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Development of Monitoring Tool to Support Lean Manufacturing Implementation

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***Abstract*—Lean is an approach that is carried out continuously to identify and eliminate waste or other activities that do not provide added value. Many companies have implemented lean concepts and got the benefits such as reduced cycle time, reduced operational costs, improved product quality, and other benefits. Although it provides many benefits, there are some weaknesses in implementing lean, one of which is due to the lack of monitoring. After the initial implementation, the process has never been reviewed and is rarely checked to ensure its implementation. Monitoring lean implementation requires tools that can help monitor work more efficiently. There are no specific tools that can be used to control and oversee lean implementation in the company. For this reason, this research will develop a tool for monitoring lean implementation. The tools to be developed adopting the logic of several methods, namely Quality Function Deployment (QFD), the framework of three matrix houses in lean implementation, and the House of Risk (HOR). This Lean monitoring tool is used to ensure that the corrective actions recommended for lean implementation are implemented. The Lean monitoring tool consists of three matrices that offer the ability to identify potential failures, the root causes of failures, and solutions to deal with lean implementation failuress.**

***Keywords*—House of Risk, Lean, Monitoring, Potential Failure, Waste Elimination Action.**

I. INTRODUCTION

COMPETITION in the business world makes a company must continuously improve its producr, both in terms of quality and service to consumers. One step to realizing this through developing operational and support systems is to reduce activities that do not provide added value or are not needed. All activities that have no added value in the process of change from input to output through the value stream are called "waste". Lean is an approach that is carried out continuously to discuss and eliminate waste or activities that do not provide added value[1]. In their research presents data related to the benefits obtained after the implementation of lean. According to the given statistics, the most significant progress is seen in such improvement areas as return on assets (100%), on time delivery (99%), machine availability (95%), machine setup time reduction (80-90%), reduction in floor space (80%), and inventory reduction (75%) [2]. Identified several weaknesses in lean implementation, one of which was due to lack of monitoring [3]. After the initial implementation, the process is never reviewed and is rarely checked to ensure its implementation. Likewise, [4] state that there is a need for ongoing evaluation to prevent failure in lean implementation. Lean manufacturing that has been implemented in a company requires a sustainable mechanism. Monitoring lean implementation requires tools that can help monitor work more efficiently. There are no specific tools that can be used to control and monitor lean implementation in the company. For this reason, this research will develop a tool for monitoring lean implementation. The tool will be developed based on (adopting) the logic of several methods, which are Quality Function Deployment (QFD), the Three Matrix House Framework for Lean implementation, and the House of Risk (HOR).

Quality Function Deployment (QFD) is a structured methodology used in the process of product planning and development to determine the specifications of the needs and desires of consumers and, systematically evaluate the capabilities of a product/service to fulfilling the needs and desires of consumers [5]. The QFD methodology involves four basic phases that occur during the product development process, that are product planning (HOQ matrix), product designing, process planning, and process control (production) [6]. Then in 2011, I. A. Rawabdeh adopted the 4-phase QFD logic in developing tools to help the process of implementing Lean Manufacturing. In this modification model, three HOQ matrices are used. House I aim to suggest waste priority which shows type of waste that significantly affected the company. In House II, the causes of each waste (from House I) are identified. Similar to the previous matrix, House II also aims to give priority to the cause of waste based on several steps of calculations. Final matrix, House III provides the rank of potential solution tools (e.g. kanban, takt time, benchmark, leadership development, etc) for cause of waste.The 4-phase QFD concept and the Three Matrix House Framework for Lean implementation provide ideas for the development of this monitoring tool.

House of Risk (HOR) is a comprehensive supply chain risk management tool developed by Pujawan and Geraldin in 2009. HOR, which is based on the integration of QFD with FMEA, is used to identify and assess risk agents, cause evaluations, and determine mitigation actions. This tool has two matrices. The matrix framework on HOR was chosen in developing the Lean Monitoring Tool in this study, where the Lean Monitoring Tool offers the ability to identify failures, the root causes of failures and solutions to deal with the failure of lean implementation.

