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Waste assessment using lean manufacturing in rubber production

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Abstract. During the rubber production process, there are several wastes caused by breakdown machines, damaged equipments, and production delays. Those wastes have negative impact to companies and thus, need to be eliminated. This study aims to assess wastes in rubber production process using lean manufacturing approach. Waste Relationship Matrix (WRM), Waste Assessment Questionnaire (WAQ), and Value Stream Analysis Tools (VALSAT) are applied to identify the wastes. Fishbone Diagram is then used to determine the root cause of problems. Finally, Failure Mode and Effect Analysis (FMEA) method is applied to evaluate the source of wastes and develop the action plans. It indicated that over production, inventory, and defects as the three highest wastes in the rubber production. Process Activity Mapping (PAM) is selected as the analysis tools in VALSAT and it obtained the activities in the rubber production are mostly categorized into value added activities. The necessary but non value added activities are also identified at a fairly high frequent. The major risks during the rubber production is related to dynamo damage and machine clogged in both hammer mill and mangle machine. It needs high attention from the production manager of rubber industry. Then, action plans are suggested to improve the maintenance program.

Keywords: waste assessment, lean manufacturing, rubber industry

1. Introduction

Lean manufacturing has been recognized as a powerful tool in finding and eliminating the wastes during the production processes. It is defined as a systematic and structured methodology that used to find, solve, and prevent the performance problems through tracking-back approaches to obtain the main hidden roots of wastes [1]. Lean manufacturing is known as a philosophy of Toyota Production System that attempts to reduce the time line between the customer order and the product delivery by constantly eliminate the wastes [2]. The basic ideas of lean manufacturing are waste elimination, cost reduction, and employee empowerment [3].

In the concept of lean manufacturing, the activities in production processes are divided into three types, namely value added activities, non-value added activities, and necessary but non-value added activities [4]. Eliminating wastes can reduce the non-value added activities and increase the value added activities. The implementation of lean manufacturing is expected to improve the flexibility of production process, overcome the changes in customer needs, and reduce the inventory level [2]. Elimination of wastes provides a high impact to companies that can increase the added value of final product. Therefore, the activities that do not provide added value to the product must be eliminated because it is categorized as a waste in the production process.

It is no doubt that the elimination of waste is a critical part for companies in order to survive in today's manufacturing world. Wastes will have a negative impact to companies such as inventory that



increase the production costs due to require the additional handling and space, delay times that create the work in process between workstations, and excessive processing that will increase the rate of redundancy operations [1]. In other hand, companies today must strive to produce high-quality and low-cost products that can reach the customers in the shortest possible time. Thus, it is necessary to improve the efficiency of the production line in order to reduce the downtime rates and fulfill the market demand [1].

Based on the preliminary study conducted in a rubber manufacturing company in Padang, Indonesia, it can be seen there are several wastes during the rubber production processes. It caused by the breakdown machines, damaged equipments, and production delays due to low maintenance on machines and equipments. The most frequently wastes occurred in the rubber production processes are over production, delays, and defects. Therefore, it is needed to eliminate those wastes. This paper attempts to assess the wastes during the rubber production processes using lean manufacturing approach.

2. Methodology

The methodology has four main stages.

2.1. Waste Identification

Waste identification is conducted using Waste Relationship Matrix (WRM) and Waste Assessment Questionnaire (WAQ). WRM is applied to determine the relationship amongst wastes, while WAQ is used to assess the type of wastes and rank the wastes. In this study, seven wastes are considered in the assessment consist of over production (O), inventory (I), defects (D), motion (M), transportation (T), over processing (P), and waiting (W). The waste relationships are assessed using a questionnaire consisting of six questions and the weight of answers ranging from zero to four adopted from [5]. The results are presented in a WRM that show the relationship value amongst the wastes. WAQ consists of 68 different questions for the purpose of allocating the wastes. Each of the questions represents an activity, a condition or a behaviour that may lead to a specific type of waste. Some questions are assigned a "From" note, which means the question represents an existing type of waste that may lead to other wastes, with reference to the WRM. Other questions are assigned a "To" note, which means the question represents any existing type of waste that may have been caused by other types of waste. All the questions have three answers and each answer is assigned a weight of 0, 0.5 or 1. The questions then categorized into four groups consist of man, machine, material and method. The results show the value of each waste and ranked in descending order.

2.2. Value Stream Analysis Tools (VALSAT)

VALSAT developed by Hines and Rich in 1997 is aimed to understand the current value stream and aid in developing the improvements to eliminate wastes in the value stream. It is a decision heuristic for selection of value stream mapping techniques. VALSAT develops the correlation matrix between the various types of waste and the seven value stream mapping tools. Implementation of improper mapping tools can result in wasting the additional resources such as time and money, and decreasing the employee confidence to the lean philosophy [6]. In this stage, an analysis tool with the highest value is selected to obtain a detail mapping analysis.

