Modified failure mode

by Stenly Tangkuman3

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ScienceDirect

Procedia Manufacturing 4 (2015) 23 – 29

Procedia MANUFACTURING

Industrial Engineering and Service Science 2015, IESS 2015

Modified failure mode and effect analysis (FMEA) model for accessing the risk of maintenance waste

Agung Sutrisno[a]*, Indra Gunawan[b], Stenly Tangkuman[c]

[a,c]Department of Mechanical Engineering Sam Ratulangi University, Kampus Bahu, Manado 95115, Indonesia
[b]School of Engineering and Information Technology Federation University, Gippsland, Australia

Abstract

The existence of methodology for ranking and mitigating the risk of non-value added activities in manufacturing strongly support the realization of sustainable manufacturing practice. However, endeavours to create tools and methodology to rank the risk of non-value added activities are mostly devoted on product design and manufacturing and very rarely in maintenance engineering discipline. Motivated by such scarcity, the goal of this study is attempted to develop a modified FMEA (Failure Mode and Effect Analysis) as means to access the criticality of waste in maintenance operations. In an attempt to facilitate decision makers in appraising the criticality of maintenance waste occurrence, an improved model for ranking the risk of maintenance waste mode by using Waste Priority Number (WPN) is proposed

Keywords: Modified FMEA, maintenance waste, Waste Priority Number (WPN), AHP (Analytic Hierarchy Process).

1. Introduction

Driven by growing issues pertaining to sustainability, nowadays global manufacturers face the challenge of

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: agungsutrisno@unsrat.ac.id

doi:10.1016/j.promfg.2015.11.010

creating sustainable manufacturing practice [1]. In order to cope with the above situation, development of engineering methodology for supporting sustainable manufacturing operations is believed to support the success in creation of sustainable manufacturing practices. While the role and contribution of studies advancing sustainability from product design and manufacturing discipline are abundantly available in literature, the situation is contrary from maintenance management and engineering discipline. According to Ventakasubramanyan (2005) [2], contribution of maintenance discipline supporting sustainable manufacturing operations is still mostly focus on extending equipment lifetime. Motivated by scarcity on studies to support creation of sustainable manufacturing operation from maintenance perspective, this study intended to develop modification of the engineering tool, the FMEA, to minimize the waste of maintenance activities from the lean manufacturing perspective. Instead of incorporating the impact of equipments' failure to the environment into its corresponding risk metric as exemplified by [3], this study takes another direction by developing model to rank maintenance waste by considering the hierarchy of maintenance waste causes and consequences of maintenance wastage. The structure of the paper is as in the following. In Section 2, a model to estimate the weight of maintenance waste causes and waste priority number (WPN) as surrogate of the RPN in conventional FMEA is provided. Section 3 relates to the research methodology and the criteria used to weight the maintenance waste causes and severity of maintenance waste effect. In Section 4 a case example and discussion of the proposed model are provided. Finally, conclusion and opportunities for further study are given in section 5.

2. Quantification of the maintenance causes weight using the AHP

When applying modified FMEA to appraise the risk of maintenance waste, a metric called the Waste Priority Number (WPN) is used as surrogate of maintenance waste risk. The WPN Index is having the similar function like the Risk Priority Number (RPN) in Conventional FMEA. The higher of the WPN score of a failure mode, the more risky the corresponding waste mode would be. In this regard, immediate corrective and or preventative measures should be taken to reduce the adverse consequences. In an attempt to find the root causes of critical maintenance waste problem, application of a typical root cause from vast array root cause analytical methods such as in [4] can be used for waste alleviation. Upon the root cause of maintenance waste occurrence identified, appropriate corrective measured is applied. Usually, for specific maintenance waste mode W_k there will be m maintenance waste causes CW_{ik}. Considering that each maintenance waste having its own degree of detect ability, probability occurrence, expected cost consequences, and difficulty to rectify, it is become necessary to determine their hierarchy for prioritizing preventative or corrective measures. The higher the hierarchy of maintenance waste cause, the more critical its weight would be. In this study, the hierarchy of maintenance root cause waste is represented by its maintenance cause weight$W_{WC_{ik}}$. If $W_{WC_{ik}}$ represents the weight of the maintenance causes affecting the occurrence of the waste maintenance mode k, then the weight of the waste priority score indicating the rank of the corresponding maintenance waste is given as in equation [1]

$$W_{WC_{ik}} = D_{C_{ik}} O_{C_{ik}} R_{C_{ik}} C_{C_{ik}} \quad (1)$$

The scale used to appraise above mentioned root cause of maintenance waste is given in Table1.

