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Lean Assessment Matrix: A Proposed Supporting Tool for Lean Manufacturing Implementation

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Abstract. During lean manufacturing implementation, some supported tools are required. Value Stream Mapping, Process Activity Mapping, Root Cause Diagram, Failure Mode Effect Analysis, Pareto chart are some examples of the tools that has been widely utilized. However, a tool that is able to support lean manufacturing implementation starting from waste identification until suggest improvement for eliminating waste, is very few. This research proposes a tool that could assist company comprehensively when applying lean manufacturing. The tools, which is called Lean Assessment Matrix, consists of two matrix but it could cover the complete stages of lean implementation starting from waste and their causes identification, the critical waste prioritizing as well as provides waste reduction plan alternatives and their ranks. Lean Assessment Matrix is developed by modifying House of Risk Matrix and integrates with combining Waste Relationship Matrix. Lean Assessment Matrix is being develop with the same approach as of HOR. This tool consist of two matrix which are lean matrix 1 and lean matrix 2. Lean matrix 1 are used to identify waste and its root causes, and determining the rank of waste by considering waste relationships. Lean matrix 2 is aimed to provide alternative actions to reduce or eliminate root causes of selected waste from matrix 1 as well as their priority level.

1. Introduction

Lean Manufacturing is one of popular approach that has been implemented in many manufacturing company around the world. It focuses on eliminating waste, shortening lead time, cutting costs and also improving employee skills. Basically, philosophy of Lean Manufacturing is originated from Toyota Production System (TPS) which emphasizes on elimination of seven waste, improves efficiency and aims at improving customer satisfaction [1][2].

According to [4], there are several steps to implement Lean Manufacturing, they are as follow: (a) identify and classify waste including their root causes, (b) formulate solutions to handle root cause of waste, (c) test and implement the solutions. There are several general and tools that are utilized to support each steps of lean implementation, such as: Value Stream Mapping, Root cause analysis, Just In Time, 5S, Kanban, Material Requirement Planning and many more. Value stream mapping (VSM) is commonly used to exhibit the flow of materials and information of a product or a product family covering customer, supplier and manufacturer. Root cause analysis (RCA) is a generic method which is utilized for trace down to root cause of a problem in many area such including quality control. Fishbone and Five Why's analysis are example of RCA tools [5]. 5S, which represents sorting, set in order, shine, standardize and sustain, is also one of popular approach that help company to reduce

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waste. This tool is focused on improving of work place effectiveness and standardizing work procedures [4].

The author [6] develops the first tool that considers relationships among seven waste, rank these waste as well as identify source of waste. This tool consist of two parts, which are *(6)(6)(6)*Waste Assessment Matrix (WAM) and Waste Relations Questionnaire (WRQ). This tool could help company to focus their improvement effort on the most significant waste and its root causes accordingly. The same author [7] in his more recent study suggest a tool consist of three matrix based on modification of Quality Function Deployment (QFD)/House of Quality(HOQ) matrix. This tool offers a more complete tool compare to his previous study, that can identify and prioritize seven waste, determine root cause of waste, and formulate appropriate improvement method. The first matrix of this tool, House I, connect between all sign in the company (e.q. high inventory cost, poor flow of material, etc) which grouped to 7M (i.e. management, material, machine, man, market, measurement, and money related) with seven type of waste and then these waste are measured and ranked. House I aim to suggest waste priority which shows type of waste that significantly affected the company. In the House II, causes of each waste (from House I) is identified. Similar with previous matrix, House II also aims to give priority of cause of waste based on several steps of calculations. Final matrix, House III provides rank of potential solution tools (e.q. kanban, takt time, benchmark, leadership development, etc) for cause of waste.

In particular for managing supply chain (SC) risk, House Of Risk (HOR) is developed by [8]. HOR is developed by integrating House of Quality with Failure Mode Effect Analysis (FMEA). HOR comprises of two matrix, they are: HOR 1 and HOR 2. HOR 1 are used to identify risk events, risk agents (e.q. causes of risk event) as well as to rank risk agents based on their significant level. HOR 2 are utilized to formulate alternatives of risk action (treatment) for each risk agent and rank them based on effectiveness and difficulty level [8]. House of Risk (HOR) offers an comprehensive and integrated tool for managing supply chain risk that could encompass all main stages of SCRM from risk identification, assessment, evaluation until risk treatment recommendation [9]. Thus, in managing SC risk a decision maker could use only one supporting tool, that is HOR, instead of using several tools (e.q. risk matrix, FMEA, etc). Moreover, HOR involves a simple yet effective calculation to prioritize risk agent as well as risk action. In addition, this tool output is applicable (practically feasible) and effective recommendation for risk treatment.