The Lean Monitoring Tool developed in this research is the next step in the implementation stage of lean manufacturing [9]. This tool will be an advanced tool of the Lean Assessment Matrix (LAM) developed by P. D. Karningsih, A. T. Pangesti, and M. Suef, where the LAM serves to identify waste and the root causes of waste to obtain recommended steps to eliminate effective waste [10]. After getting a recommendation for corrective action or waste elimination

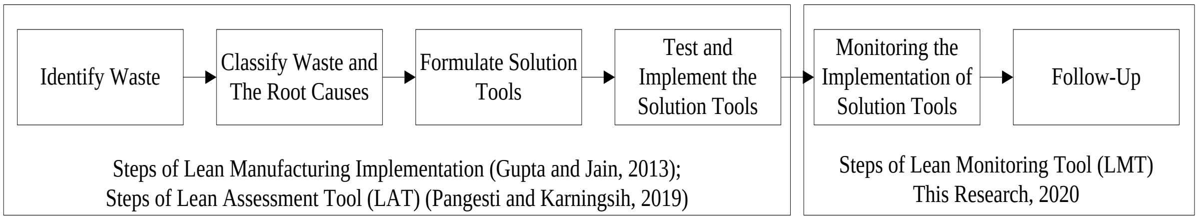

Figure 1. Stages of Lean Manufacturing Implementation.

Table 1.
Lean Monitoring Matrix (LMM) 1

Waste Classification	Waste Elimination Action (W_i)	Potential Failure (F_j)						Severity of Waste Elimination Action i (S_i)
		Financial		Managerial		Technical		
		F1	F2	F3	F4	F5	F6	
Transportation	W1	R11	R12	R13	R14			S1
	W2	R21	R22	R23				S2
Inventory	W3	R31						S3
	W4	R41						S4
Motion	W5	R51						S5
	W6	R61						S6
Waiting	W7							S7
	W8							S8
Defect	W9							S9
	W10						R_{ij}	S10
Occurance of Potential Failure j (O_j)		O1	O2	O3	O4	O5	O6	
Aggregate Potential Failure j		APF 1	APF 2	APF 3	APF 4	APF 5	APF 6	
Priority Rank of Potential Failure j		PR1	PR2	PR3	PR4	PR5	PR6	

action which is the output of the Lean Assessment Matrix (LAM) tool, the next step is to monitor the activity using this Lean Monitoring Tool. As explained in the flow chart in “Figure 1.” below.

This Lean Monitoring Tool uses three matrices. After the activities / proposed improvements in lean implementation are identified, the type of failure will be analyzed and the root causes of the failure will be searched. The root cause of failure will be given a solution or follow-up that must be implemented to ensure the lean implementation objectives can be achieved, eliminating or reducing waste.

II. LITERATURE STUDY

A. *House of Risk (HOR)*

I. N. Pujawan and L. H. Geraldin developed a supply chain risk management model by integrating the concept of House of Quality (HOQ) and Failure Models and Effects Analysis (FMEA) to develop a framework for managing supply chain risk known as the House of Risk (HOR) approach. The HOR approach aims to identify risks and design treatment strategies to reduce the probabilities of risk causes or risk agents by providing preventative measures. The FMEA in the HOR method is used to calculate the level of risk obtained from the calculation of the Risk Potential Number (RPN). The RPN value in FMEA is determined by three factors, namely the probability of occurrence, severity, and the probability of detection (detection), where each of these factors has its own rating scale. The HOQ method is used to assist in the strategic planning process so that it can be used to reduce or eliminate the causes of identified risks. The HOR method consists of two stages, namely HOR 1 and HOR. HOR 1 is used to rank each risk agent (agent of risk or cause of risk) based on the aggregate risk potential (ARP) value. Whereas HOR 2 is used to facilitate management in prioritizing risk management that has been identified and calculated the level of risk in HOR 1.

B. *Lean Assessment Matrix (LAM)*

In 2019, P. D. Karningsih, A. T. Pangesti, and M. Suef developed a Lean Assessment Matrix (LAM) tool. The development of the Lean Assessment Matrix (LAM) follows the same logic as the House of Risk (HOR) [10]. Some modifications were applied to fit lean implementation goals. LAM is a tool that can not only identify waste, determine critical waste and determine the root cause of waste, but also determine priorities for improvement actions to reduce waste, so this tool is more applicable. The Lean Assessment Matrix (LAM) was developed by modifying the House of Risk (HOR) matrix and integrating with the Waste Relationship Matrix (WRM) and accommodating nine waste. The Lean Assessment Matrix (LAM) consists of two matrices which include LAM 1 and LAM 2. In LAM 1, identification of the type of waste, assessment, the weighting of waste, and determining the root causes of waste. Lean Assessment Matrix (LAM) 2 aims to choose an improvement strategy so that the root causes of waste generation can be minimized or eliminated.

