International Journal of Global Optimization and Its Application
Vol. 1, No. 2, June 2022, pp.100-110. e-ISSN: 2948-4030
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https://doi.org/10.56225/ijgoia.v1i2.19

Article

Identifying the Shipyard Waste: An Application of the Lean Manufacturing Approach

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Citations: Fitriadi, F., & Ayob, A.F.M., (2022). Identifying the Shipyard Waste: An Application of the Lean Manufacturing Approach. *International Journal of Global Optimization and Its Application*, *1*(2), 100-110. https://doi.org/10.56225/ijgoia.v1i2.19

Academic Editor: Seri Rahayu Binti Kamat.

Received: 10 April 2022 Accepted: 12 June 2022 Published: 30 June 2022

Abstract: Shipyard is a specialised facility equipped with various tools to support the process of building, repairing and maintaining ships. There are several types of variant ships, such as military ships, tourist boats, cargo ships and passenger ships. Apart from being a place for shipbuilding, shipyards are utilised to conduct several activities, such as ship design, equipment installation, plate installation, feasibility tests and classifications. There are many production activities and flows that allow for potential waste problems that impact labour usage, product quality, costs, and production time. This research aims to identify waste in shipbuilding production lines through a lean manufacturing approach. The lean manufacturing approach is one of the ways in shipyards to observe the level of waste in the production process to reduce unnecessary activities in the production process, which can increase production efficiency and effectiveness. This study approach begins with identifying waste in the production line through mapping on each line so that activities with no added value are identified. On the basis of the results of identification using the waste assessment model (WAM) method, which consists of a waste relationship matrix (WRM) and a waste assessment questionnaire (WAQ), waste is obtained, namely inventory (27,20%), overproduction (20.24%), defective products (20.04%), motion (12.47%), transportation (9.23%), waiting time (7.46%) and process (3.37%).

Keywords: waste; shipyard; optimisation; lean manufacturing

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1. Introduction

Optimal utilisation of marine resources requires adequate fishing facilities and infrastructure, such as fishing gear and ships. The requirement for adequate ships is achieved through shipbuilding, therefore, the shipbuilding process is very important. Aceh's ship production process still relies on the traditional method, so the ship quality is not standard and requires a long production time. Increasing the production process that is more effective and efficient can be done starting from preparing raw materials to finished products. On the basis of the statistical centre in Aceh Province, the total number of ship production each year continues to increase, and it was recorded that in 2013 the number of ships in Aceh province was 6,462 units. In the latest data for 2019, there were 7,475 vessels in Aceh Province. It indicated that the shipbuilding productivity in Aceh province continues to grow (Central Bureau of Statistics of Aceh, 2019).

Shipbuilding is a very complex activity and requires high standards. The traditional approach to the shipbuilding process becomes an obstacle in developing modern lean manufacturing concepts. Therefore, it becomes a driving force in discovering the increase in shipyard production productivity (Diaz et al., 2020; Shahsavar et al., 2021). At this stage, the shipbuilding production process in Aceh lacks good working standards, which results in a significant amount of waste. The waste in the production process occurs without the company's realisation because it is not considered a cause of significant losses. On the other hand, the emergence of operational cost components that are not needed in the production process is due to the company's inability to control waste in the production process. This condition causes the productivity and cost-efficiency of shipbuilding to be not optimal. Therefore, it will require action to identify the components of production waste as part of the steps to create a lean production process.

Increasing the shipyard's productivity requires improving the production process, such as overproduction, unnecessary inventory, and defective products. An increase in productivity can be achieved if there is an identifiable reduction in waste. One indicator of increasing productivity is minimising waste from each production process. The waste from the lack of standardisation will potentially hamper shipbuilders' income. Therefore, in the production process, waste must be eliminated (Arunagiri & Gnanavelbabu, 2014; Hines & Taylor, 2000; Mostafa & Dumrak, 2015). From the perspective of the shipyard, several strategies must be implemented to improve the quality of ship production by carrying out continuous processes and improvements. For instance, the reduction of unnecessary transport of raw materials in production, a bottleneck of raw materials in process, unnecessary movements of process within the yard, waiting time to start the next activity, extraneous product development steps, unnecessary production and defective products (Ferreira et al., 2019; Oliveira et al., 2017; Phogat, 2013; Stanić et al., 2017). Reliable production management through the lean manufacturing application concepts is proven to increase productivity. Continuous improvement process in eliminating waste and environmental management will have an impact on increasing the company's revenue.

