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AN EFFECTS ANALYSIS OF MODIFYING RISK PRIORITY NUMBER IN FAILURE MODES: A PRACTICAL APPROACH

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ABSTRACT

Failure modes and effect analysis (FMEA) significantly encourages the endeavors of mechanical makers in organizing failures that require remedial activities to persistently enhance item quality. Notwithstanding, the routine approach neglects to give palatable outcomes in some down to earth applications. Along these lines, this paper shows a changed plan of risk priority number (RPN) utilized as a part of FMEA by considering quality cost as an extra determinant to mean the priority level for every failure mode. Adequacy of the modified RPN plan is assessed on an assembling chain of aluminum jars utilized for lager and soda pops. Examination comes about show that the adjusted plan beats RPN in lessening the rate of blemished items, i.e. from 14% preceding the test to 4% by the modified number contrasted and 6% by the conventional one.

Keywords: *Failure modes and effect analysis, risk priority number*

1. INTRODUCTION

Failure modes and effect examination (FMEA) has been considered as a viable analysis apparatus generally utilized as a part of a few created nations, for example, Japan, USA, and Europe in various businesses, for example, vehicle, hardware, family units, vitality plants, media communications, drug store, social insurance administrations, online business, item outline, and so forth., since it gives both subjective and quantitative measures to recognize failures and their belongings towards the nature of items/administration. Especially, FMEA [1] assesses failure modes and their conceivable causes in a size of 10 for three distinct angles, including: Severity rating (S), Occurrence rating (O), and Detection rating (D) in light of the rules in Table 1.

From the above appraisals, a supposed Risk Priority Number (RPN) for a specific cause is dictated by Eq. 1. A cause with higher RPN ought to be priorly treated; i.e. restorative activities to either dispense with or lessen failures ought to begin with the most elevated organized causes. All things considered, FMEA is a compelling device in organizing failures that require remedial activities to enhance item quality.

$$RPN=S*O*D$$

Nonetheless, traditional FMEA neglects to give adequate segregation control in a few conditions since it selects a similar weight for the greater part of the evaluations [2]; implying that they effectly affect the RPN. Indeed, S and O are two noteworthy influencing elements that ought to be more organized [3]. For cases, how about we consider a failure mode with three distinct causes A, B, and C whose evaluations are individually given as (SA=8, OA=5, DA=4), (SB=10, OB=4, DB=4), and (SC=5, OC=4, DC=8); and their RPNs along these lines are all equivalent to 160. For this situation, if just RPN is thought about paying little heed to the appraisals of seriousness, event, and discovery, none of the causes ought to be organized, prompting to scattering and wasteful usage of constrained assets, or even a few causes that have significantly negative effects may neglect to pull in extraordinary consideration.

To conquer the above inadequacy in incline producing frameworks, [4] proposed an option list called Risk Assessment Value (RAV) decided by Eq. 2

Table 1: Rating scaleguidelines

Rating value	Severity	Occurrence	Detection
1	insignificant	extremely unlikely	absolutely certain to detect
	↓	↓	↓
10	catastrophic	inevitable	no control exists

They trusted that productive location and control of failure assume essential part in limiting failure event and failure seriousness. Benchmarking the execution amongst RPN and RAV, [5] pointed that RAV gives better priority orders. In any case, with our previously mentioned illustration, the RAV of A, B, and C are individually gotten as RAVA = 10, RAVB=10, and RAVC=2.5; henceforth, amongst A and B, which one ought to be organized is still obscure. This demonstrates however RAV performs superior to RPN, despite everything it neglects to give adequate matchless quality in settling on ultimate conclusion in such cases.

$$RAV=O\times S\times D$$

In the mean time, [6] recommended utilizing a purported "Expected cost" to present S though utilizing likelihood to gauge the O and D. In any case, practically speaking, the normal cost ought to be considered in accordance with specialized issues: generation strategies that cause the failure and failure identification systems. Besides, extraordinary enterprises have diverse failures which are named repairable and hopeless, i.e. their expenses are differed. All the more vitally, once failures are not completely identified and disposed of before getting to shoppers, went with guarantee cost, pay cost for issues happened in utilizing the defective items/administrations would emerge; and even the imperceptible cost for business notoriety/brand would truly influence the execution of the entire association. These costs, hereinafter, are alluded in a more broad term as "Quality cost". Therefore, to cure the above downsides, this paper proposes incorporating the quality cost as an extra figure the routine RPN equation to improve its segregation control in dissecting failure modes and their belongings. Our proposed recipe is called "Modified Risk Priority Number" (MRPN) [7].

