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by Agung Sutrisno

The Robust Corrective Action Priority- An Improved Approach For Selecting Competing Corrective Actions In FMEA Based On Principle Of Robust Design

Agung Sutrisno
Department of Mechanical Engineering
Sam Ratulangi University, Kampus Bahu, Manado, Indonesia 95115
E-mail Address: agungsutrisno@unsrat.ac.id

Indra Gunawan
Entrepreneurship, Commercialization and Innovation Center
Adelaide University, Adelaide SA5005, Australia
E-mail Address: indra.gunawan@adelaide.edu.au

Iwan Vanany
Department of Industrial Engineering
Institut Teknologi Sepuluh November (ITS),Surabaya

E-mail address: vanany@ie.its.ac.id

***Abstract*—In spite of being integral part in risk – based quality improvement effort, studies improving quality of selection of corrective action priority using FMEA technique are still limited in literature. If any, none is considering robustness and risk in selecting competing improvement initiatives. This study proposed a theoretical model to select risk –based competing corrective action by considering robustness and risk of competing corrective actions. We incorporated the principle of robust design in counting the preference score among corrective action candidates. Along with considering cost and benefit of competing corrective actions, we also incorporate the risk and robustness of corrective actions. An example is provided to represent the applicability of the proposed model.**

Keywords : FMEA; Corrective Action; Signal to Noise Ratio; Risk; Robustness.

I. INTRODUCTION

Within risk management pillar, selecting competing corrective actions has equal importance with ranking the risk of failure occurrence in risk -based quality improvement efforts [1]. Nevertheless, investigations devoted to improve the risk-based corrective action selection method as response to the occurrence of faulty operations are still seemed limited and less explored research area [2]. Selecting corrective action is a complicated, problematic and risky decision making process. In addition, it is commonly still selected based on decision makers' subjectivity, intuition and experiences [3]. In previous references, many methodologies have been proposed to improve methodology of the FMEA-based corrective action prioritization. For instance, Bluvband, Nakar and Grabov 2004)[4] presented the use of RPN and failure occurrence rate reduction ratio before and after implementing corrective action. Esmailian et al., (2008)[5] proposed Risk Priority Number (RPN) reduction based on RPN and Overall Equipment Efficiency (OEE) index relationship. Carmignani (2009)[6] introduced economic -based ranking corrective action methodology by suggesting on the use of Priority – Profitability Diagram. Niu et al. (2009)[3] exemplified on the use of grey theory on ranking corrective actions. Childs (2009)[7] used the logarithmic scale of the RPN transformation. Hekmatpanah et al. (2011)[8] presented the use of scrap reduction ratio as basis to rank corrective action. Zammori and Gabbrielli (2011)[9] presented the use of ANP (Analytical Network Priority) for selecting risk-based corrective actions. Sutrisno et al., (2016)[10] introduced the integration of SWOT Analysis into FMEA-based improvement strategy selection. From the study of previous FMEA- based corrective action selection references; we observed that the possibility that noise variables which may impede implementation of selected corrective actions is still neglected in selecting corrective improvement priority. In addition, the reality that selecting CA is a risky process is seemed being overlooked by previous studies. Ignoring the influence of above mentioned factors in selecting corrective actions are not appropriate as those may hamper the goals of decision makers in curbing root cause of quality problems. In an attempt to provide a robust and risk considering corrective action, in this study, the robustness and quality loss function as surrogate of risk is incorporated in a new model for selecting competing corrective actions. We presented the use of robust design-based corrective action prioritization as basis for ranking corrective action. As an aid for ranking multiple options in decision making, the preference score to rank competing corrective actions which considers cost, benefit, robustness and risk of competing corrective action options simultaneously is presented. The structure of the paper is as follows. In section II, a model describing the component of robust corrective action in FMEA consisting of signal, control, and noise variables are presented and followed by formulation of control and noise priority score. In section III, a model representing corrective action priority score based on the Risk Priority Number (RPN), robustness component, impact and effort ratio and risk is presented and followed by a case example. Discussions and Conclusions are presented in section IV and V respectively.

