A Statistical Approach for Modified Evaluation and Prioritization Methodology for Risk Priority Number (RPN) in Failure Modes and Effects Analysis (FMEA)

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Abstract

Failure Mode and Effects Analysis (FMEA) is a proactive procedure intended to assess a framework, plan, process and administration for conceivable courses in which Failures can happen. The FMEA technique designates a numerical regard to each peril associated with bringing on a failure using reality, occasion and acknowledgment documents and Risk Priority Number (RPN) is obtained by copying these numerical qualities. The conventional FMEA prioritization strategy has two primary inadequacies as: different arrangements of seriousness, event and identification records may deliver an indistinguishable estimation of RPN and taking normal or higher numerical esteem, when the group has a contradiction in the positioning file. In this paper an endeavor is made to build up another RPN prioritization technique to address these two lacks. The proposed strategy has been assessed by contextual investigations and factual examination strategies.

Keywords: FMEA, RPN, Failure Mode, Prioritization, Statistical Analysis.

INTRODUCTION

Failure Modes and Effects Analysis (FMEA) is consistently portrayed as "an exact technique for recognizing potential arrangement and process Failures before they happen, with the desire to murder them or minimize the hazard associated with them" [1]. The FMEA methodology was at first reported in the 1920s yet its usage has quite recently been on a very basic level recorded since the mid 1960s. It was made in the USA in the 1960s by the National Aeronautics Space Agency (NASA) as a strategy for tending to an approach to enhance the courageous way of military gear [2]. It has been used as a part of the auto business since the mid 1970s and its usage has been enlivened in the 1990s to address the genuine quality and steadfastness challenges realized by the Far Eastern automobile producers [3].

TRADITIONAL FMEA APPROACH

FMEA is done by a cross-useful group of specialists from different offices. Typically, a group is shaped at the planning phase of another item in light of a simultaneous building approach. The group examines every part and subsystem of the item for the Failure modes. At that point, the potential circumstances and end results are resolved. These evaluations are scaled with numbers somewhere around 1 and 10 [4]. The examination begins from the fundamental structure of the framework and especially from those framework components for which exact data about Failure mode and its causes are accessible. This is an inductive strategy to break down Failure modes utilizing down-top system. Chance Priority Number, which is the result of the seriousness, event and identification appraisals is ascertained as RPN = S x O x D. The RPN must be figured for every reason for Failure. RPN demonstrates the relative probability of a Failure mode, in that the higher number, the higher the Failure mode. From RPN, a basic synopsis can be attracted up to highlight the regions where activity is for the most part required [5]. The RPN is re-ascertained after the Failure has been tended to. The reconsidered RPN affirms the adequacy of the remedial dynamic embraced [6].

Table 1: Qualitative Scale for Severity, Occurrence and Detection

Rank	Severity	Occurrence	Detection	Resolution
1	None	Almost Never	Almost Certain	If the numerical value falls between two numbers always select the higher number. If the team has a disagreement in the ranking value the following may help. 1. If the disagreement is an adjacent category, average out the difference. For example, if one member says 5 and someone else says 6, the ranking in this case should be 6 (5 and 6 are adjacent categories. Therefore 5 + 6 = 11, 11/2 = 5.5) 2. If the disagreement jumps one category, then consensus must be reached. Even with one person holding out, total consensus must be reached. No average and no majority. Everyone in that team must have ownership of the ranking. They may not agree 100 percent, but they can live with it.
2	Very Minor	Remote	Very High	
3	Minor	Very Slight	High	
4	Very Low	Slight	Moderately High	
5	Low	Low	Moderate	
6	Moderate	Medium	Low	
7	High	Moderately High	Very Low	
8	Very High	High	Remote	
9	Serious	Very High	Very Remote	
10	Hazardous	Almost Certain	Almost Impossible	

RESEARCH METHODOLOGY

This examination utilizes trial strategies to show new strategy to organize Failure modes, when at least two Failure modes have the same RPN esteem and propose another approach, when the group has a contradiction in positioning worth for the three Failure lists. The proposed technique can manage the circumstance when;

- Two or more Failure modes have the same RPN.
- The group has a contradiction in the positioning scale for seriousness, event and recognition.
- It is expected that the three S, O, and D lists are all similarly imperative.

