Advances in Economics, Business and Management Research, volume 177
Proceedings of the International Conference on Business and Engineering Management (ICONBEM 2021)

An FMEA-Based Approach to Waste Reduction A Case on a Make-to-Order Company

Didik Wahjudi[1,*] Yosua Dhiemas Picky Projesa[1]

[1]*Petra Christian University, Surabaya, Indonesia*
[*]*Corresponding author. Email: dwahjudi@petra.ac.id*

ABSTRACT

Firms conduct activities to satisfy the need of their customers. However, some activities do not add value to customers. Authors propose some approaches to identify and reduce these wastes. By reducing waste, it is expected that the firm competitiveness will increase. One method to tackle waste is to use a failure mode and effect analysis (FMEA) approach. This study aims to modify the existing model to reduce waste on a make-to-order company. The authors propose criteria to assess the severity, occurrence, and detection of the 21 identified wastes. Using the waste priority numbers (WPN), these 21 wastes are classified into six high priority wastes, four medium priority wastes, and 11 low priority wastes. Countermeasures for the high priority and medium priority wastes are identified through a discussion with the company's management. The management evaluates how effective the countermeasures by using the same scoring scales for severity, occurrence, and detection. The proposed countermeasures can reduce the waste priority numbers significantly. From the assessment results, ten waste modes with high and medium priorities get good results because the average WPN values decreased from 125.9 to 26.8. The highest WPN value drops from 213 to 40. The highest CPN value also reduces from 445 to 110. The impact of the implemented countermeasures can be observed and get a positive response from the company's management.

Keywords: *Waste Reduction, Waste Priority Number, Lean Manufacturing, FMEA, W-FMEA.*

1. INTRODUCTION

Every company is required to improve its competitiveness. One way to improve a company's competitiveness is by increasing the added value provided to its customers. Because most activities do not create value for customers, firms need to identify their wastes. Tools to reduce waste have been proposed by some studies, such as value stream mapping (VSM) [1] and waste identification diagram (WID) [2]. [3] proposes an FMEA-based method to prioritize wastes. By prioritizing wastes, firms can tackle the most critical wastes. The FMEA-based method proposed by [3] ranks wastes in terms of their waste priority numbers (WPN) and cause priority number (CPN), where WPN and CPN are products of severity, occurrence, and detection scores. A make-to-order (MTO) company has a different characteristic compared to a make-to-stock (MTS) company. It means that scales used to measure the severity, occurrence, and detection for MTO companies will be different from the scales used MTS companies. This study aims to modify the FMEA-based waste prioritizing model for a make-to-order company. The remaining of the paper is structured as follows. Literature reviews on make-to-order companies, types of waste, FMEA, and waste FMEA are discussed in Section 2. Section 3 describes the methodology of the study. Results and discussions of findings are presented in Section 4. Finally, Section 5 provides conclusions, limitations, and recommendations for future research.

2. LITERATURE REVIEW

2.1. Make-to-Order Companies

The increased demand for specialized products triggers the growth of MTO companies [4]. Earlier MTO only includes companies that offer little customization to their customers. MTO firms provide more customization than assemble-to-order firms but less than engineer-to-order firms [5]. However, [4] argues MTO also includes manufacturers that produce standard products. These are the firms that transform into MTO companies because of diversification and production cycle time-related reduction issues. Small and medium-sized enterprises (SMEs) with minimal financing are the majority of these MTO businesses. In this paper, MTO is defined as a production system where production or design does not occur until the customer confirms the order [4].

2.2. Types of Waste

Today's customers are increasingly looking for value in the products they buy. Companies that create value for their customers will succeed in the market. Yet, companies consume their resources for non-value-added work. Elimination of waste should be the center of their effort if they want to succeed. [6] identified seven types of waste: overproduction, waiting, transportation, extra processing, inventory, motion, and defects. Later, [7] suggested the eighth type of waste, non-utilized talent.

2.3. FMEA

Failure Mode and Effect Analysis (FMEA) is a systematic tool to detect and avoid product and process-related problems before they occur [8]. At first, FMEA is used to solve safety-related problems. Nowadays, FMEA is used to solve several issues related to quality improvement, project lateness, and reliability [3]. FMEA sorts the criticality level or the priority of problems based on the risk priority number (RPN), which is the product of the severity, occurrence, and detection indices [3]. The severity index measures the effect of failure when it occurs, while the occurrence index represents the likelihood or frequency of failure cause to happen. Finally, the detection index indicates the effectiveness of control to detect or prevent the failure mode. These three indices are on a scale ranging from 1 to 10.

