LEAN MANUFACTURING AND OVERALL EQUIPMENT EFFICIENCY (OEE) IN PAPER MANUFACTURING AND PAPER PRODUCTS INDUSTRY

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ABSTRACT: The purpose of this article is to study the relationship between lean manufacturing methods and overall equipment efficiency (OEE) in paper manufacturing and paper product industry using the one-year data (Jan 2015 - Dec 2015) of five lean manufacturing tools namely single-minute exchange of die (SMED), standardized work (SW), takt time, value stream mapping (VSM) and Kaizen. The current data, which is based on the five lean tools, is compared with the past data which is collected prior to the usage of such tools. Both current and past data are analyzed using IBM SPSS version 22 and the results show that the lean methods are able to reduce waste and increase the OEE. This empirical study gives valuable information to the paper manufacturers and paper product industry in Malaysia on the utilization of lean machines for improving quality and productivity management.

KEYWORDS: *Lean Manufacturing; OEE; Kaizen; VSM; Takt Time*

1.0 INTRODUCTION

The process of globalization encourages manufacturers to optimize their manufacturing process that enable them to deliver high quality products in a short period of time [1]. The pursuit of optimizing manufacturing process has increased the efforts of manufacturing organizations in improving their internal and external performances in order to achieve competitive advantages [2-3]. Competitive pressures have been driving companies toward reduction of cost and improvement of operation for providing high quality products to the demanding market [4]. Lean manufacturing has been the buzzword in manufacturing area [5]. The approach of lean manufacturing which focuses on waste reduction and performance enhancement has been gaining importance recently [6]. The implementation of lean manufacturing system is a practice that includes measuring the current situation and designing the production system [4]. The benefits of lean tools implementation are waste reduction and efficiency improvement, and these benefits are obtainable through the elimination of waste and the production of high quality products [7-8]. The lean manufacturing system was first pioneered by the Toyoda family [5]. The philosophy of lean is to seek perfection through the reduction of waste anywhere in the company, where the fundamental aim of lean tools is to eliminate non-valued added works and to identify wastes [9].

The purpose of this paper is to study the effectiveness of lean manufacturing techniques to reduce waste and to increase OEE in paper manufacturing and paper product industry. This study starts by describing the manufacturing improvement tools of waste for improving the operational performance. The waste factors that affect the operational performance are then identified. Finally, the manufacturing OEE are measured after implementing the lean manufacturing tools.

2.0 LITERATURE REVIEW

This research focus on five lean manufacturing improvement tools namely single-minute exchange of die (SMED), standardized work (SW), takt time, value stream mapping (VSM) and Kaizen to improve overall equipment efficiency (OEE) in paper manufacturing and paper product industry.

Single minute exchange of die (SMED) is one of the many lean production methods for reducing waste in a manufacturing process [10]. As the name suggests, the method provides a rapid and efficient way of converting a manufacturing process from running the current product to running the next product [8].

Standardized Work (SW) is the basic tool for continuous improvement [11]. The SW helps the organization in organizing its employees. Takt time is used to understand the production speed and to produce the one piece of product that meet customers' demand [12]. Takt time can also control the costs and problems in production such as storage and retrieval of finish goods, premature purchasing of raw materials, cost of missed opportunity to produce other goods and capital cost for excess capacity [11].

Value Stream Mapping (VSM) is an industry improvement tool that is used in a predefined set of icons for visualizing the entire production [9]. According to Rother and Shook [13], the VSM tool was popularized due to 2 main factors; it is used to understand all types of waste in a value stream, and it is used to capture a holistic view so that steps can be taken to eliminate waste. The VSM handles uncertainty and creates dynamic view of inventory, lead time and machine utilization. The VSM is a lean supply chain tool which reduces product cost and lead time, and improves quality through the improvement cycle of Plan Do Check Act [2, 12].

Kaizen is a strategy which uses the employees' talent at all levels to improve manufacturing process and to optimize productivity [14]. In short, the Kaizen focuses on continuous improvement of employees. Continuous improvement is the management element that drives efforts for cultural change in workplace. Therefore, the Kaizen can enhance the environmental management system that involves human factor, process and system.

