CHARACTERISTIC MAPPING OF OVERALL EQUIPMENT EFFECTIVENESS ELEMENTS THROUGH SIMULATION AND THE TAGUCHI METHOD

Dani Yuniawan[1, 3], Teruaki Ito[2], Effendi Mohamad[1,4]

[1]Graduate School of Advanced Technology and Science
University of Tokushima, Tokushima, Japan

[2]Institute of Technology and Science
University of Tokushima, Tokushima, Japan

[3]Universitas Merdeka, Malang, East Java, Indonesia

[4]Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka, Malaysia

Email: dyuniawan@gmail.com, tito@tokushima-u.ac.jp,
effendi@utem.edu.my

ABSTRACT

Overall Equipment Effectiveness (OEE) is one of the Key Performance Indicators (KPI) for measuring the implementation of Total Productive Maintenance (TPM) in the company. However, over time, OEE evolved into a system for the analysis of production data with the purpose of identifying potential areas for improvement and supporting lean initiatives. OEE progressed from its initial role of a base measure for efficiency to being a tool for the enhancement of effectiveness. The results derived from OEE calculations determine the OEE element requiring improvement. A simulation model was developed to mimic the actual model and serve as an experimental tool. This research combines the Taguchi method and the simulation method to acquire the data required for measuring the characteristics of each OEE element based on multiple level variations in order to extent the OEE as a key performance indicator (KPI) for the company. The outcome will reveal the characteristics of each OEE element. Through these methods, the company will be able to identify the characteristics of the machine and decide on an appropriate production line improvement in order to arrive at a significant result. With this OEE extension, the company is easier to decide for priority improvement towards better product quality, better product lead-times.

KEYWORDS*: OEE, Simulation, Taguchi Method*

1.0 INTRODUCTION

The integration of the world economy and the significant growth in industrial competition has made quality one of the most important factors in an organization's survival and success. Successful companies understand that the customer-defined quality can have the powerful impact their business. Due to this reason, many competitive firms continually increase their quality standards development. Competitive firms believe that the way to recover is through improvements in quality, and each has outlined specific changes to their operations. Whilst the quality itself cannot stand-alone. It must be support by the availability and performance of the company resources. Most of the manufacturing industries are focusing on strict quality standards in their production process and implementing a quality program called TPM, stand from Total Productive Maintenance (Jitender *et.al*., 2012).

TPM, which was introduced in 1951, is a set of activities that work to avert quality defects and breakdowns, minimize the need for maintenance, and make work easier as well as safer for equipment operators. TPM can be the foundation for the improvement of the entire production process. It has been defined as a set of activities for restoring equipment to its optimal condition and changing the work environment to maintain that condition. In order to measure the performance of TPM, Nakajima *et.al*., 1988, introduced the Overall Equipment Effectiveness (OEE) calculation. OEE allows the company to focus their efforts on prioritizing, and reducing the classic six big losses of; (1) breakdowns, (2) set-ups and changeovers, (3) running at reduced speeds, (4) minor stops and idling, (5) quality defects, scraps, yield, rework, and (6) start-up losses.

The first two losses will affect availability, the next two losses will affect the performance rate, and the last two losses will affect quality. OEE involves the three elements of availability, performance rate, and quality rate (Shirose and Nakajima, 1992). This is explained by the following equation.

$$\text{OEE} = \text{Availability x Performance Rate x Quality Rate} \quad (1)$$

$$\text{Availability} = \frac{(\text{loading time-downtime})}{\text{loading time}} \quad (2)$$

$$\text{Performance rate} = \text{operating speed rate} \times \text{net operating time} \quad \text{or} \quad (3)$$

$$\text{Performance rate} = \left(\frac{\text{ideal cycle time}}{\text{actual cycle time}}\right) \times \left(\frac{\text{actual cycle time} \times \text{output}}{\text{operating time}}\right) \quad (4)$$

$$\text{Quality rate} = \frac{(\text{total number produced -number of defected products})}{\text{total number produced}} \quad (5)$$

These three OEE elements will be employed to measure the performance of the crimping manufacturing line (CML) using a combination of the simulation and Taguchi methods.