2.4. Waste FMEA

[3] proposes the use of FMEA to identify and prioritize waste and calls it waste-FMEA (W-FMEA). In this method, wastes are ranked based on their waste priority number (WPN) and cause priority number (CPN). WPN is the product of the waste effect's severity, the likelihood of waste occurrence, and the control's effectiveness to detect and prevent the waste. CPN is the summation of all WPNs of wastes caused by the same cause. So, if something causes two waste modes with WPN of X_1 and X_2, the CPN of that cause will be equal to $X_1 + X_2$. Based on the range of the WPN, the WPN of waste will be classified as low, moderate, and high, and likewise, the CPN index will be classified into low, moderate, and high as well. High priority wastes are waste modes with moderate to high value of WPN and high value of CPN. Wastes with moderate to high WPN and low CPN or low WPN and moderate to high CPN belong to medium priority wastes. Finally, the lowest priority will be given to waste modes with low to moderate WPN and CPN values [3].

3. METHODOLOGY

3.1. Overview of the Case Company

Company X manufactures products such as building and bridge structures, gears, conveyors, rollers, drum pulleys, and crushers. Besides, company X also provides services such as repair of machine components, sandblasting, and painting. X has five production areas, namely W1 (machining section), W2 (hydraulic press section), W3 (open space for construction work), W4A (material cutting section), and W4B (sandblasting and painting area). Rollers are the most ordered products.

3.2. The Method

This study aims to implement W-FMEA in a make-to-order company. A modification on the severity, occurrence, and detection scales is needed to suit the MTO case. A literature review is used to develop a checklist for waste identification and develop severity, occurrence, and detection scales. Interviews with the head of production division and production staffs are used to 1) rate the severity, occurrence, and detection levels, 2) identify the waste causes, 3) develop alternative solutions, and 4) evaluate the effectiveness of the solution.

4. RESULTS

To ensure that no waste was missed out, a checklist was developed. Through interviews with three personnel in the production division, 21 waste modes were identified, as presented in Table 4. The scale of waste severity was adapted from [8] to suit the application on MTO company. The table of severity scales proposed by [3] cannot be used because the measures such as problems experienced by customers and market share used are difficult to estimate. Scales of waste occurrence and waste detection proposed by [3] were used in this study because the shop floor personnel can quickly evaluate the indicators. Scales of waste severity, waste occurrence, and waste detection used in this study are presented in Tables 1, 2, and 3, respectively. Three shop floor personnel were asked to score the severity of the effect, the likelihood of occurrence, and the effectiveness of detection/prevention control using these tables. Their average scores are presented in Table 4. The WPN scores in Table 4 were obtained by multiplying their respective severity, occurrence, and detection values and rounded up to the nearest integers. For every waste mode, the respondents were asked to identify the waste causes. The CPN scores were obtained by adding WPN values of waste modes that had the same causes. For example, wastes D3, W2, T1, and M2 had the same cause. So, the CPN will be the sum of WPN values of D3, W2, T1, and M2.

The range WPN was between 9 and 213. The WPN values were then divided into three categories: high for values between 146 and 213, moderate (78 – 145), and low (9 – 77). The analysis found that the highest CPN value was 445, and the lowest CPN value was 17. The CPN value was then divided into three categories, namely high (between 303 and 445), moderate (161 – 302), and low (17 – 160). Because waste D1 had a high value of WPN and a reasonable CPN value, then waste D1 was classified as medium priority waste. The remaining 20 wastes were also categorized as high, medium, or low priority waste based on their WPN and CPN values. There were six high priority wastes, four medium priority wastes, and eleven low priority wastes, as shown in Table 4. Interviews with the shop floor personnel were conducted to identify the countermeasure for every high and medium priority wastes. They were also asked to assess the severity, occurrence, and detection values if the countermeasures had been implemented. Table 5 presents the countermeasures and the final WPN for the high and medium priority wastes.

Table 1. The scale of waste severity for MTO company

Score	Effect	Quantitative Description
10	Failure to meet safety and/or regulation	Without warning, may endanger the operator.
9		Without warning, may endanger the operator.
8	Major disruption	All products may have to be discarded. Stop production or shipment.
7	Significant disruption	A portion of All products may have to be discarded. Reduced line speed or increased manpower are examples of deviations from the primary process.
6	Moderate disruption	It's possible that the entire production run will have to be reworked offline and accepted.
5		It's possible that a portion of the production run will have to be reworked offline and accepted.
4	Moderate disruption	It's possible that a portion of the production run will have to be reworked in-station before it is processed.
3		
2	Minor disruption	A minor disturbance to the process, operation, or operator.
1	No effect	There is no noticeable effect.

