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A hybrid of fuzzy FMEA-AHP to determine factors affecting alternator failure causes

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C H R O N I C L E

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A B S T R A C T

This paper presents a method to determine factors influencing alternator failure causes. Failure Mode and Effects Analysis (FMEA) is one of the first systematic techniques for failure analysis based on three factors including Probability (P), Severity (S) and Detection (D). Traditional FMEA method considers equal weights for all three factors, however, in read-world cases; one may wish to consider various weights. The proposed study develops a mathematical model to determine optimal weights based on analytical hierarchy process technique. The implementation of the proposed study has been demonstrated for a read-world case study of alternator failure causes.

1. Introduction

Failure Mode and Effects Analysis (FMEA) is one of the first systematic techniques for failure analysis based on three factors including Probability (P), Severity (S) and Detection (D). There are literally many applications of FMEA method in various areas (Rawat & Wang, 2005). Dominguez-Garcia et al. (2006), for instance, introduced a method for the dependability analysis of new automotive safety-relevant systems. By introduction of safety-relevant electronic systems in cars, it is essential to carry out a thorough dependability analysis of those systems to fully understand and quantify the failure mechanisms to make the necessary improvement in the design. They used various system level FMEAs to determine various failure modes of the system and used a Markov model to quantify their probability of occurrence. Parrott et al. (2011) applied advanced FMEA techniques to vehicle fire cause determinations. Kulkarni (2013) successfully regained lost market through application of FMEA tool to revamp design of single phase induction motor. Tsang and Ho (2002) presented an application of reliability-centered maintenance technology on electric trains.

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2. The proposed study

This paper presents a method to determine factors influencing alternator failure causes. Failure Mode and Effects Analysis (FMEA) is one of the first systematic techniques for failure analysis based on three factors including Probability (P), Severity (S) and Detection (D).

2.1. Probability

It is always essential to look at the cause of a failure mode and the likelihood of occurrence, which could be accomplished by analysis, calculations /FEM, looking at similar items or processes and the failure modes documented for them previously. A failure cause is normally considered as a design weakness and all potential causes for a failure mode such as human errors in handling, fatigue, etc. ought to be determined.

2.2. Severity

This item determines the severity for the worst-case scenario adverse end effect. It is a good idea to write these effects down in terms of what the user could see or experience in terms of functional failures. Each end effect is given a Severity number (S) from, say, I (no effect) to VI (catastrophic), based on cost and/or loss of life or quality of life.

2.3. Detection

Detection is the technique by which a failure is detected, isolated by operator and/or maintainer and the time it may take. This is essential for maintainability control and is important for multiple failure scenarios. It is necessary to make it clear on how the failure mode or cause could be discovered by an operator under normal system operation.

2.4 Risk

In FMEA technique, Risk is the combination of End Effect Probability (P×S) And Severity (D) where probability and severity incorporates the impact on non-detectability. This may affect the end effect probability of failure or the worst case impact Severity.

2.5 Weighting technique

Traditional FMEA method considers equal weights for all three factors, however, in read-world cases; one may wish to consider various weights as follows,

$$RPN = W_S \times S + W_O \times O + W_D \times D \tag{1}$$

where W_s, W_o and W_D are relative weights of S, O and D, respectively. The proposed study of this paper determines the weights using the method developed by Wang et al. (2006) as follows,

$$\min Z = \sum_{i=1}^{n} \sum_{j=1, j\neq i}^{n} \left(\left(\ln w_i^L - \ln w_j^U - \ln L_{ij}\right)^2 + \left(\ln w_i^M - \ln w_j^M - \ln M_{ij}\right)^2 + \left(\ln w_i^U - \ln w_j^L - \ln U_{ij}\right)^2 \right) \tag{2}$$

subject to

$$W_i^L + \sum_{j=1, j\neq i}^{n} W_j^U \geq 1 \tag{3}$$

$$W_i^U + \sum_{j=1, j\neq i}^{n} W_j^L \leq 1 \tag{4}$$

$$\sum_{i=1}^{n} W_i^M = 1 \qquad i = 1,2,\dots\dots\dots, n \tag{5}$$

$$\sum (W_i^L + W_i^U) = 2 \tag{6}$$

$$W_i^U \geq W_i^M \geq W_i^L \geq 0 \tag{7}$$

where W_i^U, W_i^M and W_i^L are associated with fuzzy triangular numbers assigned to each item to handle uncertainty.