2.0 RESEARCH OBJECTIVE

The objective of this research is to identify the characteristics of machines or equipment by measuring OEE elements utilising a combination of the Taguchi and simulation methods in order to extent the benefit of OEE as KPI. Through this OEE extension, the company will be easier to decide for priority improvement in the production line in order to aim better quality of product and lead-times.

3.0 RESEARCH METHODOLOGY

The research methodology is displayed in Figure 1. Arena Simulation Software was employed for this study. The simulation model in this research acts as an experimental tool for acquiring the result through the Taguchi method approach. The simulation model will produce the output for control factor measurement. Three OEE elements are used as control factors for this experiment; availability rate, performance rate, and quality rate. The availability rate represents the unplanned downtime failure factor and setup adjustment, the performance rate represents reduced speed, idling, or minor stoppages, and the quality rate represents the number of defected products.

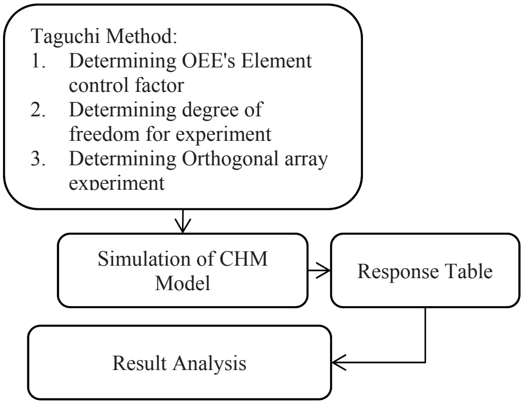

Figure 1: Research flow diagram

All the elements of OEE are observed under level variation of each parameter in an orthogonal array experiment. Taguchi's method uses the orthogonal array experiment to describe the level variation in each control factor. The orthogonal array used in this experiment is L_{27} (3^{13}).

4.0 MODELLING AND SIMULATION EXPERIMENTS

4.1 Simulation Model

A simulation model is developed using Arena Simulation Software for a Coolant Hoses Manufacturing (CHM) company (Ito et al., 2012). This factory consists of six sections. Four sections are production lines which produce Coolant Hose#4(CH4), Coolant Hose#6(CH6), Coolant Hose#8(CH8), and Coolant Hose#10(CH10), while two sections are storage warehouses as seen in Figure 2. This research will focus on the crimping manufacturing line (CML) for all coolant hoses in section 2. The CML supports two production lines (sections 3 and 4) for separate coolant hose type of crimping materials.The CML simulation model was built before the experiment commenced. This model consists of 3 workstations (WS) comprising the machining, testing and marking processes. The layout of this model can be seen in Figure 3.

The parameters for the CML are as follows: The demand for coolant hose products is 600 units (300 units of coolant CH4 and CH6, and 300 units of coolant CH8 and CH10). Production time between arrivals is 120 minutes. Product per arrival for each product = 100 units; maximum arrival = 3 units; WS1 process time $t_{0,1}$ = TRIA(0.5,1,1.5) using triangular distribution; WS2 process time $t_{0,2}$ = (0.5,0.75,1); WS3 process time $t_{0,3}$ = TRIA(1,1.25,1.5). Changeover occurs for every product type in WS1 and WS3; total time for changeover in WS1 is 40 minutes, while for WS3 total time for changeover is 20 minutes.