Whatever is left of this paper is sorted out as the accompanying. Area 2 presents essential definitions generally utilized as a part of FMEA while MRPN is developed in Section 3. Segment 4 talks about a contextual analysis at an organization creating aluminum jars for lager and soda pop industry to show the down to earth appropriateness of our proposed MRPN.

2. PRIMARY DEFINITIONS

Failure modes

Failures are any errors or defects, especially ones that affect the potential or actual customers. “Failure modes” means the ways that failures arise. Keyinputs and production process play critical role in the quality of product/service. Thus, fully identify possible failures at each stage of the process is always expected so that manufacturers/ service providers can implement suitable actions to either eliminate or reduce their negative effect, minimize production cost, and satisfy customer demands [8].

Effects

Effects of a failure refer to the consequences caused by the failure to the quality of a product/service. They can be evaluated with the satisfaction level or perception of customers who are either external customers or internal customers who are the users in the next stages of the process [9].

Cause

Cause is the source of variations and failures. Hence, to improve the quality of product/service, it is the best that possible causes should be fully identified so that we can have proper solutions to effectively deal with them. One of the commonly used tools is the Cause-Effect Diagram, also called Fishbone Diagram [10].

Control system

It is actually a system of facilities and control methods to prevent or detect failures in all phases of production process before faulty products/services are delivered to customers. Such systems can obviously abate profitless costs and time as well as other inextricable issues that may occur in the future. Therefore, an effective quality control system is always a permanent desire of every manufacturer/service provider. Depending on particular industry and their level of applying science – technology, the control systems can be either done manually or operated automatically with modern equipment [11].

3. PROPOSED MODIFIED RISK PRIORITY NUMBER

This section presents the development of our proposed modified risk priority number (*MRPN*).

Assume that there are *n* identified failure modes existing in a production process. For j^{th} mode *(j=1, 2,..., n)*, the following denotations are used.

- :occurrence probability of the j^{th} mode (given by experts);
- :detection probability of the j^{th} mode (given by experts);
- :severity level of the j^{th} mode from technicalperspective (in service industry, is actually the timing of the process); evaluated in a traditional scale of 10;
- :severity level from economic perspective in internally dealing with the j^{th} mode; thus, it closely relates to a so-called "internal failure costs";
- : Severity level from economic perspective in externally dealing with the j^{th} mode; i.e. the level of external costs occurred after non-detected faulty product/service is delivered to external customers; thus, it closely relates to a so-called "external failurecosts".

Then, a new index *MRPNj* of the j^{th} failure mode is determined by:

$$MRPN_j = P_o^j \times S_t^j \times \left[\frac{max\{P_D^1, P_D^2 \ldots P_D^n\}}{P_D^j} \times S_I^j + \left(1 - P_D^j\right) \times S_E^j\right] \quad (3)$$

Eq. 3 with the quantity of $\left(1 - P_D^j\right)$ obviously considers the effects of a failure when it is not detected by the control system. Besides, *MRPN* and the conventional *RPN* have some similar characteristics; for example, the lower detection probability in *MRPN* (i.e. P_D^j smaller) is respectively to the higher of D in RPN, which is shown in $\frac{max\{P_D^1, P_D^2 \ldots P_D^n\}}{P_D^j}$in Eq. 3. Moreover, $\left(1 - P_D^j\right)$ so reflects the effect of external failure costs on the amplitude of *MRPN*; specifically, if the probability of detecting failures is low, the chance of a faulty product/service delivered to customers is certainly high, resulting in higher *MRPN*; meaning that the j^{th} failure mode would be more prioritized. The values of *ST*, *SI*, and *SE* are evaluated as the following [12].