Overall Equipment Efficiency (OEE) is an approach that qualifies the effectiveness and efficiency of operation performance during its work time [15]. The OEE can be categorized into three measurements for tracking the level of production process; availability, performance, and quality [16-17]. The OEE can also measures six big losses which are equipment failures, set up or production adjustment, minor stoppages, reduced speed, reduced yield occurring from start up to stabilization and quality defect [17].

3.0 METHODOLOGY

This section describes in detail the process of lean implementation, lean compacting and lean analysis. First, a lean team is created to identify the factors that may affect the OEE by using Ishikawa Diagram. After identifying the factors, five lean manufacturing tools for investigating waste in paper manufacturing and paper products industry are implemented. The formula for all factors are explain in the following sub sections.

The data for this study is a daily data collected from January 2015 to December 2015 from one of the paper product manufacturers in Peninsular Malaysia. The data consists of 1000 simulations which are executed to reflect randomness and to capture specific variability of multiple interdependent processes. The data is analyzed using IBM SPSS predictive analytics software from 22.0 version.

Lean Team

Lean training is the first activity of lean implementation [18]. In our case of study which focuses on paper manufacturing, the lean team is given knowledge on lean by conducting several trainings on lean techniques and philosophy. The trainings provide clear knowledge that enables the lean team to identify the waste of paper manufacturing. The lean team consists of a group of experts which come from different departments where the objective of the team is to manage people and to implement lean manufacturing in the production process.

Ishikawa Diagram

Ishikawa fishbone diagram is a tool that is used to identify the potential factors of waste of a specific event. Figure 1 illustrates the five factors of waste in paper manufacturing which are waiting, extra-processing, defect, workforce and environment. The waiting factors are machine downtime, machine change over time, and improper machine setting which resulted in the low operational performance of paper processing. The extra-processing factors that affects the operational performance are the non-standardized work and the inadequacy of planning and organizing work which cause the occurrence of repeated process in the paper processing. The defect factors are the utilization of poor quality paper and stained paper. The workforce factor implies that there is a surplus of man power where the planner does not correctly estimates the required number of operators and mostly depends on assumptions. The environment factor that directly affects the workers' performance is the continuous half-day period which is spent on working that resulted in a messy of walk way which is a situation where the workers are unhappy or stressful, and are not performing as required.

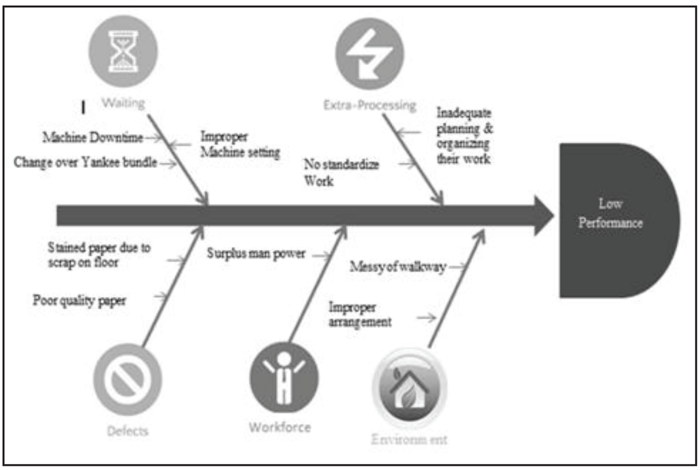

Figure1: Ishikawa Fishbone for identifying waste factors of effective operational performance

Value Stream Mapping (VSM)

The purpose of VSM is to visualize the environment impact and to understand the information flow related to the coordination of process activity based on the standardized icon and data. Figure 2 provides the VSM in a toilet tissue production which shows the flow of production from the customer to the supplier who prepares the material for the production process.

There are 3 types of materials which are used for making the toilet tissue, namely black paper, white paper and mixed paper. At first, the hydro plumper machine blends 1.5 ton of paper materials in a period of 30 minutes. The blended materials are then kept in chest storage in 0.5 day. Then, 3 tons of stock materials are blended again and they are put to storage in 0.3 day. After that, the stock materials are sent to paper making machine which produces jumbo rolls. The Yankee, which is the paper making machine, can produce 20 jumbo rolls per day. The jumbo rolls are then sent to the converting machine where 2 jumbo rolls are needed to run the process. The next change over jumbo roll time is 110 minutes. The converting machine produces logs of paper, and the logs are then stored in the accumulator by 155 logs. The log saw machine, which is the cutting machine, transforms the logs to finished goods. The log saw machine can produce 210 rolls. The finished goods are then sent to the packaging area for manual packing and auto packing. Finally, the finished goods are sent to the warehouse inventory before they are scheduled for delivery.