2.3. Fishbone Diagram

The Fishbone diagram is then developed to identify the root causes of waste. In this stage, the three highest wastes identified from the waste identification stage are selected to obtain the root causes of those wastes. The root causes are analyzed in which categories of process, product, machine, material, marketing, and environment. Identification of the root causes is conducted using brainstorming approach with industry experts.

2.4. Failure Mode and Effect Analysis (FMEA)

In this stage, the failure modes caused by the effects of wastes are identified using Failure Mode and Effect Analysis (FMEA) method. For that purpose, a FMEA questionnaire is then designed to

determine the severity, occurrence, and detection of failure modes. Next, the Risk Priority Number (RPN) is calculated to obtain the highest failure modes. Finally, the action plans are developed to minimize the failure modes.

3. Results and discussions

This study is conducted in a rubber manufacturing company located in Padang, Indonesia. Established in 1972, the company produces the crumb rubber. The production flow is shown in Figure 1.

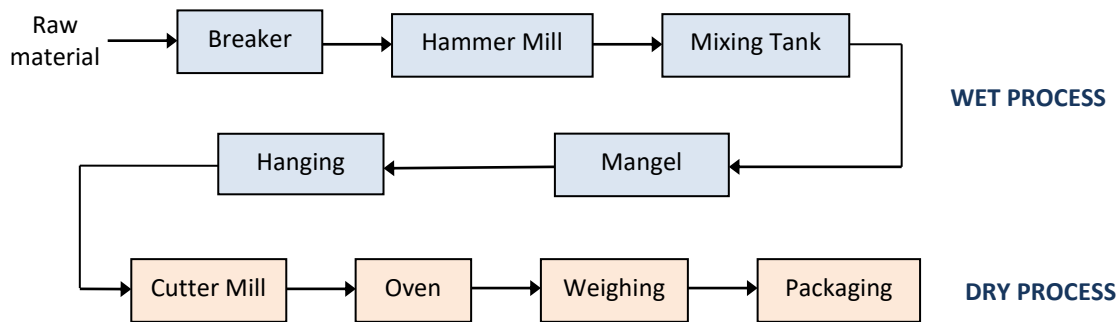


Figure 1. The crumb rubber production flow.

3.1. Waste Identification

A total of 14 production managers and staffs are consulted to determine the waste relationship. The results are shown in Table 1.

Table 1. Waste relationship score.

Question	Score	Relationship	Question	Score	Relationship
O_I	13.50	E	M_P	10.50	I
O_D	9.67	I	M_W	11.75	I
O_M	12.33	I	P_O	11.50	I
O_T	14.67	E	P_I	10.33	I
O_W	12.33	I	P_D	10.50	I
I_O	14.17	E	P_M	11.17	I
I_D	9.83	I	P_W	10.17	I
I_M	12.50	I	T_O	13.50	E
I_T	13.33	E	T_I	14.17	E
D_O	9.25	I	T_D	10.83	I
D_I	10.75	I	T_M	12.83	I
D_M	10.25	I	T_W	13.17	E
D_T	7.75	O	W_O	7.50	O
D_W	12.25	I	W_I	11.00	I
M_I	13.00	E	W_D	9.50	I
M_D	9.75	I			

The Waste Relationship Matrix of rubber production is then constructed based on the table above as presented in Table 2. The Waste Relationship Matrix is then converted into a value where A= 10, E= 8, I= 6, O= 4, U = 2, and X= 0 adopted from [5]. The percentage value is calculated and the results are shown in Table 3. It can be seen from the table, transportation (T), over production (O), and over processing (P) are the most influencing wastes, while inventory (I), defects (D), and over production

(O) are the most influenced by other wastes. The next step is validating the wastes using Waste Assessment Questionnaire (WAQ). The results are shown in Table 4.

Table 2. Waste relationship matrix.

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

Table 3. Waste relationship value.

F/T	O	I	D	M	T	P	W	Score	%
O	10	8	6	6	8	0	6	44	16.42
I	8	10	6	6	8	0	0	38	14.18
D	6	6	10	6	4	0	6	38	14.18
M	0	8	6	10	0	6	6	36	13.43
T	8	8	6	6	10	0	8	46	17.16
P	6	6	6	6	0	10	6	40	14.93
W	4	6	6	0	0	0	10	26	9.70
Score	42	52	46	40	30	16	42	268	100
%	5.67	9.40	7.16	4.93	1.19	.97	5.67	100	

Table 4. Waste relationship matrix.