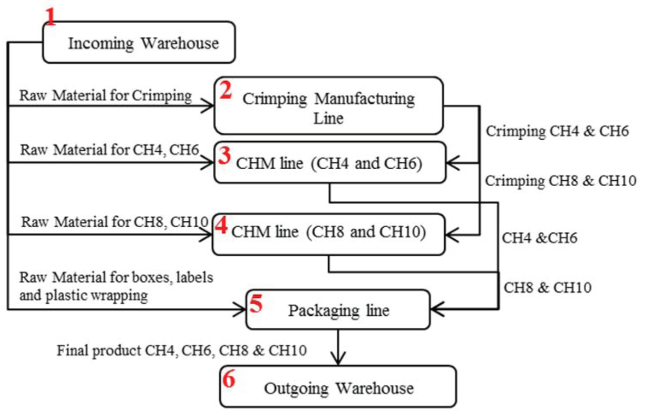

Figure2: Flow diagram of CHM factory floor for all sections

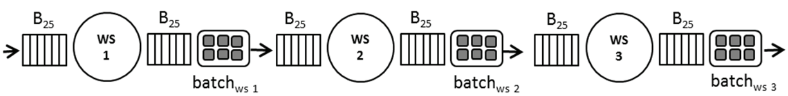

Figure 3: Layout model for the Crimping Manufacturing Line.

The batch capacity for each WS in the CML is 5 units, and buffer capacity for each WS is 25 units. Each WS is handled by a single operator. The route time between work stations is 0.3 minutes. Working time in the CHM model is set at 9 hours per day and the simulation cycle is repeated ten times.

4.2 Verification and Validation of Simulation Model

Model verification is necessary for ensuring that the model is correctly constructed. It is conducted largely by inspection and consists of matching model code to model specification (Kelton W., and Sadowski R., 2009; Altiok, T., and Melamed B. 2010). This research employs the Little's Law mathematical equation for the validation of the model, (Rooda and Vervoort, 2007):

$$w = \delta . \varphi \quad (1)$$

Whereby;

w : The mean number of products in the production line (work in progress (wip)–level w in units)

δ : The mean number of products leaving the system per unit of time (throughput δ in units/time units)
φ : The mean time a lot remains in the system (flow time φ in time units)

The production line consist of a buffer and a batch for each WS, and the calculation for waiting time for each product must consider the buffer, batch, process time, and route time. The total mean flow time for each WS can be calculated as follows:

$$\phi_{tot} = \phi_B + \phi_{Bq} + \phi_{Bk} + t_0 + t_{route} \quad (2)$$

Whereby

t_{route} : route time between workstations (in time unit)
t_0 : process time for workstations (in time unit)
ϕ_B : mean flow time for waiting in buffer (in time unit)
ϕ_{Bq} : mean flow time for queuing on the inter-arrival of a batch (in time unit)
ϕ_{Bk} : mean flow time for wait-to-batch time (in time unit)

The total production time can be calculated by multiplying the WS with the longest ϕ_{tot} (WS which causes the most bottlenecks in the production line) with the total demand/number of batches. This result will be compared to results from simulation software and mathematical calculations. A detailed animation was used to verify that the simulation model sufficiently replicated the real system. The calculation result for validation can be seen in Table 1. The validation also used confidence interval of 95% for confirming the result of the simulation model.

Table 1: Validation of the CML (Section 2 in CHM) Simulation model

Name in CHM	Average Simulation Time Result (in minute)	Calculation Result (in minute)	Confidence interval range 95%	Stated
CML Line	430.86	380.0199	368.1201-493.5999	Valid

4.3 Taguchi Experiment Design

The Taguchi method was developed by Genichi Taguchi of Nippon Telephones and Telegraph Company, Japan. It is based on orthogonal arrays which provide a set of well-balanced experiments. The Taguchi method divides all problems into 2 categories – static or dynamic. While the dynamic problems have a signal factor, the static problems do not. (Taguchi *et.al,* 2007). This research is focused on the static problem category. The objective of this study is to measure the OEE element characteristic in the CML using the simulation method, and analysing the result with the Taguchi method. The control factors for this experiment related to each OEE element are availability (A), performance rate (B), and quality rate (C). Each control factor consists of a three-level variation as can be seen in Table 2 below:

Table 2: Control factors in this experiment

Name	Control Factor	Level 1	Level 2	Level 3
A	Unplanned Downtime Failure in minute for each workstation, (Availability)	WS1 TRIA(30, 45 , 60)	WS1 TRIA(45, 60 , 75)	WS1 TRIA(60, 75 , 90)
		WS2 TRIA(15, 20, 30)	WS2 TRIA(20, 25, 30)	WS2 TRIA(25, 30, 40)
		WS3 TRIA(20, 30 ,40)	WS3 TRIA(30, 40 ,50)	WS3 TRIA(40, 50 ,60)
B	Performance Rating for each workstation in minute (Performance Rate)	WS1 TRIA(0.5, 1 , 2.5)	WS1 TRIA(0.5, 1.5 , 2.5)	WS1 TRIA(0.5, 2 , 2.5)
		WS2 TRIA(0.5, 0.75, 3)	WS2 TRIA(0.5, 1.5, 3)	WS2 TRIA(0.5, 2 , 3)
		WS3 TRIA(1, 1.25 , 3)	WS3 TRIA(1, 1.75 , 3)	WS3 TRIA(1, 2.25 , 3)
C	Quality Rate	99%	98%	97%

The variation of control factors implemented in an orthogonal array consists of 27 experiments. For each experiment, the simulation process is replicated 10 times for each variation parameter level of the control factors as portrayed in Table 2. All variation levels employ triangular random distribution in order to simplify the identification of random failure occurring in the CML simulation model. Defining the performance rate is less complicated as it basically involves the maximum capacity of the machine. This can be explained by the following example with reference to the table above. WS1 TRIA (0.5, 1, 2.5), workstation 1 will operate with a minimum time of 0.5 minutes per unit and mostly operate within 1 minute per unit. The maximum operating time for workstation 1 is 2.5 minutes per unit. Although this is considered sufficient for conducting the experiment using the L_9 (3^4), L_{27} (3^{13}) was chosen for the orthogonal array experiment as this research also considers the interaction measurement between control factors.

However, analysis of the interaction between factors is not a major concern of this research. The orthogonal array experiment is displayed in Table 3 (in the underlined column title).The values of 1, 2, and 3 are addressed as a level number for each experiment (as explained in Table 2). For example, the 20^{th} experiment recorded an availability rating of 3, a performance rating of 1, and a quality rating of 2. The Taguchi method is not applied roundly here as the aim of this research is to define the OEE elements which have a major influence on each workstation based on variation of the control factor level. The optimization step (the final step) in the Taguchi method was not conducted as there was no requirement for the prediction of the optimum condition for random failure. Obviously, the optimal condition is without random failure. As far as the objectives of this research are concerned, the orthogonal array result is deemed adequate.

5.0 RESULT ANALYSIS

Table 3 displays the experiment results of each OEE element from three workstations (WS). The average result from the three workstations for OEE is 44.17%. For all 27 experiments, the CML recorded an average availability rate of 90.72%, an average performance rate 50.1%, and an average quality rate of is 98%. From the OEE calculation, it is gathered that the element of performance requires improvement. However, the OEE calculation alone cannot be relied on to assess how significantly the improvement will affect the OEE values. The response table provides results from the performance of a simulation model utilising an orthogonal array (Table 4). The results from the simulation model are grouped according to its control factor levels. From the response table results, the characteristics of each OEE element based on variations of the control factors can be ascertained. The performance rate was identified as the highest influence response followed by availability and lastly quality.

This result indicates that if the performance level is slightly improved, the OEE performance rate value can be significantly raised above those of the other OEE elements. Coincidentally, the calculation of OEE and the response table show that performance rate is the main concern. However, the results from the calculations of OEE and the response table are not always similar. Other research OEE element measurements conducted by the same author resulted in different outcomes from OEE and response table calculations.

This research also includes a one-way analysis of variance (ANOVA). It tests the hypothesis that the means of several populations are equal. A one-way analysis of variance can indicate if there are statistically significant differences among the level means. The ANOVA calculates the degree of freedom (DF), sum of square (SS), and mean square (MS). F is calculated as the mean square for the factor divided by the mean squares for error and is utilised to determine the p-value. The p-value is used to decide if the means are different. If P is less than, or equal to the α-level that was selected, it can be concluded that the means are different. If P is greater than the α–level, it cannot be concluded that the means are different. This research employed a 95% confidence interval (α-level = 5%). Table 5 explains that as the P value is less than the α-level, it can be concluded that the means are different for each group data (for three workstations).