Continuous improvement implementation requires an action that can be used to identify waste to realise continuous improvement. The lean manufacturing concept aims to improve strategies in the production process by identifying the types and factors that cause waste in the production flow (Singh & Singh, 2015; Wahab et al., 2013). Lean manufacturing begins with data collection through questionnaires stating the relationship between waste sources. The data obtained are given weight and score to determine the frequency. The probability value is then determined to obtain the percentage of each dominant waste (Adlin et al., 2020; Breyfogle III, 2003; Rawabdeh, 2005). Lean manufacturing application is a relatively simple and structured approach to make it easy to implement to carry out an efficient process according to the capabilities and resources of a company (Lubis et al., 2020; Mourtzis et al., 2016; Soltan & Mostafa, 2015; Strandhagen et al., 2018). In conjunction with the previous issue, this seeks to identify the steps for identifying waste components to obtain the most dominant waste and waste components in the shipyard production line as part of the efficiency stage of the production process.

2. Materials and Methods

The study method used is the waste assessment model (WAM), which is a combination of the waste relationship matrix (WRM) and the waste assessment questionnaire (WAQ) (Oliveira et al., 2017). WRM's function is to analyse the relationship criteria between waste that occurs on the production line, and WAQ is used to identify and allocate waste that occurs on the production line (Oliveira et al., 2017). Research stages implementation appears in Figure **1** as below:

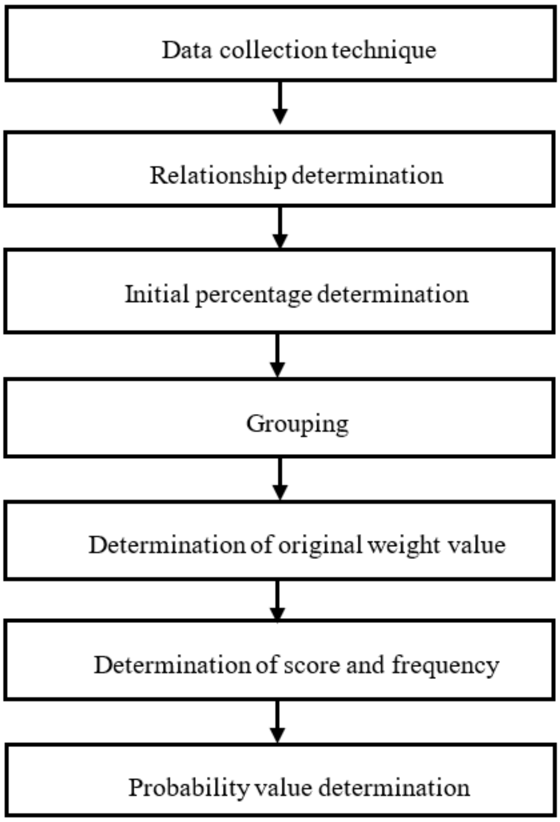

Figure 1. Step of data analysis.

Figure **1** displays several steps of data analysis. (1) Data collection consisting of 31 questions was carried out by distributing a WRM questionnaire to shipbuilders. The questionnaire used is a closed questionnaire type. (2) Determining the relationship in the WRM questionnaire related to waste in shipyards by looking at the correlation range between waste conversion scores. (3) Determination percentage of each waste is done by changing letters into numbers. (4) Grouping stage's purpose is to determine question numbers for each type of waste source. (5) Original weight value is obtained from the weight of the answers based on the questions in the questionnaire. The original weight value is obtained through the WRM related to waste sources. (6) Scoring is obtained by multiplying the weight of the relationship between waste sources and other waste sources. The frequency value (Fj) is calculated by adding the non-zero weights. New scores and frequencies are obtained from the weights on the calculated initial scores and frequencies. (7) The probability value is obtained from the quotient between the row and column percentages based on the initial percentage, and (8) The final percentage determination is obtained from the comparison value between the initial and final values (score and frequency) multiplied by the probability value.