III. DEVELOPMENT OF LEAN MONITORING TOOL

The development of tools will be carried out to create a new method that will be used in monitoring lean implementation. In developing this tool, a matrix was developed which refers to the House of Risk (HOR) matrix framework introduced by I. N. Pujawan and L. H. Geraldin [8]. This tool consists of three matrices and is named Lean Monitoring Matrix (LMM). The first matrix is a matrix that

Table 2.
Lean Monitoring Matrix (LMM) 2

Potential Failure Classification	Potential Failure (F_k)	Root Cause of Potential Failure (C_l) Financial		Managerial		Technical		Severity of Potential Failure k
		C1	C2	C3	C4	C5	C6	(S_k)
Financial	F1	R11	R12	R13	R14			S1
	F2	R21	R22	R23				S2
Managerial	F3	R31						S3
	F4	R41						S4
Technical	F5	R51						S5
	F6	R61					R_{kl}	S6
Occurance Root Cause of Potential Failure l (O_l)		O1	O2	O3	O4	O5	O6	
Aggregate Root Cause of Potential Failure l		ACF1	ACF2	ACF3	ACF4	ACF5	ACF6	
Priority Rank Root Cause of Potential Failure l		PR1	PR2	PR3	PR4	PR5	PR6	

Table 3.
Lean Monitoring Matrix (LMM) 3

Potential Failure Classification	Root Cause of Potential Failure	Solution (S_m) Financial		Managerial		Technical		Aggregate Root Cause of Potential
	(C_l)	S1	S2	S3	S4	S5	S6	Failure l
Financial	C1	E11	E12					ACF1
	C2	E21						ACF2
Managerial	C3							ACF3
	C4							ACF4
Technical	C5							ACF5
	C6						E_{lm}	ACF6
Total Effectiveness of Solution (TEs)		TEs1	TEs2	TEs3	TEs4	TEs5	TEs6	
Rank of Priority								

can identify and measure waste elimination actions against potential failures. The second matrix in this tool is used to identify and measure potential failures against the root cause of the failure. Then the third matrix is a matrix that can be used to determine solutions or follow-up which can then be used to overcome the problem of lean implementation failures that occur. The stages of developing this tool are as follows:

A. Lean Monitoring Matrix 1

Lean Monitoring Matrix (LMM) 1 is used to map the recommended waste elimination action and potential failures when implementing the corrective action recommendations. The sequence of processes in the Lean Monitoring Matrix 1 work process is explained as follows.

1. Identify waste elimination action. Waste elimination action is the scope of recommendations for improvement actions that will be used to process improvement or eliminate/reduce waste. After the waste elimination action is identified, then do the classification according to the type of waste (e.g. Transportation, Inventory, Defect, etc.). Recommendations for improvement between one company and another can differ depending on the problem or identified waste. In LMM 1 model shown in Table 1, the waste elimination action are put in the left column, represented as Wi.
2. Assess the impact (severity) of such waste elimination action. The purpose of determining the severity value is to find out how much impact is generated by a potential failure on the implementation of waste elimination action. Use 1-10 scale, where 10 represents very high severity.The severity of waste elimination action is put in the right column of Table 1, indicated as Si.
3. Identify potential failure. Potential failures are things that have the potential to obstruct or cause failure in the implementation of waste elimination action. after the potential failure is identified, then classify it based on the main obstacles or factors that cause potential failure (e.g. Financial, Managerial, Technical, etc.). In LMM 1 model shown in Table 1, the potential failure (Fj) are placed on top row of the table.
4. Assess the likelihood of occurrence of each Potential Failure. Here, a scale of 1-10 is also applied where 1 means that potential failure cannot occur and a value of 10 means potential failure can not be avoided. The associated occurrence is on the bottom row, notated as O_j.
5. Develop a relationship matrix, i.e. relationship between waste elimination action and potential failure, R_{ij} {0, 1, 3, 9} where 0 represents no relation and 1, 3, and 9 represent, respectively, low, moderate, and high relations.
6. Calculate the aggregate potential failure j (APF_j) using equation (1) below to find out potential failure which has a major influence on waste elimination action.

$$APF_j = O_j \sum S_i R_{ij} \quad (1)$$

APF_j : Aggregate Potential Failure (AF).

O_j : The probability of occurrence of potential failure (Occurance) j.

S_i : Level of the impact of waste elimination action (Severity) i.

R_{ij} : Relation between waste elimination action i with potential failure j.

7. Rank potential failure according to their aggregate potential failure in descending order (from large to low values).

Lean Monitoring Matrix (LMM) 1 which represents the steps in developing the first matrix can be seen in Table 1.

