333	7.2685	7.3186	5.3133
10	4.0000	7.6667	2.6667	3.6342	7.5595	2.5198

The AM and GM ratings or values are then use as input into the different failure mode ranking techniques.

4.2 Comparative analysis of AM and GM

The AM and GM techniques are compared by inputting both aggregated ratings in Table 3 into each of the ranking tools; RPN, CP, VIKOR, WSM and WPM in turns to determine the similarity of the AM and GM data aggregation approach and their effect on the ranking tools.

4.2.1 Comparative analysis of AM and GM based on RPN

The AM and GM aggregated ratings of failure modes in Table 3 was used as input data in turns into Equation 4 to obtain RPN of failure modes of fuel oil system based on AM and GM respectively. The RPN of failure modes and corresponding ranking obtained based on AM and GM data are presented in Table 4.

Table 4 Comparison of AM and GM based on RPN failure modes rankings

	AM					GM				
FM #	O	S	D	RPN	Rank	O	S	D	RPN	Rank
1	6.6667	7.0000	3.0000	140.0	4	6.6039	6.9521	2.8845	132.4	4
2	6.0000	7.3333	3.0000	132.0	5	5.9439	7.2304	2.8845	124.0	5
3	4.3333	7.3333	3.6667	116.5	6	4.3089	7.3186	3.5569	112.2	6
4	6.3333	7.0000	5.0000	221.7	3	6.2573	6.9521	5.0000	217.5	2
5	6.3333	8.3333	4.3333	228.7	2	6.2145	8.2768	4.1602	214.0	3

6	5.0000	7.3333	2.3333	85.6	8	4.9324	7.3186	2.2894	82.6	8
7	4.3333	7.3333	2.6667	84.7	9	4.1602	7.2304	2.5198	75.8	9
8	5.6667	7.6667	2.6667	115.9	7	5.4288	7.5595	2.5198	103.4	7
9	7.3333	7.3333	5.3333	286.8	1	7.2685	7.3186	5.3133	282.6	1
10	4.0000	7.6667	2.6667	81.8	10	3.6342	7.5595	2.5198	69.2	10

The ranks of failure modes obtained based on AM and GM data are also presented in Figure 1. From Table 4 and Figure 1, Failure mode 1, 2, 3, 6, 7, 8, 9 and 10 have the same rank when both AM and GM data are applied as input data while Failure mode 4 and 5 have one rank difference in between. From the comparative analysis, it is obvious that the ranking obtained for both AM and GM being applied as input data in RPN for the ranking of failure modes are almost completely the same.