Calculating the score (Sj) in step six above can be done using equation 1.

$$S_j = \sum_{K=1}^{K} \frac{W_{j,k}}{Ni} \quad \text{for each type of waste j} \tag{1}$$

S_j is the score of the waste, and K ranges between 1 and 68, where K is the number of question types for each waste. Meanwhile, the frequency value (F_j) is calculated by adding the weights that are not zero. Furthermore, the determination of the new value (s_j) and the new frequency value (f_j) can be calculated using equation 2.

$$s_j = \sum_{K=1}^{K} X_K \frac{W_{j,k}}{Ni} \quad \text{for each type of waste j} \tag{2}$$

s_j is the waste score, and K ranges between 1 and 68, where K is the number of question types for each waste. Meanwhile, the new frequency value (f_j) is also calculated by adding the weights that are not zero. The determination of the probability value in step seven above can be calculated using equation 3.

$$P_j = \frac{P_R}{P_C} \tag{3}$$

P_R is the initial percentage value listed in the waste matrix value in the table row. At the same time, P_C is the initial percentage value listed in the waste matrix value in the table column. The final step is to determine the final percentage of waste. Previously Y_j and the final Y_j value were determined using equation (4) and equation (5), respectively.

$$Y_j\text{initial} = \frac{s_j}{S_j}\frac{f_j}{F_j} \quad \text{for each type of waste j} \tag{4}$$

$$Y_j\text{Final} = Y_j\text{initial}\ P_j = \frac{s_j}{S_j}\frac{f_j}{F_j}\ P_j \quad \text{for each type of waste j} \tag{5}$$

3. Results and Discussions

This research was conducted based on the implementation stages of waste identification in the shipbuilding production line at the shipyard using the WRM concept combined with the WAQ, and the following data were obtained.

3.1. The Stage of Collecting Data Using a Questionnaire

This stage identifies the waste in the shipyard production line using the WRM concept combined with a WAQ Calculation of the relationship between waste is carried out through discussions with shipbuilders and questionnaires using weighting criteria (Oliveira et al., 2017). Discussions were conducted with experts who thoroughly understood the shipbuilding process and the identified wastes. There are two experts, namely the owner of the company and the head craftsman. Meanwhile, the questionnaire was distributed to 2 experts and two workers. The following data are obtained and summarised in Table 1.

Table 1. Results of the WRM questionnaire.

Relation		1		2		3		Score
		Ans.	**Wght.**	**Ans.**	**Wght.**	**Ans.**	**Wght.**	
1	O-I	A	4	A	2	A	4	18
2	O-D	B	2	C	0	B	2	6
3	O-M	B	2	C	0	C	0	6
4	O-T	B	2	A	2	B	2	11
5	O-W	B	2	B	1	B	2	13
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
31	W-D	B	2	B	1	B	2	12

Relation		4		5		6		Score
		Ans.	**Wght.**	**Ans.**	**Wght.**	**Ans.**	**Wght.**	
1	O-I	A	2	F	2	A	4	18
2	O-D	B	1	A	1	C	0	6

3	O-M	A	2	D	2	C	0	6
4	O-T	B	1	F	2	B	2	11
5	O-W	A	2	E	2	A	4	13
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
31	W-D	A	2	A	1	A	4	12

Table 1 is the result of the WRM questionnaire, which is the relationship between waste variables (as defined in Table 4). Such as overproduction-inventory (O-I), overproduction-defect (O-D), overproduction-motion (O-M), overproduction-transportation (O-T), and overproduction-waiting (O-W) and so on until we get 31 total relationships. Table 1 also displays the weight of each row or column, a value representing the effect of one type of waste on another. This score is obtained from the questionnaire (Ans) answers and then converted in the form of weights (Wght) according to a predetermined scale. Wght is added to get a score, as shown in Table 1. Concerning the column in Table 1, it captures O-I indicating the relationship between whether waste overproduction results in or produces waste inventory, O-D shows the relationship between whether waste overproduction results in or produces waste defects.