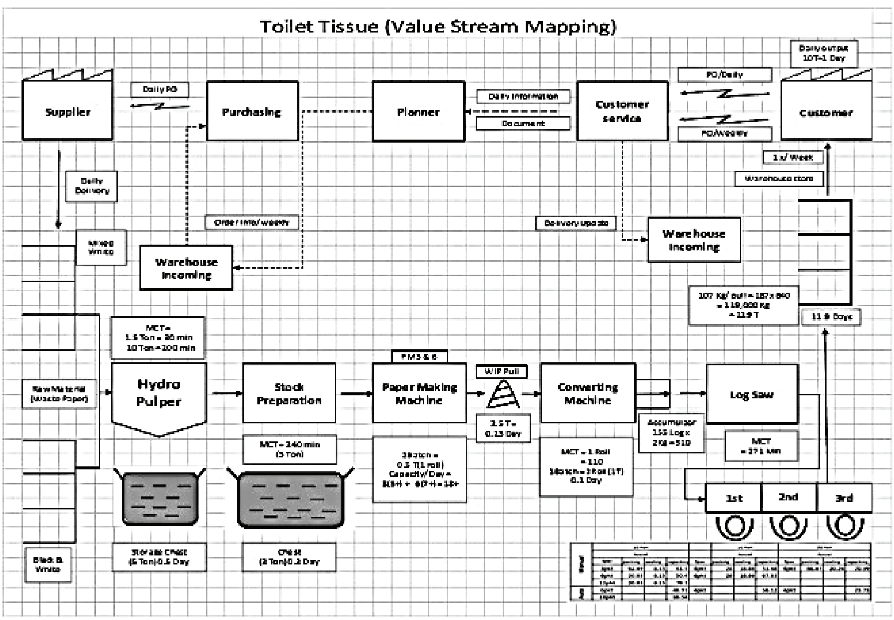

Figure 2: Value Stream Mapping in toilet tissue production

Standard Work (SW)

The Time Study Sheet identifies the accuracy of cycle time and confirms the collected data for the production process. Figure 3 provides the maximum and minimum cycle time needed for calculating and planning the process of toilet tissue production. The figure also provides the method for calculating the processing cycle time for the current production. First, the allowance is used to illustrate the extra working time needed for workers which resulted from the mass production that reduce the workers' production speed. Then, the work element is calculated to confirm, compare and identify the best cycle time that is needed for setting the target of production process. The formulas for allowance and work element are presented as Equations (1 and (2) respectively.

$$\text{Allowance} = [(\text{One Cycle Minimum} - X_{\text{minimum}}) / \text{Total Range}] \times \text{Each Range} \quad (1)$$

$$\text{Work element} = X_{\text{minimum}} + \text{Allowance} \quad (2)$$

Line	TT	Time Measurement Check Sheet							Measurement Date							
Process	toilet tissue								Measurement Time							
Part	Belux 123 10R x 10Pck								Measurer Name							
No	Work Sequence	1	2	3	4	5	6	7	8	9	10	X min	Range (max-min)	Allowance	Work Element Time	Problem
1	Arrangement pack	30.69	24.2	29.22	37.58	25.31	29.24	30.45	27.39	32.27	26.42	24.2	13.38	2.96	27.16	
2	Take Plastic	8.34	7.18	5.4	9.52	6.94	6.17	4.96	6.28	9.06	5.18	4.96	4.56	1.01	5.97	
3	Fill in Plastic	14.87	16.1	14.66	17.66	13.98	12.51	14.9	12.97	14.53	14.78	12.51	5.15	1.14	13.65	
4	Tie	20.25	21.42	17.35	20.94	18.27	18.58	16.35	20	19.89	17.37	16.35	5.07	1.12	17.47	
5	Back to position	9.07	17.31	14.66	6.31	9.62	9.45	9.48	6.36	9.4	10.37	6.31	11	2.44	8.75	
One Cycle time		83.22	86.21	81.29	92.01	74.12	75.95	76.14	73	85.14	74.12	64.33	39.16	8.67	73.00	0