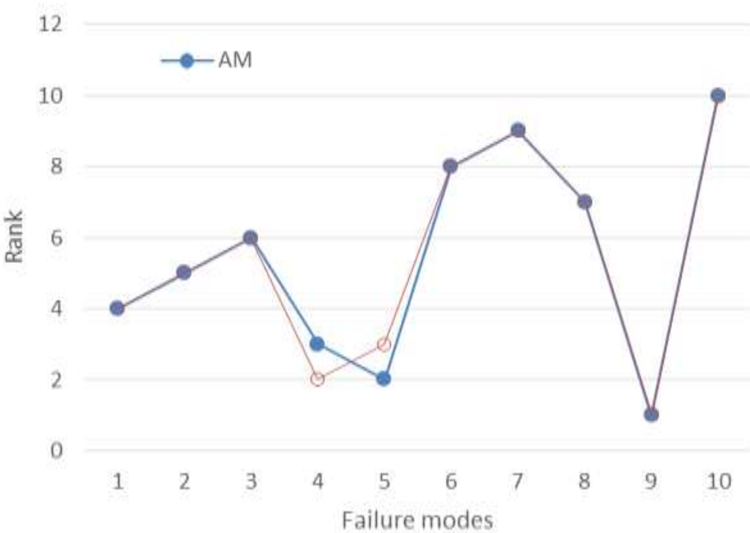

Fig. 1 Comparison of AM and GM based on RPN failure modes rankings

4.2.2 Comparative analysis of AM and GM based on CP

The first step in the comparative analysis of AM and GM is the determination of the weight of decision criteria; O, S and D. The entropy method was applied to estimate weights of decision criteria. The results for O, S and D are 0.3081, 0.0197 and 0.6722 respectively when AM data in Table 3 was applied into entropy methodology while the weights for O, S and D are 0.3162, 0.0171 and 0.6667 respectively when GM data also in Table 3 are used as input data into entropy method. The CP performance index of the failure modes is then evaluated using Equation 5 and 6 on AM and GM decision matrix data in Table 3 and criteria weights. The performance index and corresponding rank obtained for failure modes based on AM and GM input data are shown in Table 5. The ranks of failure modes obtained based on AM and GM data are also presented in Figure 2.

Table 5 Comparison of AM and GM based on CP failure modes rankings

	AM		GM	
FM#	CP	Rank	CP	Rank
1	0.2768	5	0.2911	5
2	0.2859	6	0.3029	6
3	0.2024	4	0.2297	4
4	0.0129	2	0.0143	2
5	0.0572	3	0.0747	3
6	0.4900	10	0.4942	9
7	0.4199	8	0.4673	8
8	0.3765	7	0.4102	7
9	0.0002	1	0.0002	1
10	0.4345	9	0.4994	10

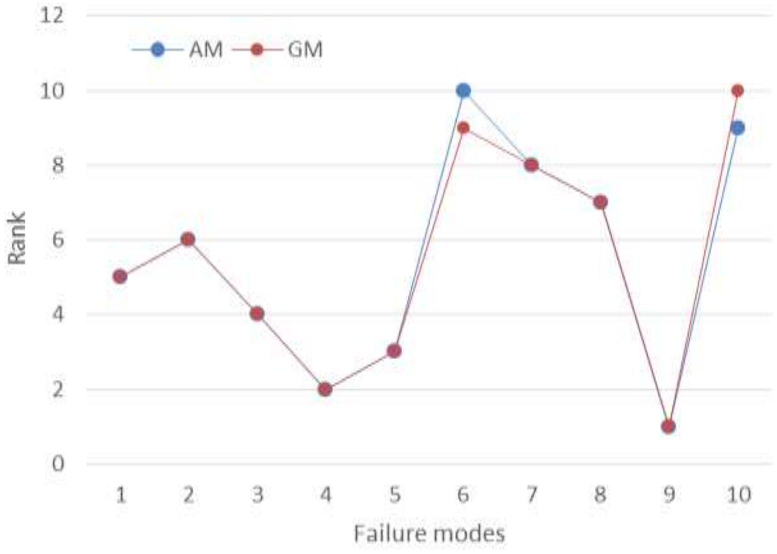

Fig. 2 Comparison of AM and GM based on CP failure modes rankings

From Table 5 and Figure 2, in almost all the failure modes, the same rank was obtained when both AM and GM data are applied as input data with the exception of failure mode 6 and 10 which has one rank difference in between. Again comparative analysis of AM and GM, showed that the ranking of failure modes are almost completely the same when AM and GM data are used as input data.

4.2.3 Comparative analysis of AM and GM based on VIKOR

Using VIKOR method as the basis of comparison of AM and GM, firstly the best and worst values of failure modes are determined using Equation 5 on AM and GM data in Table 3. This is followed by the determination of the utility and regret measures, by applying Equations 7 and 8 on the estimated decision criteria weights and the best and worst values. Finally, the performance index of each failure modes based on AM and GM data are determined using Equation 9 and the results are presented in Table. Based on the performance index, the failure modes are ranked and the results for both AM and GM are compared as shown in Table 6.