Table 1. Criteria for evaluation the hierarchy of maintenance waste cause

Scale	Detect ability of waste cause	Probability of occurrence of waste	Rectification Difficulty	Expected Cost
0.9-1.0	Absolutely difficult to detect the cause of waste	Certainty on the probability of cause occurrence	Impossible to rectify	Extremely high
0.8-0.9	Very difficult to detect the cause of failure	Very high probability of cause occurrence	Very difficult	Very high
0.6-0.7	Difficult to detect the failure cause	High probability	Medium difficult	Moderate
0.4-0.5	Medium difficult to detect the waste cause	Medium probability of detection	Low difficult	Medium
0.2-0.3	Easy to detect the waste cause	Low probability of detection	Very low difficult	Low
0.1	Very easy to detect the waste cause	Very low probability	Extremely low difficulty	Very low

detection

2.1. Waste probability avoidance score

The waste probability avoidance score reflects the probability of the maintenance waste avoidance during maintenance operation. Considering that probability is having a score ranging from 0 to 1, the determination of maintenance waste avoidance score is based on numerical value between 0 and 1. Numerical score 0 represents impossibility of a particular waste mode to be avoided and 1 represent the certainty to avoid the maintenance waste occurrence. Waste probability avoidance is denote as PWA_k. Since the number of many maintenance waste types may occur during a specific time period, in compliment with probability of maintenance waste avoidance scale, in this study, the frequency scale of maintenance waste is added and formulated as the ratio between the occurrence of a particular maintenance waste over the total of maintenance waste occurred.. Supposing that OW_i represents the score of the occurrence of maintenance waste mode i during period of (0, t), then the score of the occurrence rate of the maintenance waste of waste mode i is given by equation [2]

$$OW_i = \frac{ow_i}{\sum_{i=1}^{k} ow_i} \quad (2)$$

Table 2. Criteria for determining the score of the maintenance waste avoidance probability

Linguistic Interpretation	Time span criteria	Score
Very high probability of waste variable occurrence	Waste variable is happened all the time. It is impossible to avoid occurrence of waste variable	0.9-1
High probability of waste variable occurrence	Waste variable occur every 1 month. Low possibility to avoid waste variables	0.7-0.8
Medium probability of waste variable occurrence	Waste variable occur every 1-3 month. Medium possibility to avoid waste variables.	0.5-0.6
Low probability of waste variable occurrence	Waste variable occur every 4-6 month. High chance to get rid of waste variables	0.3-0.4
Very low probability waste variable occurrence	Waste variable may occur in more than 1 year. Very high chance to get rid of waste variables	0.1-0.2

2.2. Waste detect ability occurrence

By using control or inspection methods owned by firm, companies can determine the scale of waste ease of detection. In other words, wastes detect ability occurrence representing the probability of company's ability to detect the occurrence of specific waste. Waste detect ability occurrence is denoted with DW_k.

Table 3. Criteria for determining the score of the waste detect ability occurrence

Linguistic Interpretation	Detection criteria	Score
Very high probability undetected variable	Waste variable is almost undetected. It is impossible to detect the occurrence of maintenance waste variable using current detection tools	0.9-1.0
High probability of waste variable undetected	Medium probability to detect the occurrence of maintenance waste using available detection tool	0.7-0.8
Medium probability of waste variable undetected	High possibility to detect the occurrence of waste variable.	0.5-0.6
Low probability of waste variable undetected	Very high to detect the occurrence of maintenance waste variable	0.3-0.4
Very low probability of maintenance waste undetected	Waste variable occurrence is certainly detectable with confident	0.1-0.2

2.3. Waste severity score

The occurrence of a particular waste will cause many consequences. Those could be in the form of increased lead time, dissatisfied consumers, safety matters, financial losses and others. Evaluation of the waste occurrence should consider many aspects such as economics, environmental, safety, reputational and so on. Considering that maintenance waste may have many consequences in terms of negative technological, economical, safety reputational impact; the use of multi criteria decision tool such as the AHP can aid decision makers in appraising severity of maintenance waste consequences using multiple criterion [5]. Now SW_k is denoted as severity of maintenance waste.