Evaluation of severity of failures from technical perspective ST

The seriousness level of specialized failures (ST) is resolved in view of key necessities about innovation, style, principal qualities and determined gauges. Essentially, the failures might be come about because of info materials, creation handle, control strategies, work, offices, and even from the effects of workplace. Thus, for every failure (potential or recognized), we have to precisely distinguish its significant causes with the goal that we can assess the cure probability as far as innovation, process, offices, control techniques and work powers, and so on. It is likewise basic to assess its negative effects on the following stages in the creation procedure, item quality and client discernment. Therefore, the seriousness ST in MRPN is really the seriousness level S in the conventional RPN. Table 2 represents a case of the assessment of the specialized seriousness ST utilized for reduced fluorescent tube produced in Company P specified in Section 4 [13].

Severity	Impact level	Evaluation criteria
10	Extremely serious, unpredictable	Technical failures can't be detected from production process; e.g. cracked circle, cracked tipping, cracked stress-bending, etc.
9	Extremely serious, predictable	Technical failures only detected after checking finished products; e.g. cracked head, kaput bulb, lessened luminosity, etc.
8	Serious	Technical failures only detected after completing production; e.g. wrong dimensions, deficient loading pressure/electric current/voltage/color transfusion/ initial light band, etc.
7	High	Technical failures priority long time to be remedied; e.g. mock-marked weld, cracked weld-point, blackened/ stained electrodes, etc.
6	Quite high	Failures affecting next stages; e.g. mouth-contorted weld, semi-product dimensions, high tipping, etc.
5	Significant	Failures affecting finished product beauty; e.g. flaked fluorescent, arch rib, bubbled coating, etc.
4	Quite significant	Failures due to equipment can be immediately remedied; e.g. greasy tube, chipped bend, scratched neck, redundant/deficient mercury, etc.
3	Low	Failures due to operational failures.
2	Very low	Normal failures only affect the cost of materials; e.g. dirty wash/bend, fluorescent slip, bubbled bend, etc.
1	Extremely low	Almost no impact on product quality.

Table 2: Evaluation of severity level ST from technical perspective

As mentioned above, quality cost closely related to quality assurance of semi-products and finished products in all stages of production process from inputs to outputs and using period by customers. The quality cost can be divided into four groups: (1) Prevention costs; (2) Appraisal costs; (3) Internal failure costs; and (4) External failure costs (Montgomery, 2013). Among them, the first two groups are controllable while the last two ones directly relate to production process which accounts for a significant part of the total cost of an organization. So, this paper investigates the last two groups as a key component in our proposed *MRPN [14]*.

Internal failure cost (IFC)

IFC are actually the costs occurred due to the quality incompliance of any component, part, material, product, and/or related service provided that defective products are detected before being delivered to customer. *IFC* takes a value of 0 if no defective product is found prior to delivery. Particularly, it consists of the following components: scrap; rework; retest; failure analysis; downtime; and yield losses, etc.

External failure cost (EFC)

EFC includes all costs occurred due to the failures detected after products are delivered to customers. It takes a value of 0 when all products meet specified requirements. *EFC* consists of the following components: field servicing and handling complaints; recalls, returns, replacements; warranty; other indirect costs because defective products/services lead to the dissatisfaction of customers and their negative impression about the products/services and the manufacturers/providers; consequently, damage customer good-will, lose sales due to bad reputation, etc.

Therefore, for every failure mode, we priority to carefully and fully identify associated *IFC* and *EFC* so that we can have proper solutions for quality improvement.*IFC* and *EFC* can be respectively converted into *SI* and *SE* with the following procedure. Assume that we have *n* failure modes inthe production process of a product. Let IFC_j and $EFC_j\,(j = 1, n)$ respectively denote the internal and external failure costs of the jth mode. S_I^j and$S_E^j$are then determined by:

$$S_I^j = \frac{IFC_j}{FC_{min}}; \qquad S_E^j = \frac{EFC_j}{FC_{min}} \qquad (4)$$

The determination of and shown in Eq. 4obviously not only overcomes the shortcomings of the *RPN* in conventional *FMEA* approach and the *RAV*proposed by Sawhney et al. (2010) but also considers the severity level of two prominent quality costs namely *IFC* and *EFC* of the same failure mode; i.e. for a failure whose *SE* is higher than *SI*, we can conclude that the inspection for defects should be especially concerned in the final stage of quality control to minimize defective products delivered to customers because its external cost is higher than that if internally detected; or, if *SI* is higher than *SE*, we priority to carefully investigate and eliminate the causes for the failures in each stage of the production process [15].