Table 6 Comparison of AM and GM based on VIKOR failure modes rankings

FM #	AM		GM	
	Qi	Rank	Qi	Rank
1	0.7136	5	0.7216	5
2	0.7450	6	0.7506	6
3	0.6340	4	0.6335	4
4	0.1546	2	0.1448	2
5	0.3267	3	0.3644	3
6	0.9929	10	0.9682	10
7	0.9288	8	0.9388	8
8	0.8577	7	0.8771	7
9	0.0000	1	0.0000	1
10	0.9432	9	0.9612	9

From Table 6, same rankings of failure modes were obtained when both the AM and GM data were applied as input into the VIKOR technique.

4.2.4 Comparative analysis of AM and GM based on WSM

In comparing AM and GM based on WSM ranking of failure modes, the process starts with normalisation of decision matrix in Table 3 using Equation 10. The normalised matrix and the evaluated decision criteria weights is then applied as input into Equation 12 to determined WSM performance index. The performance index and corresponding rankings obtained for failure modes when AM and GM aggregated data are used as input into WSM are presented in Table 7. The ranking of failure modes based on AM and GM data are also presented in Figure 4.

Table 7 Comparison of AM and GM based on WSM failure modes rankings

	AM		GM	
FM#	WSM	Rank	WSM	Rank
1	0.6776	7	0.6768	7
2	0.6504	5	0.6488	5
3	0.6650	6	0.6602	6
4	0.9175	9	0.9125	9
5	0.8360	8	0.8319	8
6	0.5237	1	0.5223	2
7	0.5380	3	0.5352	3
8	0.5948	4	0.5934	4
9	1.0027	10	0.9979	10
10	0.5248	2	0.5216	1

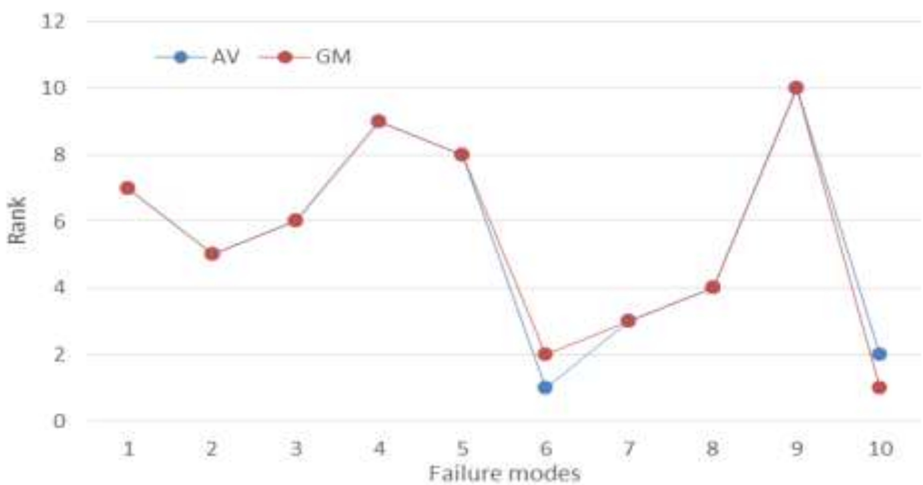

Fig 4 Comparison of AM and GM based on WSM failure modes rankings

From Figure 4, rankings obtained when AM and GM data are used as input into WSM are the same for failure modes 1,2,3,4,7 and 8 and slightly different for failure mode 5, 6, 9 and 10 with each having a rank difference of one between failure modes. Conclusively, ranking obtained for failure modes for both AM and GM data are relatively similar.

4.2.5 Comparative analysis of AM and GM based on WPM

To compare AM and GM methods based on WPM, decision matrix for both AM and GM input data are normalised firstly. The normalised matrix and the evaluated decision criteria weights for AM and GM are applied as input into Equation 13 to produce WPM performance index for failure modes. The WPM performance index and corresponding rank for failure modes are shown in Table 8. The ranks for failure modes in both cases are also presented in Figure 5.