The proposed Failure mode prioritization technique gives plausibility of considering diverse Failure modes with indistinguishable estimation of RPN, so staying away from a further work trouble for originators [7]. The suspicion is that the three Failure mode files are all similarly vital. A general strategy with "n" Failure mode is examined underneath with the same RPN.

STATISTICAL ANALYSIS

The utilization of measurable strategies in assembling, advancement of sustenance items, PC programming, pharmaceutical and numerous different ranges includes the social occasion of data or logical data. Measurable techniques help us to examine the data and to decide. Moreover, it is utilized to figure out if the decisions made from a review are to be trusted and to give prove that the model is factually valuable for the reason.

Numerous Regression Analysis

This application includes an examination of the components that influence the RPN. This review presents a different relapse show as a method for relating a reliant variable RPN to three autonomous factors S, O and D [8]. Most functional utilizations of relapse examination use straight-line demonstrate. The reliant variable y is currently composed as a component of three free factors x1, x2 and x3. The arbitrary blunder term is added to make the model probabilistic as opposed to deterministic [9].

The form of multiple regression models is as shown in equation (1);

$$y = \beta 0 + \beta 1x1 + \beta 2x2 + \beta 3x3 + \varepsilon \quad (1)$$

Where;

y is the dependent variable RPN.

x1, x2 and x3 are the three independent variables S, O and D.

β0, β1, β2, and β3 are unknown model parameters.

ε is the random error.

To fit the model, we have selected a sample of n = 24 RPN values from three failure modes 1, 2 and 3. The failure modes of a motor are given in Table 2.

Table 2. RPN Values for Three Failure Modes

FAILURE MODES	S	O	D	RPN
(1) Stator insulation failure	2	7	4	56
	2	7	3	42
	2	6	4	48
	2	6	3	36
	3	6	4	72
	3	6	3	54
	3	7	4	84
	3	7	3	63
	1	3	6	18
	1	3	7	21

	1	2	6	12
	1	2	7	14
(2) Rotor vibration	6	3	6	108
	6	3	7	126
	6	2	6	72
	6	2	7	84
(3) Loss of power supply	5	2	3	30
	5	2	2	20
	5	5	3	75
	5	5	2	50
	8	2	3	48
	8	2	2	32
	8	5	3	120
	8	5	2	80

Table 3: Multiple Regression Analysis

Regression Analysis: RPN versus S, O, D

The regression equation is

RPN = - 132 + 14.9 S + 15.3 O + 15.1 D

Predictor	Coef	SE Coef	T	P
Constant	**-131.70**	15.40	-8.55	0.000
S	**14.853**	1.176	12.63	0.000
O	**15.273**	1.504	10.15	0.000
D	**15.131**	1.675	9.03	0.000

S = 11.1150 R-Sq = 89.9% R-Sq(adj) = 88.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	21957.8	7319.3	**59.24**	**0.000**
Residual Error	20	**2470.9**	**123.5**		
Total	23	24428.6			

Multiple regression analysis was carried out using MINITAB software package. A portion of the print out is reproduced in Table 3. The least square estimates of the parameters (highlighted) are β0 = -132, β1 = 14.9, β2 = 15.3, and β3 = 15.1. Therefore, the equation that minimizes SSE for this data set (i.e., the least square prediction equation) is;

$$y = -132 + 14.9x1 + 15.3x2 + 15.1x3 \quad (2)$$

The minimum value of the sum of squared errors, highlighted in Table 3 is SSE = 2470.9

The estimator of σ^2 for the straight-line model is S^2 = SSE / (n-2) and n = number of estimated β parameters in the straight-line model. Since, we must estimate four parameters β0, β1, β2, and β3 for the first-order model, the estimator of σ^2 is;

$$S^2 = SSE / (n-4) = SSE / (24-4) = 2470.9 / 20 = 123.545$$

This value often called the mean square for error (MSE) is also highlighted at the bottom of the MINITAB printout in Table 3.

The estimate of σ is, S = √123.545 = 11.1150

This is highlighted in the middle of the print out in Table 3. One helpful understanding of the assessed standard deviation S is that the interim ±2S will give a harsh estimation to the exactness with which the model will foresee future estimations of y for given estimations of x [10].

Assessing the Overall Adequacy of the Model

We want to test whether the data in Table 4 provides sufficient evidence to conclude that the model is statistically useful for prioritizing RPN values.