II. ROBUST CORRECTIVE ACTION SELECTION MODEL

A. Signal-Control and Noise Variables of Corrective Actions

A corrective action as manifestation of risk response or recovery effort is a kind of activity with has numerous interrelated entities such as input, output, control, suppliers, customer, and noise variables. By representing corrective action into a model that enables to represent interrelationship of above-mentioned entities, we can easily map all possible factors that hinder and or accelerate in implementing corrective actions. Parameter Diagram (P Diagram) can be defined as a graphical representation of any parameters which may influence the systems, products, processes being observed to yield intended and unintended outcomes [11]. The use of P Diagram will beneficial toward achievement of robust corrective action [12]. In the followings, related terminology concerning to robust corrective action selection formulation is provided.

Signal factors is defined as any factors becoming input to determine the degree of robustness of targeted goals as intended by decision makers. The value of signal factors can be determined based on decision makers' judgments and or from customers' input.

Control factors are any factors whose value determines the controllability of corrective actions. The identification of control factors can be determined by using decision makers' judgment, preliminary test, or previous experiences. Since the company spending financial and intellectual capital in mitigating negative impact of noise variables, financial and organizational competency attributes can be used as basis to estimate the value of control factors. Some other organizational attributes such as adequacy of facilities and quality of administrative control and its supporting data can be used as control variable.

As the name imply, the occurrence of noise variables impede in implementing the selected strategy, their negative impact shall be estimate quantitatively. In this paper, the risk due to the noise variables can be estimated based on their impact to influence the response variables and the possibility that the noise variable occurrence which may base on time span as criterion. The score of Noise Priority Index (NPI) of noise variable k can be formulated by equation (1).

$$NPI_k = O_k IF_k \quad (1)$$

The rating representing the value of noise occurrence probability and impact factors of noise variables against intended response can use a Likert like ordinal scale.

Following Jugulum and Samuel[13], the degree of robustness of a corrective action is represented by the value of signal to noise ratio (S/N ratio). The higher the value of signal to noise ratio, the more robust the corrective action will be. However, in this paper, the S/N ratio is formulated as the comparison between signal and noise priority index as represented in equation (2). The signal to noise ratio of a particular corrective action CA_k is then represented by equation (2).

$$SNR_k = CCA_k / NPI_k \quad (2)$$

The larger value of the S/N ratio of certain corrective action represents the larger degree of corrective action robustness and that is the most desired by decision makers.

In an attempt to solve critical quality problem, FMEA team spent resources in the form of financial, time, human skill and materials in implementing corrective improvement efforts. From this point of view, all necessary inputs to accomplish specific improvement activities are called efforts [14]. According to Yasin and Alavi (2007)[15] and Henriksen and Røstad (2010)[16], some categories of company goals in implementing strategy are; to improve quality, increase sustainability, maximize profitability, and company growth. Depending of the specific targeted goal, every targeted goal usually requires different efforts level. For ease of calculation, all above efforts variables are quantified by monetary metrics, the implementation cost of corrective action $ICCA_k$. When decision maker decided to select specific corrective action, a positive impact is certainly expected. The impact of an effort can be defined as the amount of benefit from which a corrective action task will be implemented. The benefits of selected strategies can be categorized into three classes; financial, operational, and organizational benefits. Depending on the benefit category, the value of strategy benefit can be defined using some measures such as level of customers' satisfaction, financial gain, and reduced time to markets and so on. Usually to estimate the benefit of proposed corrective action, the monetary metric such as the net present value (NPV) preferably used. However, since the outcome of competing corrective actions are unknown until being implemented, pair wise comparisons among some measures of above mentioned benefits using the AHP (Analytic Hierarchy Process) can be useful in estimating corrective action benefit in qualitatively manner. The power of AHP when used to weight the benefit of efforts of competing corrective action is also justified since criteria to determine the impacts of benefits are possibly heterogeneous in nature [17]. The brief procedure to use the AHP to weight the benefit of competing corrective actions can be referred to [18]. Besides considering the implementing cost (effort), expected benefit (impact), decision makers should also consider the risks may incur in selecting corrective action candidates. The risk of selecting specific corrective action shall be considered since uncertainty is unavoidable prior implementing strategy [19]. In the model, the risk is defined as any unintended outcome of the corrective action's implementation. According to their typologies, the risks inherent in selecting strategy may be classified into some categories such as resources, competitors, customers, political, and technical risks [20]. Following Taguchi's quadratic loss function categories and assuming that generally decision makers are risk averter, the quality loss function model of the smaller the better (STB) category will be chosen as top priority. Therefore, the equation to estimate the risk of selecting specific corrective action can be represented by equation (3).