3.2. Relationship Determination Stage

On the basis of the questionnaire, the relationship between each waste can be determined by looking at the conversion of the linkage score range between the wastes, and the WRM can be determined as attached in Table 2.

Table 2. Waste relation matrix (WRM).

F/T	O	I	D	M	T	P	W
O	A	A	O	O	I	X	E
I	I	A	I	I	I	X	X
D	I	I	A	I	E	X	I
M	X	O	E	A	X	E	A
T	U	O	I	U	A	X	I
P	I	U	I	I	X	A	I
W	I	A	I	X	X	X	A

Table 2 shows that the value in the row is the value of the effect of certain waste on other waste sources, while the value in the column shows that certain waste can affect the value of other waste sources. The diagonal value in the table is the highest value which is the value associated with the waste value itself.

3.3. Initial Percentage Determination Stage

The following Table 2, the percentage of each waste can be determined by converting the letters in the table back into numbers with values A = 10, E = 8, I = 6, O = 4, U = 2, X = 0 (Oliveira et al., 2017). The conversion of symbols A, E, I, O, U and X is carried out to facilitate calculating the percentage. The higher the value obtained, the greater the linkage between wastes. The percentage of each waste is shown in Table 3.

Table 3. Waste matrix value (WMV).

F/T	O	I	D	M	T	P	W	Score	%
O	10	10	4	4	6	0	8	42	16.4
I	6	10	6	6	6	0	0	34	13.3
D	6	6	10	6	8	0	6	42	16.4
M	0	4	8	10	0	8	10	40	15.6

T	2	4	6	2	10	0	6	30	11.7
P	6	2	6	6	0	10	6	36	14.1
W	6	10	6	0	0	0	10	32	12.5
Score	36	46	46	34	30	18	46	256	100
Percent-age	14.1	18	18	13.3	11.7	7	18	100	[redacted]

Table 3 shows the row position, overproduction and defect are the highest waste with 16.4%, and the lowest is in transportation with a percentage of 11.7%. Meanwhile, in the position column, inventory, defects and waiting are the highest waste (18%), and the lowest is in the process (7%).

3.4. Grouping Stage

The above value will be used in calculating the waste assessment process question. The questionnaire is distributed with 68 questions with three answers with a weight of 1, 0.5 and 0 (Oliveira et al., 2017). Waste assessment results will be grouped into types of questions (refer to Table 4).

Table 4. Number of grouped assessment questions.

I	Type of question (i)	No of questions (Ni)
1	From Overproduction	3
2	From Inventory	6
3	From Defects	8
4	From Motion	11
5	From Transportation	4
6	From Process	7
7	From Waiting	8
8	To Defects	4
9	To Motion	9
10	To Transportation	3
11	To Waiting	5
Total of question		68

3.5. Stage of Determining Original Weight, Score and Frequency

The next step is determining the original weight value obtained through the waste relationship matrix (WRM). These weight values can be shown in the Table 5.

Table 5. Original Weight Value from WRM.

Question type	Question (K)	I	D	M	T	P	W
1. Man							
To motion	1	6	6	10	2	6	0
From motion	2	4	8	10	0	6	10
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
From Process	7	2	6	6	0	10	6
2. Material							
To waiting	8	0	6	10	6	6	10
From waiting	9	10	4	0	0	0	10
.	.	.	.	.	.	.	.

.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
To motion	31	6	6	10	2	6	0
3. Machine							
From process	32	2	6	6	0	10	6
To waiting	33	0	6	10	6	6	10
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
From process	43	2	6	6	0	10	6
4. Method							
To transporta-tion	44	6	8	0	10	0	0
From motion	45	4	8	10	0	6	10
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
From defects	68	6	10	6	8	0	6

Table 5 describes the weight of each waste determined using the questionnaire questions. Weight is calculated by dividing the Original Weight Value of the waste relationship matrix (WRM) by the number of questions (Ni). The result of the analysis can be seen in Table 6.