Referring to the previous elaboration of supporting tools for Lean Manufacturing based on study of [8] and for Supply Chain Risk Management from study of [9], this study proposes a tool for Lean Manufacturing implementation that could cover all steps including recommend practical and effective improvement plan by modified House of Risk matrix and integrated them with Waste Relations Matrix to consider relations between waste (weight of waste). The tool is called Lean Asssessment Matrix is only consist of two connected matrix and involved a simple but yet effective calculations. Moreover, as nowadays the type of waste goes beyond seven waste, therefore this study also take into account nine waste in the development of this roposed tool.

2. Literature study

2.1 Waste Assessment Matrix (WAM)

Waste assessment Model (WAM) are tools that was developed by [6] which aiming at mapping relationships among seven waste (figure 1)and calculating weight of each waste. WAM consist of Waste Relationship Matrix (WRM) and Waste Assessment Questionnaire (WAQ). In general, both WRM and WAQ are questionnaire based tool that required inputs/feedbacks from experts (top management). Table 1 shows list of questions of WRM. These questions are applying to each pair of waste, for example between waste defect with waste overproduction, waste motion with waste over inventory, and vice versa. By answering the questions number 1 to number 3 then relations between two waste could be identified including calculated its (weight) magnitude as the answers are then converted into a score. The result of relationship of seven waste are 31 relations which is showed at

Figure 1. Questionnaire of WAQ has 68 questions that are categorized into man, machine, method and material. The questions of each category are varies as it represents different activity related to type of waste. For each question of WAQ has three options (answers) and each answer has different weight (e.q. 4, 2, and 0).

Table 1. List of questions for developing Waste Relationship Matrix [6]

No	Questions	Answers	Score
1	Does *i* produce *j* ?	a. Always	= 4
		b. Sometimes	= 2
		c. Rarely	= 0
2	What is the type of the relationship between *i* and *j* ?	a. As *i* increases *j* increases	= 2
		b. As *i* increases *j* reaches a constant level	= 1
		c. Random depends on conditions	= 0
3	The effect of *j* due to *i*	a. Appears directly and clearly	= 4
		b. Need time to appear	= 2
		c. Not often appears	= 0
4	Eliminating the effect of *i* on *j* is achieved by . . .	a. Engineering Methods	= 2
		b. Simple and direct	= 1
		c. Instructional solution	= 0
5	The effect *j* due to *i,* mainly influences …	a. Quality of products	= 1
		b. Productivity of resources	= 1
		c. Lead time	= 1
		d. Quality and productivity	= 2
		e. Productivity and lead time	= 2
		f. Quality and lead time	= 2
		g. Quality, productivity, and lead time	= 4
6	In which degree does the effect of *i* on *j* increase manufacturing lead time?	a. High degree	= 4
		b. Medium degree	= 2
		c. Low degree	= 0

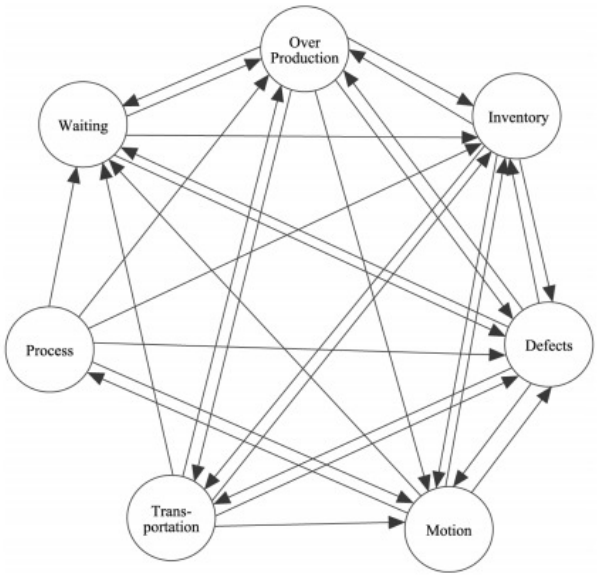


Figure 1 Interrelationship among 7 waste [6]

2.2 House Of Risk (HOR)

Authors [8] propose House of Risk (HOR), a tool for managing risks in supply chain context which is developed by integrating Failure Mode and Effect Analysis (FMEA) and House of Quality (HOQ). HOR consists of two main matrixs. The first matrix, HOR 1 matrix (table 1) for identifying and classifying risk events and their associated causes (risk agents) based on five SC processes of SCOR (i.e. Plan, Source, Make, Deliver, Return) framework . Aggregate Risk Potential (ARP) is calculated by multiplying occurence of each risk agent with sum of multiplication betwen severity of risk event and relation value betwen risk event and risk agent. Thus, from this matrix, ARP value for each risk agents are calculated and it could be ranked. The decision maker then could selects how many risk agents that would be further analyzed in HOR 2 matrix [8]. Then, risk action/treatment for each selected risk agent from Matrix 1, is formulated in Matrix 2. The relations score between risk action/treatment with associated risk agent is utilized to represent level of effectiveness of risk action to handle risk agent. Ranking of risk action/treatment is determined based on calculation of Effectiveness to Difficulty (EtD) Ratio. The score of difficulty as well as effectiveness for each risk action is determined by top management/expert.