$$LCA_k = kX^2 \quad (3)$$

Where k represents the cost coefficient that related to the targeted outcome of specific corrective action and X related to the performance specification targeted by decision makers.

Based on the idea that decision makers will choose the corrective action having the largest signal to noise and impact and effort ratio and the least risk; therefore, by combine equation (1), (2), (3), the preference scores (PS) of each corrective action CA_k can be represented as in equation (4):

$$PSCA_k = RPNFM_k SNR_k BCA_k \ / IC_k LCA_k \qquad (4)$$

III Case Example

As an example to demonstrate the model on offer, an FMEA sheet excerpted from [21] is used. It is pertaining to the application of FMEA in ranking the risk of service failure in consumers' good service. In the case example, single critical failure "unreliable supply of goods" is used as basis to select competing corrective actions as depicted in table 1. Note that all variables in the case example are hypothetical and merely used for illustrative purpose only.

TABLE I. A CASE EXAMPLE

Service Failure Mode	RPN	Possible Cause	Potential Corrective Action
Unreliable supply of goods/ merchandise (FM1)	27.29	• Poor supplier evaluation and relationship • Inappropriate supplier relationship management • Insufficient inventory of suppliers • Inadequate marketing research • Lack of upward communication • Insufficient customer relationship focus	• Performing supplier evaluation (CA_{11}) • Improve supplier relationship(CA_{12}) • Add adequacy of suppliers(CA_{13}) • Improve technique of marketing research(CA_{14}) • Facilitate upward communication(CA_{15}) • Improve focus on customer relationship communication(CA_{16})

Using Table 1, the risk of service failure mode "Unreliable supply of goods/merchandise (FM1) is 27,29. The occurrence of FM1 is possibly due to many root causes ranging from "poor supplier evaluation and relationship" until "Failure to match supply and demand". Linking possible root causes with potential corrective actions, for solving "unreliable supply of goods / merchandise", the corrective action options are many, started with "Performing supplier evaluation" until "Improve capability to perform supply and demand estimation". Following our idea to consider influence of noise, control, impact, effort and risk of competing corrective actions, the variables of above element of case example is described in table III. The score of Noise Priority Index is based on equation (2). The impact of corrective action is based on the AHP-based pairwise comparison of benefits. Meanwhile the score of effort is based on the implementing cost represented by ordinal scale ranging from 1 to the least cost and 5 to the largest score. Taguchi loss function is used as basis to determine the corresponding risk of corrective action. The risk

The result of the calculation of the hypothetical corrective actions of case example is given in Table II and III

TABLE II. NOISE, CONTROL AND RISK VARIABLES OF CASE EXAMPLE

Corrective Action	Noise Variable	Control Variable	Risk
• Performing supplier evaluation (CA11)	Possibility of supplier resistance (N11); Knowledge gaps among FMEA team to perform Supplier Evaluation (N12)	Known procedure to evaluate suppliers Having experiences in evaluating suppliers	Negative responses from suppliers Degrading employee morale when supplier evaluation failed
• Improve supplier relationship(CA12)	Unknown procedure to improve supplier relationship Lack of communication skill Unknown suppliers needs	Possessing capable persons to improve suppliers relationship management	Suppliers shift to competitors
• Add adequacy of suppliers(CA13)	Lack of Financial capability to enlarge suppliers adequacy	Having loyal suppliers	Cost Overrun

