New Means to Risk-Priority-Number for System Improvement

Shahryar SOROOSHIAN

Faculty of Industrial Management and Center for Earth Resources Research & Management,
Universiti Malaysia Pahang, Malaysia; E-mail: sorooshian@gmail.com

Abstract

Manufacturing could be an example of a typical system. Various manufacturing systems are reported to be failed because of the simultaneous onslaught of failure modes. The classic RPN (Risk Priority Number) formulation used in the failure mode and effects analysis was not successful to prevent the system failures and system improvements. Hence, this article proposes an improvement of the RPN formulation. The aim of the proposed formulation is to expand the RPN to a better system-oriented model. The proposed formulation is able to consider the manufacturing system with its several components in RPN calculation. This system-oriented formulation can reduce the classic RPN defects.

Keywords: *Failure Modes and Effects Analysis (FMEA); Risk Priority Number (RPN); System Improvement Process (SIP); Pair-wise Comparison (PWC).*

1. Introduction

There is an increasing interest in implementing the concepts of systems (Xiulan Zhang, 2014) for evaluating manufacturing systems. To ascertain all probable failures in a manufacturing system, a step-by-step approach is adopted through failure modes and effects analysis (FMEA). FMEA is an important method for analysing risks for every component of a manufacturing system, and hence it plays an essential role in improving the performance of the manufacturing system (Eva Nedeliaková, 2015). A fundamental part of the FMEA approach is the formulation of the Risk Priority Number (RPN). RPN specifically analyses the system-failure modes and their probable reasons and rates them on a scale of 10 for three aspects: detection rating (D), occurrence rating (O), and severity rating (S) (Sorooshian, 2014; Sorooshian, 2015; Ansah et al., 2017). A system component that has a high RPN should be treated with high priority (Thanh-Lam Nguyen, 2016; Rapinder Sawhney, 2010; Sorooshian an Ze En, 2017). RPN is an efficient tool in prioritising the system components that require corrective measures in order to enhance the system's function. The calculation of RPN is simple to understand. But it has a scope for severe defects (Zhao, 2013; Thanh-Lam Nguyen, 2016; Rapinder Sawhney, 2010; Jr, 2008). Another area of concern in this is that the evaluation criteria for S, O and D rankings are not clearly defined (Zhao, 2013). Hence, the selection of rankings of failure modes becomes difficult and obscure for the experts (Zhao, 2013). The RPN also has another challenge where it fails to offer adequate discrimination power under certain circumstances as it employs the same weight for all the ratings of S, O, and D (Rapinder Sawhney, 2010; Thanh-Lam Nguyen,2016; Jr, 2008; Cox LA Jr, 2005; Zambrano et al., 2007). Also, RPN does not provide clear differences between the adjacent levels in a system (Zhao, 2013).

Therefore, it is necessary to implement a system enhancement process that aims to reduce the failure rate of a system and emphasises on the behaviour of all components of the system. It is also important to analyse and compare the risks aspects of the components in order to enable the system improvement plan and to manage the system-failure risk effectively. In reality, to ensure improvement of the system functionality, the RPN for system-improvement should study every component of the system. The conventional RPN evidently fails to deliver such a system-based decision in the analytical environment as a result of its slow discrimination power. Hence, the objective of this study is to propose a new way of calculating RPN that is based on a system-approach.

2. Method

This paper suggests the use of pairwise comparison (PWC) for analysing the instances of failures in a manufacturing system, before the classic-RPN is calculated. The recommended approach uses paired comparison to analyse the extent of importance of each predetermined and predefined criterion S, O, and D, as the selected criteria is in agreement with the RPN calculation. In PWC, the analysis of the level of importance of the predetermined criteria is performed on the basis of expert judgement, where every criterion is weighed against each other before the criterion is assigned with a degree of importance (Štefan et al,2017).