Table 6. Weight Value from WRM.

Ques. type	**(K)**	**(Ni)**	**$W_{o,k}$**	**$W_{i,k}$**	**$W_{d,k}$**	**$W_{m,k}$**	**$W_{t,k}$**	**$Wp_{,k}$**	**$W_{w,k}$**
Man									
To motion	1	9	0.44	0.67	0.67	1.11	0.22	0.67	0.00
From motion	2	11	0	0.36	0.73	0.91	0	0.55	0.91
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
From Process	7	7	0.86	0.29	0.86	0.86	0	1.43	0.86
Material									
To waiting	8	5	1.6	0	1.2	2	1.2	1.2	2
From waiting	9	8	0.5	1.25	0.5	0	0	0	1.25
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
To motion	31	9	0.44	0.67	0.67	1.11	0.22	0.67	0.00
Machine									
From process	32	7	0.86	0.29	0.86	0.86	0	1.43	0.86
To waiting	33	5	1.6	0	1.2	2	1.2	1.2	2
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
From process	43	7	0.86	0.29	0.86	0.86	0	1.43	0.86
Method									
To transportation	44	3	2	2	2.67	0	3.33	0	0.00
From motion	45	11	0	0.36	0.73	0.91	0	0.55	0.91
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.

.	.	.		.	.	.	.	.	.	.
From defects	68	8		0.75	0.75	1.25	0.75	1	0	0.75
Score (S_j)				53.4	63.5	70.7	56.1	58.0	29.8	59,6
Frequency (F_j)				58	64	68	57	43	33	49

Note: Ni is No of questions; K is Question.

The score (S_j) in the table above can be calculated using equation 1. For example, we take the $W_{o,k}$ column, so the calculation results can be seen as follows.

$$S_j = \sum_{1}^{68} \frac{4}{9} + \frac{0}{11} + \ldots + \frac{6}{8}$$

$$S_j = \sum_{1}^{68} 0.44 + 0 + \ldots + 0.75$$

$$S_j = 53.4$$

The frequency (F_j) value in the table above is calculated by adding the non-zero weights. After obtaining the Score (S_j) and Frequency (F_j) values, the next step is to determine the new value (s_j) and the New frequency (f_j) value. This step begins by determining the weight value for each source of waste. The results of this calculation can be seen in Table 7.

Table 7. New score (s_j) and new frequency (f_j).

Ques. type	**(K)**	**(Ni)**	**Ans. Weight**	$W_{o,k}$	$W_{i,k}$	$W_{d,k}$	$W_{m,k}$	$W_{t,k}$	$W_{p,k}$	$W_{w,k}$
Man										
To motion	1	9	1.00	0.44	0.67	0.67	1.11	0.22	0.67	0
From motion	2	11	0.50	0	0.18	0.36	0.45	0	0.27	0
. . .	. . .	. . .		. . .	. . .	. . .	. . .	. . .	. . .	. . .
From Process	7	7	0.33	0.29	0.10	0.29	0.29	0	0.48	0
Material										
To waiting	8	5	0.00	0	0	0	0	0	0	0
From waiting	9	8	2.50	1.25	3.13	1.25	0	0	0	3
. . .	. . .	. . .		. . .	. . .	. . .	. . .	. . .	. . .	. . .
To motion	31	9	1.00	0.44	0.67	0.67	1.11	0.22	0.67	0
Machine										
From process	32	7	0.33	0.29	0.10	0.29	0.29	0	0.48	0
To waiting	33	5	0.00	0	0	0	0	0	0	0
. . .	. . .	. . .		. . .	. . .	. . .	. . .	. . .	. . .	. . .
From process	43	7	0.33	0.29	0.10	0.29	0.29	0	0.48	0
Method										
To transportation	44	3	0.75	1.50	1.50	2.00	0	2.50	0	0
From motion	45	11	0.50	0	0.18	0.36	0.45	0	0.27	0
. .	. .	. .		. .	. .	. .	. .	. .	. .	. .