Table 2. The scale of waste occurrence for MTO company

Score	Likelihood	Quantitative Description
10	Almost certainly	Probability of occurrence more than 50%
9	Very likely	Probability of occurrence from 35 to 50%
8	Very frequently	Probability of occurrence from 25 to 35%
7	Frequently	Probability of occurrence from 15 to 25%
6	A considerable number of occurrences	Probability of occurrence from 8 to 15%
5	Few occurrences	Probability of occurrence from 5 to 8%
4	Slight chance of occurrence	Probability of occurrence from 3 to 5%
3	Small chance of occurrence	Probability of occurrence from 1 to 3%
2	Unlikely	Probability of occurrence from 0.1 to 1%
1	Very remote	Probability of occurrence less than 0.1%

There are ten wastes discussed in this research, six wastes with high priority categories and four wastes with medium priority categories. One of the most significant results is the medium priority waste, waiting for work equipment (W1). This waste mode has an initial WPN score of 213 and changes to 40. This waste of waiting occurs because the welding operator takes the work equipment and consumables himself. The proposed solution is to add an assistant worker to help the welding operator make new work instructions. This will prevent the welding operators from taking their work equipment and consumables and other activities that the assistant worker can carry out. Thus, the stoppage of the production process due to the unavailability of welding operators is prevented. This assistant worker's existence can also help other operators so that the production process can run more efficiently because the utilization of the workforce is maximized. The benefits of waste countermeasure that have been applied can be felt and get a positive response from the company. The WPN values of the remaining nine waste modes also decreased drastically. All waste modes become low-priority waste when the countermeasures are implemented. The average WPN values of the ten wastes drop from 125.9 to 26.8. The highest CPN value also decreases from 445 to 110.

Table 3. The scale of waste detection for MTO company

Score	Detection	Quantitative Description
10	No failsafe system neither inspection.	It just identifies nearly 1% of the time, and the wastes usually have an effect on the customers.
9	No failsafe system but there is an inspection a few times.	It identifies 10% after the occurrence, before affecting the customer.
8	No failsafe system, but inspection takes place almost half the time.	It identifies 50% after the occurrence, before affecting the customer.
	No failsafe system, but	It identifies 90% after the

Score	Detection	Quantitative Description
7	there is a full inspection after processing.	occurrence, before affecting the customer.
6	There are failsafe systems which avoid waste very few times.	It identifies and prevents occurrence 10% of the time, and only identifies the rest.
5	There are failsafe systems that avoid waste a few times.	It identifies and prevents occurrence 30% of the time, and only identifies the rest.
4	There are failsafe systems that avoid waste half of the time.	It identifies and prevents occurrence 50% of the time, and only identifies the rest.
3	There are failsafe systems that almost avoid waste.	It identifies and prevents occurrence 70% of the time, and only identifies the rest.
2	There are failsafe systems that almost avoid waste.	It identifies and prevents occurrence 85% of the time, and only identifies the rest.
1	There are failsafe systems that avoid waste.	It identifies and prevents occurrence 100% of the time.

Table 4. List of identified wastes with their WPN and CPN values

Waste type	Waste mode	Waste cause	S	O	D	WPN	CPN	Priority
Defect	The bearing housing hole is not centered (D1)	Use of conventional work method that is prone to error	8	4.7	5	187	240	Medium
Defect	The paint is uneven and has sagging (D2)	Lack of knowledge and training	2	4.7	5.7	53	240	Medium
Defect	Defective product during transportation among workstations (D3)	Process layout	5.3	3.7	2.3	46	445	Medium
Overproduction	Mold construction (O1)	Preparation of customer orders	4.3	6	1	26	26	Low
Overproduction	Duplicate document printing (O2)	For work facilities and documentation	2	8.3	1	17	17	Low
Overproduction	Manufacture of rollers for stock (O3)	Utilization of material stock when there is no work	3.3	2.7	1	9	18	Low
Waiting	Waiting for work equipment (W1)	A limited number of tools	7	4.3	7	213	213	Medium
Waiting	Waiting for products from the previous section (W2)	Process layout	7	5.3	4.3	162	445	High
Non-utilized talent	Welding operators perform plate cutting work (N1)	Shortage of labor	2.3	5	2	24	44	Low
Non-utilized talent	The painting operator does the cleaning work (N2)	Shortage of labor	2	5	2	20	44	Low
Transportation	Product delivery to the next section (T1)	Process layout	7	7	2.3	115	445	High
Inventory	Excessive raw material inventory (I1)	Lower prices for purchase in large quantities	4	3.3	2.3	32	32	Low
Inventory	The stock of finished products (I2)	Utilization of material stock when there is no work	3.3	2.7	1	9	18	Low
Motion	Searching for tools and work equipment (M1)	Lack of standardization of tools and work equipment	2	8.7	7.7	133	361	High
Motion	Opening/closing the gate when sending products to the next process (M2)	Process layout	7	8.7	2	122	445	High
Motion	Refilling the coolant on the lathe (M3)	Lack of maintenance on the automatic nozzle	7	7	2.3	115	361	High
Motion	Searching for the stock of material (M4))	Lack of standardization of material stock	2	7.3	7.7	113	361	High
Extra processing	Checking machines and work equipment (E1)	Unreliable inventory data	2	4.3	7	61	133	Low
Extra processing	Checking stock of materials and consumables (E2)	Unreliable inventory data	2	4.3	6	52	133	Low
Extra processing	Checking the production results (E3)	Unreliable inventory data	1	10	1	20	133	Low
Extra processing	Packing the product without request (E4)	Protect and enhance product appearance	2	4.7	2	19	19	Low