4. PRACTICAL APPLICATION

In order to evaluate the applicability of the proposed *MRPN*, we conduct a practical study at Company P specializing in producing aluminum cans used in beer and soft drink industry, located in Dong Nai province, Vietnam. Basically, the company usually has a critical problem in delivery schedule because their defective cans account for about 14% of total manufactured products. Such high percentage of defective cans certainly reduces the annual performance of the company. To deal with this problem and minimize the number of defective products, we set up an *FMEA* team consisting of 15 members who are administrators, top engineers, leaders of related departments, and group leaders. The team focuses on analyzing production process and identifying major failure modes in each production stage as shown in Table 3 [16].

Table 3: Evaluation of severity level ST from technical perspective

Production stage/phase	Failure modes
Oil coating	Superfluous oil, insufficient oil
Cup banging	Irregular thickness, scratched/ rumpled body, rumpled bottom
Cup refining	Holed/ rumpled/ torn cup
Edge cutting	Irregular cut, swarf agglutination, uneven/ unusual height
Cup washing and desiccating	Oily cup, spotted body and bottom
Vanish coating	Uneven coat, overlapped coat, inside-cup vanish
Printing	Incorrect tone, unexpected printing stroke, blurred colour
Lacquer coating and IBO desiccating	Uneven coat
Can-neck bending	Rumpled can-neck, deformed/rough edge

With the *FMEA* approach, the team determines the occurrence rate of each mode (*PO*), detection rate (*PD*), the severity levels of failures from technical and economic perspectives (*ST, SI, SE*). Consequently, the *MRPN* for each failure mode can be easily obtained.Finally, the team agrees to take corrective actionsagainst four modes that have the highest *RPN* and *MRPN* as shown in Table 4 clearly shows that the risk priority orders for the four failure modes are significantly different. Specifically, the traditional *RPN* results in a descending order as: (1) Holed/torn cup at the cup refining stage; (2) Rumpled cup at the cup banging stage; (3) Spotted cup at the cup washing and desiccating stage; and (4) Rumpled can-neck, deformed/rough edge at the cup-neck bending stage [17].

Table 4: Four major failure modes with the highest RPN and MRPN

Stage	Cup banging	Cup refining	Cup washing and desiccating	Can-neck bending
Failure mode	Rumpled	Holed, torn	Spotted	Rumpled, deformed/ rough
Causes	Improper pressure of banging piston; loose mold	Incorrect operation parameters, distracting workers	Substandard washing liquid, carelessly cleansing of rust	Swarf agglutinated shackle
Current control	After the stage; manual check	After the stage; manual check	After the stage; manual check	After the stage; manual check
O	9	10	6	5
D	4	4	7	5
S	8	8	5	7
RPN	288	320	210	175
PO	0.08	0.12	0.07	0.06
ST	8	8	5	7
PD	0.95	0.96	0.85	0.92
SI	12	15	16	18
SE	21	26	20	22
MRPN	8.43	15.40	7.37	8.63

5. CONCLUSION

FMEA approach has been widely applied in analyzing failure modes and their effects towards product/service quality as it can help manufacturers/ service providers to identify failures/ defects of their products/services, their severity levels as well as their negative effect on related stakeholders and their business performance. However, the traditional approach with the *RPN* consisting of three components, namely occurrence rating, detection rating and severity level, reveals certain disadvantages in prioritizing failures to be solved. Thus, this paper proposes an advanced index by modifying the conventional *RPN* with associated quality cost and the capability of failure detection system because the capability intimately relates to the possibility of defective products/services delivered to customers, i.e. such capability can either establish or damage the quality reputation of an organization. The performance of our modified index *MRPN* was tested in an empirical case at a company specializing in producing aluminum cans used in beer and soft drink industry. We found that the percentage of defective cans has been significantly reduced from about 14% before the trial period to 4% with the *MRPN* or 6% with the traditional *RPN* after the trial. Hence, *MRPN* outperforms *RPN* in identifying priority order to deal with detected failures.

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