2.4. Waste effect controllability score

Despite the occurrence of maintenance waste affecting negatively to the firm operations, the severity of maintenance waste occurrence will be low in case that the controllability of corresponding maintenance waste consequences is high. Considering this situation, the criticality of maintenance waste consequences is reversal with possibility of the company controllability level to the corresponding maintenance waste. Now, the probability of maintenance waste controllability is denoted as PCW_k. The controllability index is related to the existence of control factors. In this study, *control factors* are defined as any factors whose value determines the controllability of waste effects. The identification of control factors can be accomplished by using decision makers' judgment, pre-limitary test, or previous experiences in dealing with previous maintenance waste occurrence. As companies spend financial and intellectual capital in mitigating negative impact of waste variables, the 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.

Based on the logic that the criticality of a maintenance waste is equals to the rank of maintenance waste causes, its probability occurrence, detect ability and severity and reversal with companies capability to control its occurrences, the criticality of waste occurrence is given as

$$WPN_k = \frac{W_{WC_k} OW_k DW_k SW_k WF_k}{PCW_k} \quad (3)$$

The notation method for the variables in equation [3] is as follow:
WPN_k= Waste priority number for maintenance waste mode k ;
W_{WC_k}= Weight of maintenance waste cause of maintenance waste mode k ;
OW_k= Occurrence rate of maintenance waste mode k ;
DW_k= Detect ability level of maintenance waste mode k;
SW_k= Severity level of the consequences due to the occurrence of maintenance waste mode k;
WF_k= Weight of the maintenance waste mode k;
PCW_k= Probability level of company's controllability against to the consequences of maintenance waste mode k;
k= 1,2,3,……

3. Research methodology

In an attempt to validate the proposed modified FMEA model, a case study type research is used since the goal of this study is on answering the 5Ws questions and the researchers has no control over it. The company where the case example applied is electricity–generating company. To achieve the targeted research goals, company visit, interviews, departments meeting and investigating archival documents from maintenance and operations unit of the company are performed. For obtaining relevant data pertaining to how maintenance and operation are practiced in its everyday activities, interview with maintenance, quality assurance and operations manager who has more than 15 years of working experiences is conducted. Intended to demonstrate the proposed model for accessing the risk of maintenance waste causes, the criteria used to access the severity of maintenance waste consequences are expected cost incurred when a particular waste occurred, customer dissatisfaction, the impact of maintenance waste to the environment and electricity generating lead time. The electricity generating lead time is defined as the time span from the occurrence of the maintenance work order request until the success on generating electricity due to the completion of maintenance work. The weight of the maintenance waste category was based on the pair wise comparison among aforementioned criteria using the AHP method. The result of such quantification is given in table 3. For the sake of simplicity to avoid the small Figure. when multiplying the models' components, the WPN is multiplied with 10^6. The result is then depicted in Table 3.

Referring to the case example, based on the four criteria of the impact of maintenance waste occurrence, "delay" becomes the most critical maintenance waste type followed by overproduction and defect. For the maintenance waste "overproduction", "bad maintenance circulation data" is becoming the most critical root cause. Meanwhile, for the "waiting time/interruption/delay", the critical root cause is "spare part unavailability". At last, for solving maintenance waste " defect", decision makers should concentrate on the 2 (two) root causes, " knowledge gaps among maintenance crew", and " unclear maintenance working order".