The first step is the construction of Comparative Judgements (PWC Matrices) for each criterion [S, O, and D]. On completion of the hierarchy construction, the next step is to ascertain the priorities of the variables at every level by creating a set of comparison matrices for all variables in relation to each other. The values are saved in a discrete matrix for every criterion, in which the rows and columns are composed of written components of the manufacturing-system in the same sequence as they occur. It is expressed as follows: if the *i*-th variable is *a* times more favourable than the *j*-th variable, then, $A_{ij} = a$. The measurement of these logical preferences takes place with the help of a judgement scale of point one to ten (1-10). For example, if in the row of component *i*, in the column of component *j* has a written value 10, then the component *i* is much more important than the component *j*. Similarly, in the row of criterion *j* and the column of criterion, *i* is the written inverse value of 0.1. The rows and columns with the same number have a written value of 1. The mathematical representation of a sample matrix is in equation (1):

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

$$Where\ A = a_{ij},\ a_{ij} > 0 \text{ and } \frac{1}{a_{ji}} = a_{ij}$$

$$[a_{ij}], where, i, j = 1, 2, \ldots., n$$

A = n × n n signifies the comparison numbers of the system-components, “A” indicates the criteria (S, O, and D), and a_{11} - a_{1n} and the other variables in the equation denote the PWC(s). To find the weights of all the criteria and the local weight of the alternatives from the PWC matrices, every value in a column ‘*j*’ is divided by the sum of the values in a column ‘*j*’. The total value of the columns in the matrix must be equal to 1, which implies the normalisation of the PWC matrix (Ansah et al., 2017). This is depicted in the form of the given equation (2):

$$Aw = \begin{bmatrix} \frac{a_{11}}{\sum a_{i1}} & \frac{a_{12}}{\sum a_{i2}} & \cdots & \frac{a_{1n}}{\sum a_{in}} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \frac{a_{n1}}{\sum a_{i1}} & \frac{a_{n2}}{\sum a_{i2}} & \cdots & \frac{a_{nn}}{\sum a_{in}} \end{bmatrix} \quad (2)$$

The next step in this process is to determine the global weights of the alternatives through the synthesis of the local weights. The eigenvector of matrix A is obtained by calculating C_i as the average; the C_i as the average values in the row ‘*i*’ of Aw matrix will be determined for the column vector C where the C_i value denotes the relative degree of significance. It is illustrated as equation (3):

$$C = \begin{bmatrix} C_1 \\ \vdots \\ \vdots \\ C_n \end{bmatrix} = \begin{bmatrix} (\frac{a_{11}}{\sum a_{i1}} + & \frac{a_{12}}{\sum a_{i2}} + & \cdots & + \frac{a_{1n}}{\sum a_{in}})/n \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ (\frac{a_{n1}}{\sum a_{i1}} + & \frac{a_{n2}}{\sum a_{i2}} + & \cdots & + \frac{a_{nn}}{\sum a_{in})})/n \end{bmatrix} \quad (3)$$

Since people's assessments are inconsistent to a considerable extent, the modified-RPN does not need the judgment matrix's consistency to be entirely matched or complemented. However, it is expected to be less than a certain upper limit. One of the benefits of this system-based RPN calculation with PWC is the scope for a consistency test. This enables the detection of judgement errors through the calculation of the consistency ratio (CR). The CR shows the degree of deviation of the judgement result (Štefan et al, 2000). The consistency vector needs to be calculated (A x C Matrix) for the synthesis of CR. After this, the x_i is calculated by multiplying A and C (Ansah et al., 2017). It is shown in equation (4):

$$A \times C = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \times \begin{bmatrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \quad (4)$$

In the subsequent step, the λ_{max} is estimated. The λ_{max} is calculated with the help of the following equation (5):

$$\lambda_{max} = \sum_{i=1}^{n} \frac{x_1}{C_1} \quad (5)$$

Where λ_{max} *is the eigenvalue of the PWC matrix*.

Following this, the approximation to the consistency index (CI) is made (Ansah et al., 2017). This is expressed as equation (6):

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (6)$$

In the final step, the consistency judgement for appropriate value of n by CR has to be determined to ensure the consistency of the PWC matrix, as shown in the equation (7):

$$CR = \frac{CI}{RI} \quad (7)$$

RI denotes the random consistency index and the RI values for different numbers of n as shown in Table 1. If CR ≤ 0.10 (10%), then the degree of consistency is considered to be satisfactory; if CR is more than 10%, then it indicates major inconsistencies.

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 1. Random Consistency Table (Aziz et al., 2015; Ansah et al., 2017)

Next, after consistency tests, is to use the global weights of the alternatives (Ai) for each criterion S, O, and D to construct the final RPN decision-matrix. This is shown in equation (8):

$$\begin{array}{c c} & \begin{array}{ccc} \text{Severity} & \text{Occurrence} & \text{Detection} \end{array} \\ \begin{array}{c} A_1 \\ \cdots \\ A_n \end{array} & \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ \cdots & \cdots & \cdots \\ C_{n1} & C_{n2} & C_{n3} \end{bmatrix} \end{array} \quad (8)$$

The Risk Priority Number (RPN) represents the overall level of risk for every component of the system being analysed. The conventional RPN formula (Sorooshian, 2015): RPN = S × O × D; is used for calculation, as shown in equation (9):

$$\text{RPN}(A_i) = C_{i1} \times C_{i2} \times C_{i3} \quad (9)$$

Lastly, from comparison of RPN(A_i)s, the decision maker could identify the riskiest component of the system for prioritizing the correction actions.