Wastes	Score (Y_j)	P_j Factor	Final Result ($Y_{j\text{final}}$)	Final Result (%)	Rank
O	0.195	257.296	50.149	20.244	1
I	0.179	275.117	49.323	19.911	2
D	0.181	243.373	44.124	17.812	3
M	0.155	200.490	31.012	12.519	5
T	0.173	192.136	33.178	13.393	4
P	0.126	89.107	11.261	4.546	7
W	0.189	152.038	28.673	11.575	6

The results show over production (O) indicated as the major type of waste. It is followed by inventory (I) and defects (D). Over production has considered as the most important waste because it has a high influence on the occurrence of other wastes [7]. Producing more items than required by the next station or the market will create an excess inventory. It clearly shows the strong relationship between over production and inventory. Over production also tends to lead to increased lead time and increased storage. As a result, defects may not be detected at early stage.

An investigation was carried out and shows that the production is often incompatible with the predetermined schedules. It can be caused by a sudden downtime on the machine that cause delays in

the production process and loss of production day. This leads to over production and increased inventory on the crumb rubber production. In addition, it might also be due to the push-based production process that causes the high inventory levels on raw material and finished product [8].

3.2. Value Stream Analysis Tools (VALSAT)

VALSAT approach is applied to select an analysis tool by multiplying the final results (% of $Y_{j\text{final}}$) from the waste identification stage with the scale of VALSAT. In this stage, the correlation value of VALSAT consisting of high (9), medium (3), and low (1) is determined for each of the wastes and the mapping tools. The results are presented in Table 5.

Table 5. The results of VALSAT.

Wastes	Weight	Mapping Tools						
		Process Activity Mapping	Supply Chain Response Matrix	Production Variety Funnel	Quality Filter Mapping	Demand Amplification Mapping	Decision Point Analysis	Physical Structure Mapping
O	20.244	20.244	60.733	0	20.244	60.733	60.733	0
I	19.911	59.732	179.197	59.732	0	179.197	59.732	19.911
D	17.812	17.812	0	0	160.308	0	0	0
M	12.519	112.672	12.519	0	0	0	0	0
T	13.393	120.540	0	0	0	0	0	13.393
P	4.546	40.912	0	13.637	4.546	0	4.546	0
W	11.575	104.172	104.172	11.575	0	34.724	34.724	0
Total	476.085	356.621	84.944	185.098	274.654	159.735	33.304	268

The results are identified the Process Activity Mapping (PAM) as the highest value of mapping tools with a score of 476.085. The PAM is then used to describe the crumb rubber production process in detail using symbols that represent the activities such as operation, storage, transportation, inspection, and delay. PAM is a tool used to describe in details the order fulfilment process and find out the activities which include Value Added (VA), Non Value Added (NVA), and Necessary but Non Value Added (NNVA) activities. This tool is also used to identify wastes in the value stream and optimize the process to be more effective and efficient by eliminating unnecessary activities, simplifying processes, and combining processes. The results are presented in Table 6.

Table 6. Results of process activity mapping.

Classification	Quantity	Percentage (%)
Value Added	32	66.67
Non Value Added	2	4.17
Necessary but Non Value Added	14	29.17
Total	48	100.00

The value added activities have identified as the most frequent activities in the rubber production processes with a value of 66.67%. The necessary but non value added activities also have a fairly high value of 29.17%. It mostly caused by the activities of transportation and inspection. The transportation in the rubber production process highly affects the material flow. It might be caused by the plant layout and the continuous production flow of rubber production. In term of inspection, a high frequent of inspections are conducted to maintain the quality of products in the company.

3.3. Fishbone diagram

The Fishbone diagram is used to identify any possible causes of a problem [9]. A series of discussions were conducted to production managers and staffs of the rubber company to develop the Fishbone diagram. The three highest wastes identified in the waste identification stage consisting of over production, inventory, and defects are described. The causes of problem are defined into some categories. The Fishbone diagrams of three wastes are presented in Figure 2–4.