Table 5. List of high-and-medium priority wastes with their countermeasures

Waste type	Waste mode	Waste cause	Countermeasure	Initial WPN	Final WPN
Waiting	Waiting for products from the previous section (W2)	Process layout	Change the plant layout to group technology	162	56
Motion	Searching for tools and work equipment (M1)	Lack of standardization of tools and work equipment	Implement 5S	133	6
Motion	Opening/closing the gate when sending products to the next process (M2)	Process layout	Change the plant layout to group technology	122	28
Motion	Refilling the coolant on the lathe (M3)	Lack of maintenance on the automatic nozzle	Perform preventive maintenance	115	28

Waste type	Waste mode	Waste cause	Countermeasure	Initial WPN	Final WPN
Transportation	Product delivery to the next section (T1)	Process layout	Change the plant layout to group technology	115	6
Motion	Searching for the stock of material (M4)	Lack of standardization of material stock	Implement 5S	113	18
Waiting	Waiting for work equipment (W1)	No assistants to prepare equipment	Adding an assistant workforce to prepare the needed equipment	213	40
Defect	The bearing housing hole is not centered (D1)	Use of conventional work method that is prone to error	Making special jigs to avoid errors	187	48
Defect	The paint is uneven and has sagging (D2)	Lack of knowledge and training	Carry out coaching and job training	53	18
Defect	Defective product during transportation among workstations (D3)	Process layout	Change the plant layout to group technology	46	20

5. CONCLUSIONS

Waste can occur due to a lack of awareness of the impact of an activity, resulting in a waste of resources. Therefore, the identification of the eight wastes is needed to minimize and even prevent waste from occurring. This study demonstrates how to implement W-FMEA proposed by [3] in an MTO company. WPN and CPN scores help us better prioritize a waste, where the interrelated waste receives high priority. The values of WPN values of the ten waste modes decrease significantly from 125.9 to 26.8. Some limitations identified in this study are the determination of ranges of WPN and CPN values. Furthermore, we do not take into account the cost and level of difficulty to implement the countermeasures.

REFERENCES

[1] M. Rother, J. Shook, Learning to See: Value Stream Mapping to Create Value and Eliminate Muda. 1999.

[2] J. Dinis-Carvalho, F. Moreira, S. Bragança, E. Costa, A. Alves, R. Sousa, Waste identification diagrams, Productio Planning & Control 26(3) (2014) 235-247.DOI: https://doi.org/10.1080/09537287.2014.891059

[3] R.V.B. de Souza, L.C.R. Carpinetti, A FMEA-based approach to prioritize waste reduction in lean implementation, International Journal of Quality & Reliability Management 31(4) (2014) 346-366. DOI: https://doi.org/10.1108/IJQRM-05-2012-0058

[4] M. Stevenson, L.C. Hendry, B.G. Kingsman, A review of production planning and control: the applicability of key concepts to the make-to-order industry, International Journal of Production Research 43(5) (2005) 869-898. DOI: https://doi.org/10.1080/0020754042000298520

[5] G. Amaro, L. Hendry, B. Kingsman, Competitive advantage, customisation and a new taxonomy for non make-to-stock companies, International Journal of Operations & Production Management 19(4) (1999) 349-371. DOI: https://doi.org/10.1108/01443579910254213

[6] T. Ohno, Toyota Production System. 1988.

[7] J.K. Liker, The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer. 2004.

[8] R.E. McDermott, R.J. Mikulak, M.R. Beauregard, The Basics of FMEA. 2009.