B. Lean Monitoring Matrix 2

Lean Monitoring Matrix 2 is a continuation of the first matrix. The next step is to find the root cause of potential failure in each potential failure that occurs. This root search is done to be able to find out the source of the causes of failure in eliminating waste or potential failure. The sequence of processes in the Lean Monitoring Matrix 2 work process is explained as follows.

1. Potential failures that have been identified and classified in the previous LMM 1 matrix are then inputted again in the left column of Table 2, which is represented as F_k.
2. Assess the impact (severity) of such Potential Failure. The purpose of determining the value of severity is to find out how much impact is generated by the potential failure that occurred. Use 1-10 scale, where 1 represents negligible severity and 10 represents very high severity. The severity of potential failure is put in the right column of Table 2, indicated as S_k.
3. Identify the root cause of Potential Failure. The purpose of this identification is to find out the source of the cause of failure when doing waste elimination action. In LMM 2 model shown in Table 2, the root cause of potential failure (C_l) are placed on top row of the table.
4. Assess the likelihood of occurrence of each root cause of potential failure. Here, a scale of 1-10 is also applied where 1 means the root cause of potential failure can not occur and a value of 10 means root cause of potential failure can not be avoided. The associated occurrence is on the bottom row, notated as O_l.
5. Develop a relationship matrix, i.e. relationship between potential failure and the root cause of potential failure, R_{kl} {0, 1, 3, 9} where 0 represents no relation and 1, 3, and 9 represent, respectively, low, moderate, and high relations.
6. Calculate the aggregate root cause of potential failure l (ACF_l) using equation (2) below to find out the root cause of potential failure which has a major influence on potential failure.

$$ACF_l = O_l \sum S_k R_{kl} \quad (2)$$

ACF_l : Aggregate root cause of potential failure (ACF)
O_l : The probability of occurrence of the root cause of potential failure (Occurance) l
S_k : Level of the impact of potential failure (Severity) k
R_{kl} : Relation between potential failure k with root cause of potential failure l

7. Rank the root cause of potential failure according to their aggregate root cause of potential failure in descending order (from large to low values).

Lean Monitoring Matrix (LMM) 2 which represents the steps in developing the second matrix can be seen in Table 2.

C. Lean Monitoring Matrix 3

The Lean Monitoring Matrix (LMM) 3 is the last matrix in the Lean Monitoring Tool series. The matrix in this third stage aims to find and also choose the right solution to effectively reduce the probability of the emergence of the root cause of potential failure. The steps in this third matrix are as follows:

1. All root causes of potential failures that have been identified will be given a solution, that will be placed in the left side of LMM 2 as depicted in Table 3. Put the corresponding ACF_l values in the right column.
2. Identify solutions considered relevant to overcome problems to the root cause of potential failure. Note that one root cause of potential failure could be tackled with more than one solution and one solution could simultaneously reduce the likelihood of occurrence of more than one root cause of potential failure. The actions are put on the top row as the "Solution" for this LMM.
3. Determine the relationship between each solution and each root cause of potential failure, E_{ml}. This relationship (E_{ml}) could be considered as the degree of effectiveness of solution m in reducing the likelihood of occurrence of root cause of potential failure l. The values could be {0, 1, 3, 9} which represents, ineffective, weak effectiveness, moderate effectiveness, and high effectiveness between solution m and root cause of potential failure l.
4. Calculate the total effectiveness level of each action as follows:

$$TEs = \sum ACF_l E_{ml} \quad (3)$$

TEs : The Total Effectiveness Level of Each Solution.
ACF_l : Aggregate root cause of potential failure l.
E_{ml} : Degree of effectiveness of the solution m in solving the root cause of potential failure l.

5. After knowing the value of TEs from each solution, then the ranking is determined by sorting the value of the TEs ratio from the largest to the smallest.

In this matrix all solutions must be implemented, so that there are no failures when the waste elimination action is carried out and the objectives of monitoring is achieved. Lean Monitoring Matrix (LMM) 3 which represents the steps in developing the third matrix can be seen in Table 3.

IV. CONCLUSION

A new tool for monitoring lean implementation is proposed. This tool is named the Lean Monitoring Matrix, which was developed by modifying the terminology of the House of Risk (HOR) matrix. The stages of work in this matrix are also similar to the stages of the matrix in the House of Risk (HOR). This tool consists of three matrices, the first matrix identifies and measures the waste elimination action against potential failures. The second matrix is used to identify and measure potential failures against the root causes of these potential failures. The third matrix is used to determine solutions or follow-up to overcome the problem of lean implementation failures that occur. Future work of this research is the application of Lean Monitoring Tool in a case study

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