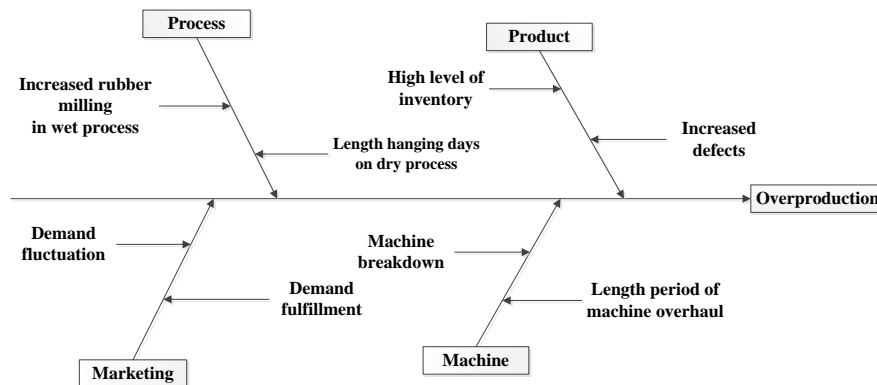


Figure 2. Fishbone diagram of over production.

The root causes of over production are categorized into process, products, marketing, and machine. Over production in the rubber production is mostly caused by the increased milling process in the wet process and the long hanging days. This causes the excess inventory. Over production is usually caused by the high level of inventory and increased defects [8]. In addition, the demand fluctuation from customer makes the company difficult to predict the future demand and thus causing the over production.

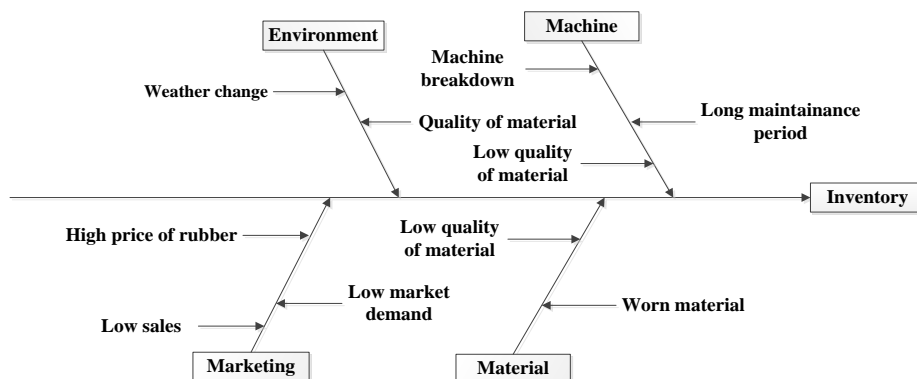


Figure 3. Fishbone diagram of inventory.

Identification of the root causes of inventory consist of four categorizes of environment, machine, marketing, and material. When the sunny, raw material of rubber at a high quality and a high quantity. Company usually buys the raw material at this time. The inventory level also increases during the machine breakdown. In term of marketing, the inventory is caused by high price of material, low sales, and low market demand. Improper production planning causes the excess inventory.

The root causes of defects are divided into four categories of process, machine, product, and material. Defects in the rubber production processes caused by nonconformance process, duration of hanging days, operator error. Nonconformance process will result the product produced not conform to the quality standard [8]. Nonconformance process can be caused by operator and machine. Raw material contaminated with other substances such as iron, stone, and plastic can cause the defects. Besides, low quality of material and high speed of rotation will also affect the product defect.

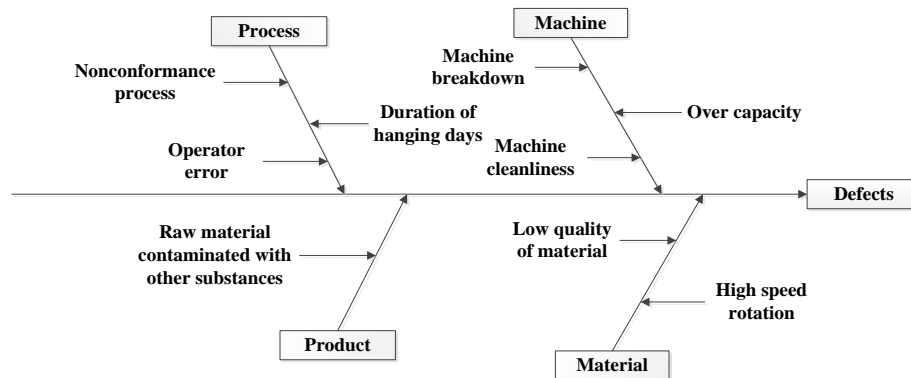


Figure 4. Fishbone diagram of defects.

3.4. Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) method is applied to identify the failure modes caused by the affected wastes. Failure modes are the error conditions which affecting waste in the system [9]. The failure modes are assessed in terms of severity, occurrence, and detection with a scale ranging from 1 to 10 adopted from [4]. A total of 34 failure modes are identified from three main machines in the rubber production based on the results of Fishbone diagram. The Risk Priority Number (RPN) is computed to each of the failure modes. The failure mode with a high RPN means the activity needs an urgent attention and a proper improvement. The results of Risk Priority Number of failure modes in the rubber production are shown in Figure 5.