3. The case study

The case study of this paper is associated with determining factors influencing alternator failure causes. Decision makers have given the following triangular numbers for three factors of S, O and D summarized in Table 1 as follows,

Table 1
The summary of triangular numbers

	S	O	D	Relative weight
S	(1,1,1)	(4,5,6)	(4,5,6)	(0.674, 0.701, 0.715)
O	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{4})$	(1,1,1)	(2,3,4)	(0.169, 0.202, 0.238)
D	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{4})$	$(\frac{1}{4}, \frac{1}{3}, \frac{1}{2})$	(1,1,1)	(0.084, 0.097, 0.119)

In Table 1, the relative weights are calculated based on fuzzy analytical hierarchy process (Chang, 1996). Table 2 demonstrates the summary of the factors gathered from decision makers.

Table 2
The summary of factors associated with alternator failure along with fuzzy

Item	Factors	S			O			D			RPN			Defuzzy	Rank
1	Limp and tolerance levels	5	6	7	2	3	4	5	6	7	50	108	196	113	7
2	Failure in the alternator assembly devise	6	7	8	4	5	6	2	3	4	48	105	192	110	8
3	Bearing failure	6	7	8	3	4	5	3	4	5	54	112	200	117	6
4	Conflict between rotor and stator	7	8	9	5	6	7	3	4	5	105	192	315	198	5
5	Electromagnetic noise	3	4	5	6	7	8	6	7	8	108	196	320	202	3
6	Aerodynamic noise	4	5	6	5	6	7	6	7	8	120	210	336	216	1
7	Electrical leakage stator	7	8	9	4	5	6	4	5	6	112	200	324	206	2
8	Electrical leakage of rotor	6	7	8	5	6	7	4	5	6	120	210	336	216	1
9	Lack of proper regulation voltage	6	7	8	3	4	5	6	7	8	108	196	320	202	3
10	Corrosion of coal	7	8	9	3	4	5	5	6	7	105	192	315	198	5
11	Rectifier of excitation system failure	7	8	9	2	3	4	7	8	9	98	192	324	198.33	4
12	Rectifier of power system failure	5	6	7	6	7	8	4	5	6	120	210	336	216	1
13	Failure to stimulate alternator on time	2	3	4	1	2	3	7	8	9	14	48	108	52.333	9
14	The transmission system of power	5	6	7	3	4	5	7	8	9	105	192	315	198	5
15	The transmission system of flow	7	8	9	3	4	5	5	6	7	105	192	315	198	5

Combining the information of Table 1 and Table 2 yields the final ranking based on the relative weights of the factors, which are summarized in Table 3 as follows,

Table 3
The results of final ranking

Item	Factors	RPN			Defuzzy	Rank
1	Limp and tolerance levels	4.128	5.394	6.79	5.4373	12
2	Failure in the alternator assembly devise	4.888	6.208	7.624	6.24	7
3	Bearing failure	4.803	6.103	7.505	6.137	9
4	Conflict between rotor and stator	5.815	7.208	8.696	7.2397	1
5	Electromagnetic noise	3.54	4.894	6.431	4.956	13
6	Aerodynamic noise	4.045	5.396	6.908	5.4497	11
7	Electrical leakage stator	5.73	7.103	8.577	7.1367	2
8	Electrical leakage of rotor	5.225	6.604	8.1	6.643	5
9	Lack of proper regulation voltage	5.055	6.397	7.862	6.437	6
10	Corrosion of coal	5.645	6.998	8.458	7.0337	3
11	Rectifier of excitation system failure	5.644	6.99	8.458	7.0307	4
12	Rectifier of power system failure	4.72	6.105	7.623	6.1493	8
13	Failure to stimulate alternator on time	2.105	3.283	4.645	3.3443	14
14	The transmission system of power	4.465	5.79	7.266	5.8403	10
15	The transmission system of flow	5.645	6.998	8.458	7.0337	3

4. Discussion and conclusion

The results of Table 3 indicate that conflict between rotor and stator is number one priority for detecting any failure followed by electrical leakage of stator, corrosion of coal, the transmission system, rectifier excitation system failure and electrical leakage of rotor. The proposed fuzzy FMEA of this paper has enabled us to assign weight for each of three items in FMEA model. This is an advantage because we used analytical hierarchy process to rank the factors. There are also other opportunities for ranking three factors based on other multi criteria decision making techniques and we leave it for interested researchers as future studies.

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