Table 3: Orthogonal array experiment and its results (average results from three workstations)

Exp	Availability	Performance	Quality	Availability rate	Performance Rate	Quality Rate	OEE Rate
1	1	1	1	0.924803	0.525849	0.99	0.483526
2	1	1	2	0.923943	0.527844	0.98	0.479397
3	1	1	3	0.923963	0.530016	0.97	0.480466
4	1	2	1	0.925747	0.494467	0.99	0.448628
5	1	2	2	0.9243	0.499288	0.98	0.449199
6	1	2	3	0.922243	0.507413	0.97	0.44997
7	1	3	1	0.932383	0.459575	0.99	0.424206
8	1	3	2	0.930163	0.458725	0.98	0.421692
9	1	3	3	0.930753	0.461115	0.97	0.420597
10	2	1	1	0.907057	0.538275	0.99	0.477034
11	2	1	2	0.907577	0.535605	0.98	0.47352
12	2	1	3	0.90349	0.543916	0.97	0.473158
13	2	2	1	0.906357	0.508124	0.99	0.439395
14	2	2	2	0.907457	0.494912	0.98	0.438645
15	2	2	3	0.90557	0.503807	0.97	0.436513
16	2	3	1	0.911063	0.466983	0.99	0.415798
17	2	3	2	0.911377	0.458484	0.98	0.411654
18	2	3	3	0.910713	0.45986	0.97	0.410406
19	3	1	1	0.88578	0.549907	0.99	0.467548
20	3	1	2	0.883567	0.55509	0.98	0.466319
21	3	1	3	0.884497	0.555308	0.97	0.464734
22	3	2	1	0.886367	0.505487	0.99	0.425022
23	3	2	2	0.884943	0.500347	0.98	0.429745
24	3	2	3	0.884787	0.509667	0.97	0.426226
25	3	3	1	0.891273	0.457057	0.99	0.406798
26	3	3	2	0.891523	0.459919	0.98	0.40487
27	3	3	3	0.891373	0.460796	0.97	0.400179
	Average OEE's value for 3 WS			0.907151	0.501031	0.98	0.441676

Table 4: Response Table for Mean of experiment result

Level	Availability Rate	Performance Rate	Quality Rate
1	0.4509	0.474	0.4431
2	0.4418	0.4381	0.4417
3	0.4324	0.4129	0.4402
Delta	0.0185	0.0611	0.0029
Rank	2	1	3

Table 5: ANOVA Result

Source	DF	SS	MS	F	P
Factor	2	0.658387	0.329193	441.6	0
Error	78	0.058146	0.000745		
Total	80	0.716533			
S = 0.02730	R-Sq = 91.89%		R-Sq(adj) = 91.68%		

5.0 CONCLUSIONS AND FUTURE WORK

Combining the simulation method and the Taguchi method will produce specific results of the CML characteristic OEE element measurement. It will provide another perspective which can prove to be useful for making decisions related to productive maintenance. As each company has its own characteristic production line, this combination method will provide useful information specifically related to the OEE as an indicator for productive maintenance.

The result shows that the Taguchi method can provide characteristics for OEE element measurement. In this CML case, the performance rate element is the main priority for improvement based on OEE calculations and the response table result. As for the response table, the highest influence factor arrived at is similar, the performance rate element. It is indicated that if there is improvement in the performance rate, the consequent rise in value will be greater than that of the other OEE elements.

With this OEE extension, it will give more detail result to the decision-maker in the company to make priority improvement. Furthermore, through this research, the production line improvement toward better product quality and better lead-times can be achieved as it expected.

For future work, we intend to focus on other sections of the production line in the CHM simulation model in order to gather characteristic data of each machine for the purpose of measuring the OEE element influence based on several parameter variations.

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