H0: β0 = β1 = β2 = β3 = 0 [Note: k = 3]

Ha: At least one of the three model coefficients is non-zero.

$$\text{Test Statistic: } F = \frac{(SSyy - SSE)/k}{SSE/[n-(k+1)]} = \frac{(R^2)/k}{(1-R^2)/[n-(k+1)]} \quad (3)$$

= Mean square (Model) / Mean square (Error) = 7319.3/123.5 = 59.2655

Rejection region: F > Fα with k numerator degrees of freedom and [n-(k+1)] denominator degrees of freedom.

P-value: less than .0001

The test is to compare this computed value of F with the tabulated value based on k = 3 and n = 24. If we choose α = .05, then $F_{.05}$ = 3.01 and the rejection region is F > 3.01

In a multiple regression analysis, use the value of R^2 as a measure of how useful a linear model will be for prioritizing RPN [12].

The multiple coefficient of determination R^2, is defined as;

$$R^2 = 1 - \frac{SSE}{SS_{YY}} = \frac{SS_{YY} - SSE}{SS_{YY}} \quad (4)$$

$$= \frac{24428.6 - 2470.9}{24428.6}$$

= Explained variability / Total variability = 0.8988

According to equation (4); $R^2 = 89.9\ \%$

As an alternative to using R^2 as a measure of adequacy, the adjusted multiple coefficient of determination, denoted, is often reported.

The adjusted coefficient of determination is given by [13];

$$R_a^2 = 1 - \frac{(n-1)}{n-(k+1)} \frac{SSE}{SS_{yy}} = 1 - \frac{(n-1)}{n-(k+1)}(1-R^2) \quad (5)$$

According to equation (5);

$$R_a^2 = 1 - \frac{(24-1)}{24-(3+1)}(1-0.899) = 0.88385 = 88.4\ \%$$

The squares model has explained about 88.4 % of the total sample variation in y values (RPN) after adjusting for sample size and number of independent variables in the model.

Since, α = .05 surpasses the watched hugeness level, p < .0001, the data give solid confirmation that no less than one of the model coefficients is non-zero [14]. The general model seems, by all accounts, to be factually helpful for organizing RPN values.

Analyzing Residuals

Leftover examinations are helpful for recognizing at least one perceptions that go astray altogether from the relapse display. We expect roughly 95% of the residuals to fall inside 2 standard deviations of the 0 line and all or all most every one of them to exist in 3 standard deviations of their mean of 0. Residuals that are to a great degree a long way from the 0 line are separated from the main part of alternate residuals.

The leftover for straight-line display for the data is appeared in Table 4. The residuals are highlighted in the MINITAB printout.

Table 4: Residual for Straight-Line Model

The	regression equation is					
RPN	= - 132 + 14.9 S + 15.3 O + 15.1 D					
Predictor		Coef	SE Coef	T	P	
Constant		-131.70	15.40	-8.55	0.000	
S		14.853	1.176	12.63	0.000	
O		15.273	1.504	10.15	0.000	
D	11.115	15.131	1.675	9.03	0.000	
S =	0	R-Sq = 89.9%		R-Sq(adj) = 88.4%		
Analysis of		Variance				
Source		DF	SS	MS	F	P
Regression		3	21957.8	7319.3	59.24	0.000
Residual Error 20			2470.9	123.5		
Total		23	24428.6			
Obs	S	RPN	Fit	SE Fit	**Residual**	St Resid
1	2.00	56.00	65.45	4.23	**-9.45**	-0.92
2	2.00	42.00	50.31	4.23	**-8.31**	-0.81
3	2.00	48.00	50.17	3.44	**-2.17**	-0.21
4	2.00	36.00	35.04	3.84	**0.96**	0.09
5	3.00	84.00	80.30	4.26	**3.70**	0.36
6	3.00	63.00	65.17	4.01	**-2.17**	-0.21
7	3.00	72.00	65.03	3.20	**6.97**	0.66
8	3.00	54.00	49.89	3.33	**4.11**	0.39
9	1.00	18.00	19.76	4.44	**-1.76**	-0.17
10	1.00	21.00	34.89	4.76	**-13.89**	-1.38
11	1.00	12.00	4.49	5.27	**7.51**	0.77
12	1.00	14.00	19.62	5.27	**-5.62**	-0.57
13	6.00	108.00	94.03	4.38	**13.97**	1.37
14	6.00	126.00	109.16	5.72	**16.84**	1.77
15	6.00	72.00	78.75	4.24	**-6.75**	-0.66
16	6.00	84.00	93.88	5.35	**-9.88**	-1.01
17	5.00	30.00	18.51	4.75	**11.49**	1.14
18	5.00	20.00	3.38	6.04	**16.62**	1.78
19	5.00	75.00	64.33	2.80	**10.67**	0.99
20	5.00	50.00	49.20	3.60	**0.80**	0.08
21	8.00	48.00	63.07	4.73	**-15.07**	-1.50
22	8.00	32.00	47.94	5.47	**-15.94**	-1.65
23	8.00	120.00	108.89	4.94	**11.11**	1.12
24	8.00	80.00	93.75	4.81	**-13.75**	-1.37