Figure 3: Time Measurement Check Sheet for toilet tissue production

Takt time calculates the production speed required for meeting the customers' order. The standardized cycle time and the takt time are then used for calculating the man power required for the production process. The formulas for takt time is shows in Equation (3) and man power is represented by Equation (4).

$$\text{Takt time} = (\text{1 Day Working Minutes}) / (\text{Required Volume/ Day}) \quad (3)$$

$$\text{Man power need} = (\text{Cycle time}) / (\text{Takt time}) \quad (4)$$

Standardized work chart visualizes the overall production view and the process flow of each part of working area, working sequence, quality, safety, man power, work place and standard in the process of producing stocks. In Figure 4, the work sequence from 1 to 5 demonstrates the approaches of packaging process for the toilet tissue production; arrange the pack, take a plastic, put the pack in the plastic, tie the plastic closely, and return back to position. In particular, the line shows the flow while the dot line indicates the walk way.

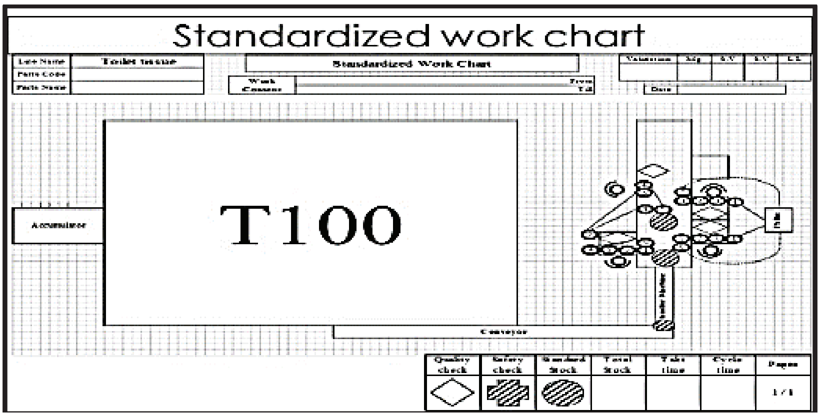

Figure 4: Standardized Work Chart for toilet tissue production

Kaizen

In our case of study which focuses on toilet tissue production, the Kaizen is the walkway management for before and after implementing 5S. It can be seen from Figure 5 that the shine was carried out for keeping the workplace clean and smooth. In particular, the walk way was designed so that the plate of steel and the place for trolley are not blocking the way.

Figure 5: Walkway management before and after 5S

Overall Equipment Efficiency (OEE)

The OEE sheet in Figure 6 shows the time, man power, target, product specification, total, remark, reject and downtime for the toilet tissue production. The OEE uses common data and important sources of manufacturing productivity, places the data and sources into 3 main categories, and provides a measuring gauge for continuous improvement. Therefore, the OEE formula consists of availability, performance and quality of the production process.

There are 3 elements which are required for measuring availability, where the 3 elements depend on the time used in workplace. The performance has two categories which are actual production output and planned production output (target). The actual production output is the current production output, while the planned production output (target) depends on the potential machine cutting per minute. The calculation of quality depends on the rejected bundle which is measured in kilograms. The formulas for measuring availability, performance, quality and OEE are provided in the Equations (5) to (8) below.

$$\text{Availability} = (\text{Planned working time-downtime}) \,/\, (\text{Plant production}) \text{ time} \tag{5}$$

$$\text{Performance} = (\text{Actual output per rolls}) \,/\, (\text{Actual working time} \times \text{Potential cutting per minute}) \tag{6}$$

$$\text{Quality} = ((\text{total output per roll})-(\text{total reject roll})) \,/\, (\text{total output per roll}) \tag{7}$$

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \times 100\% \tag{8}$$

Toilet Roll Department

Date: | Shift A

Time	Man Power	Target	Total Target	10 Roll Actual 3pkt	6pkt	9pkt	10pkt	12pkt	Total	20 Roll Actual 2pkt	4pkt	6pkt	Total	30 Roll Actual 4pkt	Total	Remark	Down Time
7-8am (60min)		60	60														
8-9 am 60min		60	120														
9-10 am 60min		60	180														
10-11am (45min)		45	225														
11-12pm (30min)		60	285														
12-1pm (30min)		30	315														
1-2pm (60min)		60	375														
2-3pm (45min)		45	420														