3. Development of Lean Assessment Matrix

Basically, development of Lean Assessment Matrix (LAM) is following similar logic as House of Risk. Some modification is applied to allign with Lean implementation purpose. Moreover, to take relations between waste into this tool, it is integrated with Waste Relationship Matrix (WRM) approach. For identifying non added value activities (waste) purpose, generic tools such as Value Stream Mapping, Big Picture Mapping or Process Activity Mapping are still utilized before using LAM.

Lean Assessment Matrix has two matrix, they are: Lean matrix 1 and Lean matrix 2. Lean matrix 1 is aiming at identification non value added activities that is categorized into types of waste. This study refer to study of [10] that suggests nine types of waste, they are as follow: defect, motion, transportation, overproduction, over inventory, over processing, environment health and safety, and underutilized people's skills. Then, for each non added value activity (waste), its root source of waste are determined by applying Root Cause Analysis (e.q. 5 Why's Analysis) logic. Next, the impact value of each root source of waste to its associated waste is determined according to value 1, 3 and 9 (i.e. low, moderate, high relation respectively). Impact value 9 means that a particular root source of waste has high impact to associated waste. The weight of each waste is determined by calculating relationships between nine waste using WRM questionnaire (table 1) but only question number 1 to 3 that is applied for this study. Judgement from top management/experts are essential to fill WRM questionnaire, as well as determine level of severity of waste and occurence of root source of waste. While, output of the first matrix of House of Risk is risk agents ranks. Lean Matrix 1 (table 5) determines rank of waste types since Lean concept focuses more on eliminating waste so top management generally needs to prioritize one or several particular waste that significantly affecting their manufacturing operations. After value of severity, occurrence and impact are determined then Aggregate Cause Value (ACV) is calculated according to this formula (1).

$$ACV_i = O_i \sum S_j I_{ij} \quad (1)$$

Where O_j = occurrence level of the root source of waste j, S_i = severity level of waste i, I_{ij} = impact value of root source of waste j to waste i.

Lean Matrix 1 use Aggregate Waste Number (AWN) to determine waste ranking which influenced by waste type k weight (WT_k) according this formula (2).

$$AWN_i = WT_k S_i \sum O_j I_{ij} \quad (2)$$

After AWN is calculated then Waste rank is applied for each waste (non added value activities). To decide the most significant waste, Pareto rule or expert judgement could be applied. Based on one or several priority (significant) waste type that have been selected, then their root source(s) of waste are tracked down accordingly based on the mapping at Table 5.

Lean Matrix 2 (Table 6) is aiming at determining the rank of alternatives waste elimination action based on selected root source of waste from Lean Matrix 1. Firstly, one or more alternatives waste elimination action is formulated for each selected root cause of waste. Then, degree of effectiveness of action in eliminating/reducing the presence of root source of waste (E_{mk}) is measured according to three value, they are: 1, 3 and 9 (i.e. low, moderate and high). Next, value of total effectiveness of waste elimination action (TE_m) is calculated from total sum of multiplication between aggregate cause (AC) with effectiveness of these action as is shows in the equation (3) .

$$TE_m = \sum ACV_i E_{mj} \quad (3)$$

Where TE_m = the total effectiveness of waste elimination action m, AC_i = Aggregate Cause i, E_{mj} = degree of effectiveness of action m in eliminating/reducing root source of waste j.

Furthermore, the degree of difficulty performing action m (D_m) is determined by level of required funding and other resources in doing the action. In this study, three degree of difficulty (i.e. 3=low, 4=medium, and 5=high) is utilized as is in [8]. Lastly, to allocate priority for each waste elimination action is determined by calculate Effectiveness to Difficulty ratio (ETD_m) following the equation (4).

$$ETDm = \frac{TEm}{Dm} \quad (4)$$

After the value of ETD_m is determined, then action priority rank from highest ETD_m to lowest ETD_m can be presented (Table 6).

4. Appplication of Lean Assessment Matrix: a case study

This proposed Lean Assessment Matrix (LAM) is tested by using data from a case study that was conducted by [11]. In the original article, the authors combines Waste Assessment Matrix with Root Cause Analysis and Failure Mode Effect Analysis.