TABLE III. PREFERENCE SCORE OF CASE EXAMPLE

Corrective Action	S/N Ratio	Benefit/ Cost Ratio	Loss Score	Preference Score
• Performing supplier evaluation (CA11)	0.080	0.00053	80	14.46
• Improve supplier relationship(CA12)	0.00026	0.00042	25	1.19
• Add adequacy of additional suppliers(CA13)	0.005	0.00053	65	1.11

Considering to the value of the preference score that will be meaningless based on the result of the calculation using equation (4), the constant of 10^6 is applied to the result of preference score in Table III. Accordingly, as having the largest score, corrective action "Performing supplier evaluation" should be chosen as top priority among two other competing corrective actions.

IV. DISCUSSIONS

Considering to the characteristics of corrective action selection as a risky process, this paper proposed an alternative method for selecting competing corrective action based on four criteria, the risk of failure effects, robustness, impact and effort ratio and risk of implementing a particular corrective action. In an attempt to map of all necessary input and expected output of competing corrective actions, a preference score which considers above-mentioned criteria is used to weight the attractiveness of competing corrective actions. By utilizing the proposed model and compare with previous approaches in ranking corrective actions, some advantages for academic and practical purposes offered can be elaborate briefly as follows. First above all, the proposed model is relatively simple for use for practical purpose and covers all mentioned gaps in previous FMEA-based corrective action improvements. If compare to previous approaches in ranking corrective actions, by incorporation of robustness index upon utilizing the P Diagram, decision makers can estimate and prepare company resources with any necessary actions to mitigate the adverse effect of noise variables. Utilizing the Diagram can facilitate the FMEA team in preventing any overlooked factors that may cause failed corrective action. Thus, it is also enable to increase the reliability of proposed corrective actions. The theoretical procedures presented here provides exemplary on how to tackle complexity of corrective action selection based on risk and robustness as overlooked factors in previous studies. In spite of having potential benefit for both academic and practical purposes, the theoretical model presented in this study also own some shortcomings. First, since based on conceptual model, the proposed model is lack of strong validity and generalization to other service types. In addition, the proof of economic benefit between conventional and robust – based FMEA corrective action prioritization should be re-tested in practice by hypothesis and other statistical testing. Secondly, even though the use of Taguchi loss function is enabling to estimate the magnitude of risk of implementing corrective action quantitatively, the probability occurrence of failed corrective action is not considered that inappropriate in real application. At last, the equation to estimate the preference score is based on consideration on the occurrence of negative risk only. In real situation, there are positive risks (opportunities) which may give positive effects in accelerating the implementation of corrective actions and that is not accommodate in the proposed model.

CONCLUSIONS

Improving robustness and inclusion of the FMEA- based corrective action selection is important for sustaining business improvement effort. Nevertheless, previous endeavors in proposing methods to select corrective action upon FMEA - based improvement accomplishment are overlooking on considering the robustness and risk of implementing corrective action. Ignorance on robustness and risk is inappropriate, as in reality in the improvement planning, uncertainty, and risk in inherently incurred. In attempt to narrow down the gap, in this study, a conceptual model of decision support for weighing competing corrective action is proposed. A model of preference score to rank competing corrective action which considers robustness, risk, benefit and impact of corrective action are proposed. Exemplary on how to implement the robust-based FMEA based corrective action based on case example is provided. This study is based on case example with hypothetical variables used. Future studies have to reiterate proposed model by real application and within various settings and also accompanied by sensitivity analysis to obtain better reliability and generalization of the model. It is also important to reconsider the categorical data in estimating the S/N ratio in future studies. Finally, since company may face numerous constraints prior selecting strategy, extending this study by incorporating *the Theory of Constraint* with inclusion of non-monetary metrics is still warrant for investigation.

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