Overall Equipment Efficiency (OEE)

Availability :

(Actual Working Time (in min)) / (Planned Working time (in min)) x 100% =

Performance/Efficiency :

(Total Output per Roll) / (Actual Working time (in min)) x 110 x 100% =

Quality :

(Total Output per Roll) - (Total Reject Roll) / (Total Output per Roll) x 100% =

OEE:

(Availability) x (Performance/Efficiency) x (Quality) x100 =

Reject Roll	
1 Pack = 10 rolls	
6 Pack	
10 Pack	

Figure 6: Overall Equipment Efficiency sheet for toilet tissue production

4.0 RESULTS AND DISCUSSIONS

The Pearson correlation is used to investigate the relationships amongst variables, while the stepwise method is applied to obtain the best multiple regression model. The independent variables for the regression model are machine downtime (MDT), improper machine setting cause delay time (MST), machine changed over causes downtime (MCO), standardized works (SW), implementation of VSM, defect on stained paper (DSP) and defect on poor quality paper (DPQP), surplus man power (SMP), and implementation of Kaizen in environment messy walkway (Kaizen). The dependence variable is the overall equipment effectiveness (OEE).

The results of Pearson correlation are shown in Table 1. The results show that five (5) independents variables (variables with asterisks) have significant correlation with the OEE. However, the MST-MCO pair has an unusually high correlation (0.941). Therefore, the MST variable is retained since it has a relatively higher correlation with the

OEE compared to the MCO. Finally, four independent variables are retained, and they are the MDT, MST, DPQP and KAIZEN.

The results from the stepwise method support the results from the Pearson correlation analysis. The R square and Durbin Watson are shown in Table 2. The regression model fulfils the Durbin Watson requirement where the Durbin Watson value is equal to 1.723, which falls in the range of 1.5 to 2.5. In addition, the model is able to explain 74.7% of the total variation in the OEE.

Table 3 provides the estimated coefficient for the four (4) independent variables. The OEE can be calculated by using multiple regression linear equation and yield the following model as shown in Equation (9).

$$OEE = -0.393MST - 0.241\ MDT + 0.215\ Kaizen - 0.23DPQP \qquad (9)$$

A negative coefficient decreases the OEE performance, while a positive coefficient increases the OEE performance. As an example, the increment of one unit of MST decreases 0.393 unit of OEE, assuming that other independent variables are constant. For a positive coefficient, the regression model shows that the implementation of Kaizen increases 0.215 unit of OEE.

Table 1: Pearson correlation matrix

	Correlation	**Sig.**
Pearson correlation		
OEE	**1.0**	
MDT	**-.648****	**.000**
MST	**-.749****	**.000**
MCO	**-.645****	**.000**
SW	**.186**	**.063**
VSM	**-.018**	**.430**
DSP	**.146**	**.076**
DPQP	**-.738****	**.000**
SMP	**.222**	**.074**
KAIZEN	**.586****	**.000**

Notes: ** Very significant at 0.001 significance level & *significant at 0.05 significance level

Table 2: Model summary

R	R square	Adjusted R Square	Change	Durbin-Watson
.864[d]	.747	.736	.06058	1.723

Table 3: Coefficient analysis between independent variables and dependent variable

Model	**Standardized Coefficients**		**Collinearity Statistics**	
	Beta	**t**	Tol.	VIF
(Constant)		14		
MST	-.393	-5	.469	2.131
MDT	-.241	-3	.596	1.677
KAIZEN DPQP	.215	3	.711	1.415
	-.230	-2	.402	2.490

5.0 CONCLUSION

This research has adopted five lean manufacturing tools for investigating waste in the paper manufacturing and paper products industry. The empirical results provide several valuable views for managers to improve the quality and productivity management of their production process. Subsequently, the related organizations may respond to the regulation, policy and control by making efforts to reduce the machine setting time and machine downtime, and avoid from buying poor quality papers. The Kaizen must also be sustained in the paper manufacturing and paper product industry.

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