Table 2. Identified Waste

W1	Cutting thread using a cutter on the knitting machine
W2	Setting the length of the knitting machine
W3	Dotting process
W4	Maintenance Activity
W5	Rework/repair defective product
W6	Move from one station to another with flow of production processes that are not in the same direction
W7	Transfer of raw material from the first floor to the second and third floor using a hoist and small capacity

The company that is utilized in this case study is a knitted gloves company. This medium scale manufacturing industry has 100 employees and every month should produce around 112.000 dozen knitted gloves. Knited gloves are produced through four main processes, namely knitting, sorting out the side of stitch, dotting, and packaging. This company is operated in a three floors building [11]. The first floor is utilized for storing raw materials, finished goods, and marketing offices. Then, the second floor is used for knitting, sort out the side of stitch and packaging. Lastly, the third floor is used for knitting and dotting gloves.

Table 3. Root cause of Waste

S1	The needle was broken during the production process
S6	The brush is wear out
S7	The operator less focus
S8	Screen printing covered by screen printing liquid
S9	Rubber screen printing has been worn
S3	There is a dial during the production process
S2	Raw material has poor quality
S4	The chain of machine is interrupted during the production process because it has been used for a long time
S5	Cutter machine doesn't work

To appply Lean Matrix Assessment, firstly the weight of each waste can be calculated after the company manager fill out the WRM questionnaire (Table 1) . The WRM results indicates that the weight of each waste in this company. In addition to, in lean matrix there is severity aspect, occurrence, non-added value activity (waste), The level of occurrence of root cause of waste, severity of waste, and their impact value are also determined by using expert's judgement through questionnaire. List of waste, root cause of waste and elimination action are presented in 2, Table 3 and Table 4.

Table 4. Waste Elimination Action

WEA1	Make a buffer on the part
WEA2	Provide ventilation in warehouses
WEA3	Put pallet as a base for storing raw material
WEA4	Make cards and maintenance forms
WEA5	Make schedule for technicians to do maintenance
WEA6	Replace brushes, screen printing rubber and equipment regularly
WEA7	Make schedule of operator shift

Based on Lean matrix 1 analysis (Table 5), the highest ranking waste type is defect due to activity of dotting process. The weight of waste defect is to 17.65. The root cause of waste can be formulated using root cause analysis. For example, broken needles during the production process, wear brushes, operators who lack focus, screen printing screens are covered with screen printing fluids, and the screen printing rubber is worn out. In lean matrix 2 (Table 6), the root source of waste used consists of the root source of waste that is owned by W2 and W3.

In Lean matrix 2 (Table 6), waste elimination actions are determined for each selected root cause of waste. Based on this case study, Waste Elimination Action 5 (WEA5) has the highest ratio, so it has the highest priority to be applied to reduce/eliminate waste in this knitted gloves company.

5. Conclusion

This study proposes a new tool for supporting top management in implementing Lean Manufacturing. The tool is called Lean Assessment Matrix is developed by modifying House of Risk Matrix and integrates it with Waste Relationship Matrix to ensure relations between waste is considered. This tool consists of two matrix, considers nine types of waste and offer top management with feasible waste elimination/reduction action.

For future research, this tool will be modified further to cover ten waste and application on service industries.

6. Acknowledgement
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Table 5. Lean Matrix 1

		Root Source of Waste																				
Waste Type	Non Added Value Activity (Waste)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	Waste Type Weight	Severity level of Waste	Aggregate Waste Number	Waste Rank
Defect	W1	9				9		3											17.65	9	27639.9	3
	W2		3	9	3	9														9	29069.55	2
	W3	9					1	9	3	1										10	31064	1
Waiting	W4										9	9	9						12.75	7	19278	4
	W5										9		9	9						6	18589.5	5
Transportation	W6															9	9	9	14.71	4	15886.8	6
	W7														9		9			4	10591.2	7
Occurrence level of Root Source of Waste j		10	10	7	6	8	10	4	10	10	7	7	10	10	10	10	10	10				
Aggregate Cause Value		1710	270	567	162	1296	100	468	300	100	819	441	1170	540	360	360	720	360				

Table 6. Lean Matrix 2

		Waste Elimination Action							
Waste type	Root Source of Waste	WEA_1	WEA_2	WEA_3	WEA_4	WEA_5	WEA_6	WEA_7	Aggregate Cause i
Defect	S1	9							1710
	S6				1	3	9		100
	S7							9	468
	S8		9	9					300
	S9				1	3	9		100
	S3	9							567
	S2		9	9					270
	S4				1	3	9		162
	S5				1	9			1296
Total Effectiveness of Waste Elimination Action m (TE_m)		20493	5130	5130	1658	12750	3258	4212	
Degree of difficulty performing action m (D_m)		3	3	3	3	3	4	3	
Effectiveness to difficulty ratio (ETD_m)		6831	1710	1710	552.67	4250	814.5	1404	
Rank of action priority		1	3	3	7	2	6	5	