4. Discussions

Determining an improved model for maintenance waste reprioritization is important for supporting the realization of sustainable manufacturing. In this study, a new model for accessing the criticality of maintenance waste occurrence is proposed in an attempt to narrow down the scarcity of the modified FMEA references in maintenance engineering discipline and ignorance of previous modified FMEA models which neglects on hierarchy of root causes of maintenance waste and inclusion of multiple factors in appraising the severity of maintenance waste effects and also controllability of organization in overcoming the occurrence of maintenance waste. Pertaining to its benefits on offer, this study offers many benefits to both of practical and theoretical purposes. First, the model proposes probability components of failure analysis into three components different from previous modified FMEA references, probability of waste mode avoidance, detect ability and controllability components which in our opinion, is inherent in failure assessment and overlooked by previous modified FMEA components. Second, it presents on the utilization of multi criterion aspect in appraising the severity of maintenance waste effects making it enable to adapt the real situation where decision makers usually using many criterion in declining their decision. And at last, it develops a framework of modified FMEA model for accessing the risk of maintenance waste occurrence in which to our knowledge, is vacant in previous study.

Despite the contributions offered, some limitations are observable in the proposed modified FMEA model. First, depending on its application context, difference industrial settings may give different maintenance waste modes and in consequences different waste priority number will be exist. Second, we still observe that the different root cause may give the same hierarchy even though it is having different components prioritization criteria.

5. Conclusions

In this paper, an improved model for evaluating the criticality of maintenance waste mode is proposed. The model presents new components for criticality assessment of maintenance waste modes using modification of FMEA. Different from previous works, probability of waste effect controllability aspect is considered thus enable to consider the companies' controllability capability in dealing with specific maintenance waste occurrence. Meanwhile, the use of AHP (Analytical Hierarchy Process) in accessing the hierarchy of maintenance waste consequences enables manager to consider many qualitative and quantitative criteria on impact of maintenance waste occurrence. Intended to fill in the gap on reference focusing the application of modified FMEA in dealing with maintenance waste, in this study opens many further opportunities for investigations. For instance, in some situations, solving the root cause of maintenance waste usually consider contradiction among competing solutions. In resolving above situation, extending this study by utilizing the TRIZ method for selection corrective action in modified FMEA is a new opportunity for study.

Acknowledgements

The authors thank to the Directorate General of Higher Education, Indonesian Ministry of Research, Development and Higher Education for funding this research under contract number: 023.04.1.673453/2015.

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Table 3. Modified FMEA sheet for ranking maintenance waste of case example

				Maintenance Waste Effect				Maintenance Waste cause					
Maintenance Waste Category (weight)	Maintenance Waste Mode (weight)	Waste Occurrence Rate	Waste Avoidance Probability Score	Effect	Controllability	Detectability	Severity	Cause	Occurr e-nce	Detect ability	Rectification difficulty	Weight	Maintenance Waste Priority Number
Overproduction (0.350)	Duplicating Maintenance Data (0.329)	0.25	0.10	Productivity loss	0.20	0.1	0.0115	Bad Maintenance Data circulation method	0.8	0.1	0.2	0.016	230
		0.25	0.10	Energy generating Opportunity loss	0.30	0.7	0.080	Delay in Maintenance Report Making	0.1	0.1	0.1	0.001	46.7
Waiting Time /Interruption /Delay (0.378)	Additional Waiting time spent for executing maintenance process (0.158)	0.50	0.30	Productivity loss	0.30	0.2	0.0119	Incomplete maintenance apparatus	0.9	0.1	0.7	0.063	119.7
		0.50	0.30	Customer dissatisfaction	0.50	0.2	0.0119	Absence of competence technicians when un-resolvable maintenance problem occurred	0.3	0.1	0.8	0.024	28.7
		0.50	0.30		0.50	0.30	0.0119	Spare part unavailability	0.4	0.1	0.5	0.020	142
Defect (0.272)	Erroneous maintenance activities (0.513)	0.25	0.2	Maintenance quality loss	0.30	0.20	0.027	Knowledge gap between maintenance managers and their sub-ordinate	0.3	0.2	0.6	0.036	2.0
		0.25	0.2	Endangering crew safety	0.20	0.10	0.013	Unclear maintenance working order	0.2	0.3	0.1	0.006	2.0

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