Table 8 Comparison of AM and GM based on WPM failure modes rankings

	AM		GM	
FM#	WPM	Rank	WPM	Rank
1	0.3257	6	0.3261	7
2	0.3156	5	0.3156	5
3	0.3267	7	0.3255	6
4	0.4520	9	0.4510	9
5	0.4120	8	0.4112	8
6	0.2520	1	0.2520	1
7	0.2638	3	0.2633	3
8	0.2868	4	0.2868	4
9	0.4943	10	0.4936	10
10	0.2576	2	0.2569	2

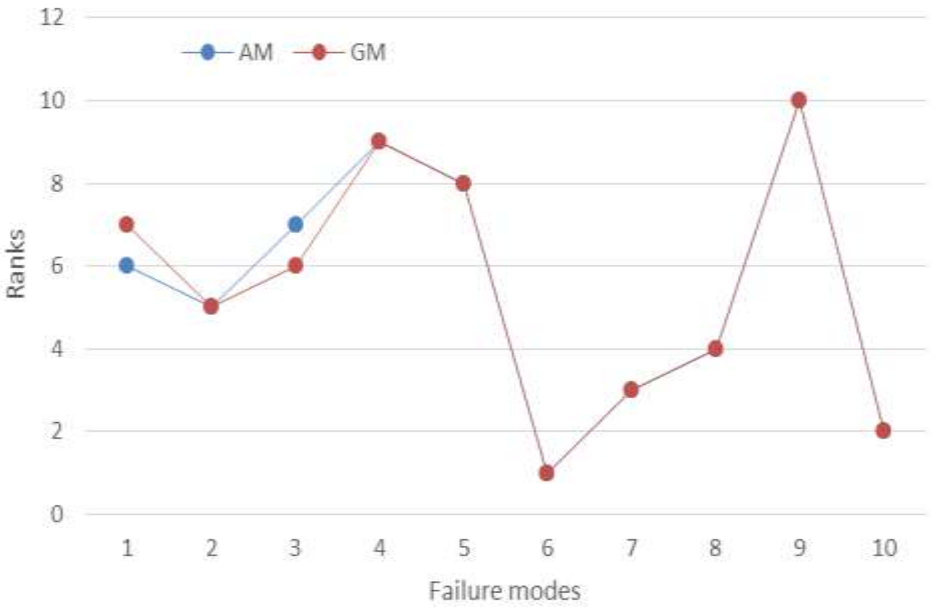

Fig 5 Comparison of AM and GM based on WPM failure modes rankings

From Figure 5, failure modes 2, 4, 5, 6, 7, 8, 9 and 10 representing 80% of the total failure have the same rank for both AM and GM aggregating technique while failure modes 1 and 3 representing 20% of the total failure modes have a difference of one rank in between failure modes. The rank obtained in both scenario; AM and GM are almost completely the same.

5. Conclusion

In this paper two techniques are presented for the aggregation of experts assigned ratings for failure modes of marine machinery system. The two techniques are AM and GM. To ascertain the effectiveness of the two approaches, a comparative analysis was performed in search of the better option using a case study of fuel oil system of marine diesel engine of a ship system. To achieve the paper objective, ratings assigned to failure modes of fuel oil system were aggregated with both AM and GM techniques. The aggregated ratings obtained by both methods were then used input data into RPN of FMEA, CP, VIKOR, WSM and WPM for the ranking of failure modes. The comparative analysis revealed that when AM and GM data are applied as input into RPN, CP and WPM, almost completely same ranking for failure modes were produced in both cases while when applied as input into VIKOR method, same result were generated for failure modes in both scenarios. However, when AM and GM data are applied as input into the WSM method significant difference in failure modes ranking were observed in both scenarios. Conclusively, the level of similarity between the AM and GM depend on the ranking tool applied for the prioritising failure modes. It can further be concluded, that VIKOR method is most stable of all the ranking methods having produced same ranking for failure modes irrespective of the aggregated data applied as input into the methodology.

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