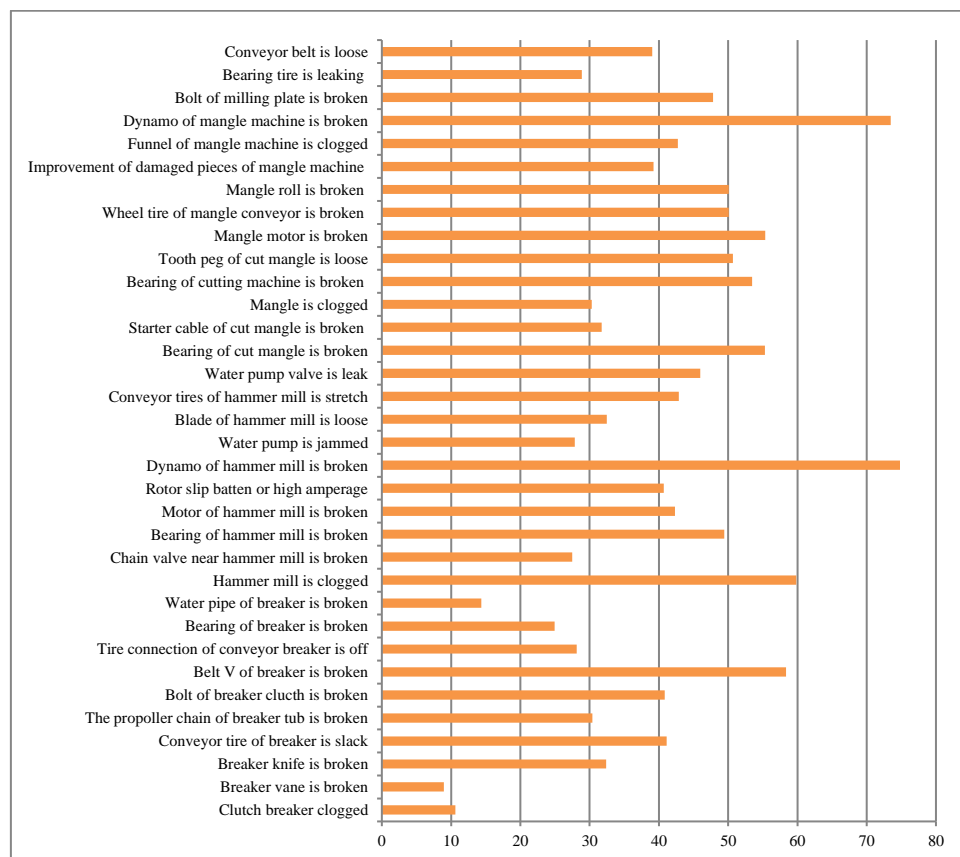


Figure 5. Risk priority number.

It can be seen that the dynamo of hammer mill is broken identified as the major failure in the rubber production with the highest RPN of 74.813. It is followed by the dynamo of mangle machine is broken with RPN of 73.813 and the hammer mill is clogged with RPN of 73.486. Based on the results, it can be concluded that major failures are mostly caused by the production equipment. Thus, it needs urgent attention from production department to improve the maintenance program. The preventive maintenance should be conducted to production equipments. The quality control on the raw material is also suggested since the failure can cause the customer dissatisfaction, major system problems, and rework. It is required the appropriate inspection for material supplied. The comprehensive inspection is needed rather than regular inspection. Besides, the relationships with the supplier need to be improved in order to provide a good quality of material.

Conclusions

This paper has applied lean manufacturing to assess wastes in the rubber production processes. Waste Relationship Matrix (WRM) and Waste Assessment Questionnaire (WAQ) are used to identify the wastes. The results show over production is indicated as the major type of waste in the rubber production processes, followed by inventory and defects. Through Value Stream Analysis Tools (VALSAT), the Process Activity Mapping (PAM) is selected as the analysis tools. It identified the activities in the rubber production processes are mostly categorized as value added activities with a value of 66.67%. However, necessary but non value added activities also have a fairly high value of 29.17%. It mostly caused by the activities of transportation and inspection. Then Fishbone Diagram is applied to determine the root cause of the three highest wastes identified. Finally, Failure Mode and Effect Analysis (FMEA) is used to evaluate the source of wastes and develop the action plans. FMEA indicates the highest failure was caused by the production equipments. Thus, the action plans suggested to the rubber companies are to improve the maintenance program. Besides, the quality control of raw material and the relationships with suppliers should also need to be improved. It is hoped the rubber company can improve their production processes to be more efficient.

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