3. Conclusion

The foremost reason for the defects mentioned in the conventional RPN approach is the selection of inappropriate factors (S, O and D) for evaluating the data gathered in the production line. On the other hand, the comparison method is simpler to comprehend and more intuitive for the workers to analyse the RPN criteria (Zhao, 2013). This study presented a quantitative analysis method for calculating RPN for each component of a system. There are three main steps in this method: establishment of judgement matrix, consistency test, and calculation of RPN. This method is simple, practical, and flexible. It also uses a mathematical formula to determine the weights which reflect the relative S, O, and D for each component of the system. To conclude, the method calculates the comparative weights of all the RPN criteria by taking into consideration the membership of the components in a functioning system.

Acknowledgment
This study thanks flagship grant, RDU172205, from Universiti Malaysia Pahang.

References

[1] Ansah, R.H., Sorooshian S., Shariman M. (2015). Analytic hierarchy process decision making algorithm. *Global Journal of Pure and Applied Mathematics*, 11(4), 2393-2400.
[2] Ansah, R.H., Sorooshian, S, Mustafa, S, Oludapo, O.S. (2017). Constructions project management risks' framework. *Quality-Access to Success*, 18(158), 90-95.
[3] Aziz, N.F., Sorooshian, S, Fatimah M. (2015). MCDM-AHP method in decision makings. *ARPN Journal of Engineering and Applied Sciences*, 11(11), 7217-7220.
[4] Cox LA Jr, B.D. (2005). Some limitations of qualitative risk rating systems. *Risk Analysis*, 25(3):651-62, DOI:10.1111/j.1539-6924.2005.00615.x.
[5] Eva Nedeliaková, M.P. (2015). New Trends in Process-Oriented Quality Management. *Procedia Economics and Finance*, 4: 172-179, DOI: 10.1016/S2212-5671(15)01616-0 .
[6] Jr, C.L. (2008). What's wrong with risk matrices? *Risk Analysis*, 28(2): 497-512, DOI:10.1111/j.1539-6924.2008.01030.x.
[7] Rapinder Sawhney, K.S. (2010). A modified FMEA approach to enhance reliability oflean systems. *International Journal of Quality and Reliability Management*, 27 (7): 832-855, https://doi.org/10.1108/02656711011062417.
[8] Sorooshian, S. (2014). Delay-based reliability analysis on construction projects. *Life Science Journal*, 11(SPEC. ISSUE 3), 104-113.
[9] Sorooshian, S. (2015). Project risk-based reliability control. *Proceedings of the 2014 International Conference on Industrial, Mechanical and Manufacturing Science*, 13-16.
[10] Sorooshian, S., Ze En Ler (2017). Lean tools application failure. *International Journal of Applied Business and Economic Research*, 15(18), 425-443.
[11] Štefan Kudláč, Vladimíra Š., Jozef M. (2017). Using the Saaty Method and the FMEA Method for Evaluation of Constraints in Logistics Chain. *Procedia Engineering*, 187: 749-755, https://doi.org/10.1016/j.proeng.2017.04.433.
[12] Thanh-Lam Nguyen, D.H.-H. (2016). Modifying risk priority number in failure modes and effects analysis. *International Journal of Advanced and Applied Sciences*, 3(4):76-81.
[13] Xiulan Zhang, GB. (2014). Advancing the application of systems thinking in health: managing rural China health system development in complex and dynamic contexts. *Health Research Policy and Systems*, 12, https://doi.org/10.1186/1478-4505-12-44.
[14] Zambrano L, Sublette K, Duncan K, Thoma G. (2007). Probabilistic reliability modeling for oilexploration and production (E&P) facilities in the tallgrass prairie preserve. *Risk Analysis*, 27(5): 1323-1333, DOI:10.1111/j.1539-6924.2007.00961.x.
[15] Zhao, Y., Fu, G., & Wan, B. (2013). An improved risk priority number method based on AHP. *Reliability and Maintainability Symposium*, DOI :10.1109/RAMS.2013.6517757.