.	.	.		.	.	.	.	.	.	.
From defects	68	8	0.60	0.45	0.45	0.75	0.45	0.60	0	0
New score (s_j)				62.5	90.0	63.5	45.0	53.4	14.4	63.5
New frequency (f_j)				54	64	64	53	39	29	19

Note: Ni is No of questions; K is Question.

The new score (sj) in Table 7 above can be calculated using equation 2. For example, we take the Wo,k column so that the calculation results can be seen as follows.

$$s_j = \sum_{1}^{68} 1.00 \ \text{x} \ \frac{4}{9} + 0.50 \ \text{x} \ \frac{0}{11} + \ \dots + 0.60 \ \text{x} \ \frac{6}{8}$$

$$s_j = \sum_{1}^{68} 0.44 + 0 + \ \dots + 0.45$$

$$s_j = 62.5$$

3.6. Probability Value Determination Stage and Final Percentage

The next step is to determine the Probability value (P_j), which can be calculated using equation 3, so the results are as in Table 8.

Table 8. Probability value (P_j).

Percentage	O	I	D	M	T	P	W
Row	16,4	13,3	16,4	15,6	11,7	14,1	12,5
Column	14,1	18,0	18,0	13,3	11,7	7,0	18,0
Pj	0,023	0,024	0,029	0,021	0,014	0,010	0,022

The final step is to determine the final percentage of waste, where the Yj value was previously determined using equation (4) and the final Y_j value using equation (5). The results of these calculations can be seen in Table 9.

Table 9. Result of the WAQ.

Description\Waste	O	I	D	M	T	P	W
P_j	0,0231	0,0239	0,0295	0,0208	0,0137	0,0099	0,0225
Y_j Initial	10,905	14,168	0,8449	0,7470	0,8358	0,4235	0,4127
Y_j Final	0,0252	0,0338	0,0249	0,0155	0,0115	0,0042	0,0093
Final Percentage	20,24	27,20	20,04	12,47	9,23	3,37	7,46

Table 9 indicates the highest percentage of the waste is in the inventory (27.20%), while the lowest percentage of waste was processed (3.37%). It shows that the shipbuilding process is still carrying out an excessive supply of raw materials. This condition will impact the provision of storage warehouses and continue to increase production costs (Ramirez-Peña et al., 2020). In the end, it will reduce the company's productivity. On the other hand, the dominant raw material for shipbuilding is wood, which, if stored for a long time, is vulnerable to damage and can influence ship quality (Bengtsson et al., 2014).

4. Conclusions

In conclusion, this study has successfully identified the shipyard through a lean manufacturing approach using the WAM method consisting of a WRM and a WAQ and found that the waste that occurs is inventory (27.20%), overproduction (20.24%), defective products (20.04%), movement (12.47%), transportation (9.23%), waiting time (7.46%) and process (3.37%). The highest percentage of waste is inventory (27.20%), while the lowest percentage of waste is process (3.37%). It happens because the ship production process in Aceh still relies on traditional methods. Through the results of waste identification, it is hoped that continuous improvements can be made to the production line, especially at the highest sources of waste, by paying attention to lean manufacturing. In future studies, waste identification can be investigated using different methods, suggesting pathways for continuous improvements based on the lean manufacturing approach.

Author Contributions: Conceptualization, F.F. and A.F.M.A.; methodology, F.F. and A.F.M.A.; software, F.F. and A.F.M.A.; validation, F.F. and A.F.M.A.; formal analysis, F.F. and A.F.M.A.; investigation, F.F. and A.F.M.A.; resources, F.F.; data curation, A.F.M.A; writing—original draft preparation, F.F. and A.F.M.A.; writing—review and editing, F.F. and A.F.M.A.; visualisation, F.F. and A.F.M.A.; supervision, A.F.M.A.; project administration, A.F.M.A.; funding acquisition, A.F.M.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank the Universitas Teuku Umar, Universiti Malaysia Terengganu and Aceh Human Resources Development Agency for supporting my study, research and publication. Also, we would like to thanks to individuals and organizations who generously shared their time and experience for the purposes of this project. We would also like to thank the reviewers for all their constructive comments.

Conflicts of Interest: The authors declare no conflict of interest.

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