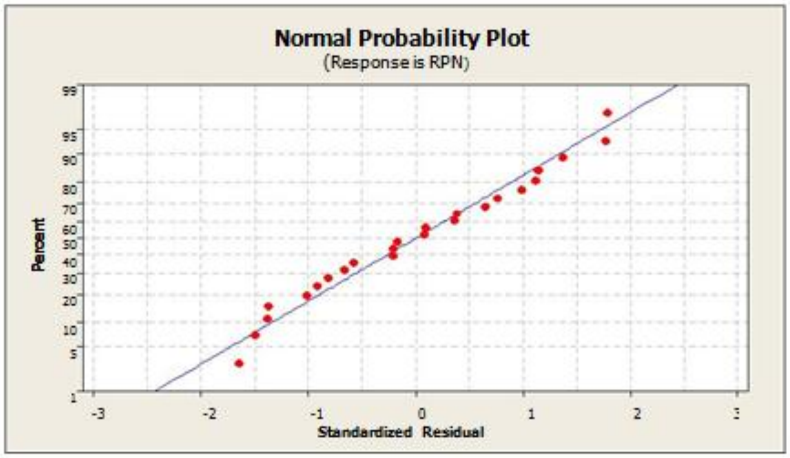

Fig. 1: Normal Probability Plot

A normal probability and residual plot for the residuals are shown in Figure 1 and 2.

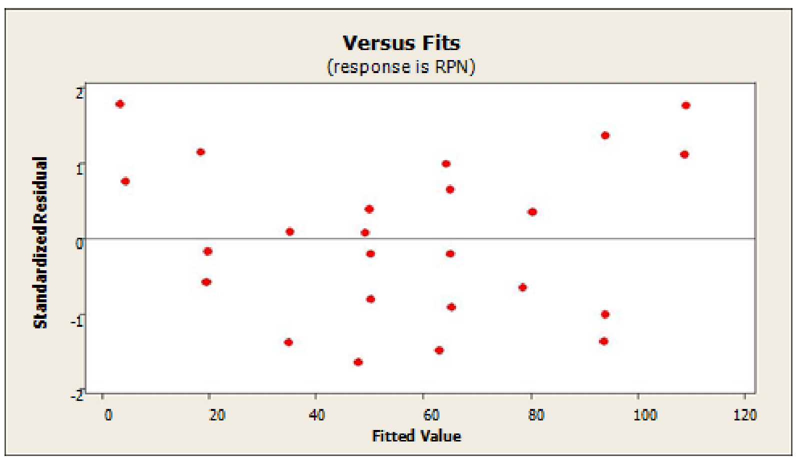

Fig. 2: Residual Plots for RPN

Figure 1 appears, how well the residuals coordinate an ordinary appropriation. The residuals fall in a straight line, that implies the typicality condition is met. Figure 2 appears, every one of the (100 percent) of the standard residuals fall inside two standard deviations of the mean, which is - 2 to +2 and none of them lies past 3 standard deviations.

CONCLUSION

The point of this paper is to build up a successful hazard prioritization technique to enhance the customary FMEA prepare. This paper has concentrated on the outline FMEA to enhance current plan handle and to guarantee high caliber and unwavering quality of the items. The contextual investigations displayed in this paper settle the accompanying restrictions of conventional FMEA system;

- If at least two Failure modes have the same RPN esteem, it is conceivable to organize the Failure modes with the assistance of Risk Priority Code (RPC).

- RPN run organizes the Failure modes, when the group has a contradiction in the positioning quality for seriousness, event and recognition files.

- The factual investigation gives solid proof that the proposed strategy is measurably helpful for organizing RPN qualities and Failure modes.

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