INTERRELATIONSHIP BETWEEN AVAILABILITY WITH PLANNING FACTOR AND MEAN TIME BETWEEN FAILURES (MTBF) IN OVERALL EQUIPMENT EFFECTIVENESS (OEE)

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ABSTRACT: One of the limitations of Overall Equipment Effectiveness (OEE) implementation in traditional approach is the lack of planning direction. The study is carried out in an aerospace plane part-manufacturing company to examine the efficiency of planner in affecting the machine utilization. The time data of Autoclaves is acquired from the computerized recording system. The Autoclaves with constant curing time are evaluated to calculate availability using total calendar-time approach. The OEE value of this study is the multiplications of four elements as availability, performance ratio, quality ratio and the planning factor. The performance ratio and quality ratio are always 100% due to constant cycle time (ideal cycle time) and non-defect production. The planning factor is defined as ratio of loading amount with respect to the maximum capability of autoclave. This is to promote the concept of On Time In Full (OTIF). After that, the scheduling, planning and control of production based upon the OEE data obtained are demonstrated and explained in details. The breakdown time is then estimated using Mean Time between Failures, MTBF, based on the availability obtained, and the frequency of preventive maintenance is suggested. In short, the significance and novelty of this study is the new definition of planning factor in terms of the panel number loaded over the maximum capability instead of time unit like in traditional approach. This enables the equipment with constant and fixed cycle time like Autoclave to be evaluated in varying planning factor to highlight the necessity of more effective planning.

KEYWORDS: Overall Equipment Effectiveness (OEE), Planning factor, Availability, total calendar-time approach, Mean Time Between Failures (MTBF), Preventive maintenance.

1.0 INTRODUCTION

Overall equipment effectiveness (OEE) indexes machine stands in comparison with an ideal machine which always runs at full speed and capacity at the same time produces good quality products (Rouhani, 2009). Although the data of overall effectiveness of equipment seem very simple, extracting useful information from a series of calculations is a very important and difficult task (Aliahmadi, 2003). The ambiguity of the OEE implementation could further contribute to deviation in evaluating the utilization and performance of a particular equipment. "If you can't measure it, you can't manage it", as stated by Paul Dean Ceng (2006).

One of the problems observed in lean implementation is the lack of direction of planning and adequate project sequencing (Bhasin and Burcher, 2006). Applying the same concept in OEE, many studies evaluate the planning factor as the percentage of production time planned for or realized over the total theoretical production time (Francis Wauters and Jean Mathot, 2007; Andre Icso, n.d.). This concept is actually similar to the concept of total-calendar time approach and should be simplified. On the other hand, it is hard to know the equipment utilization with respect to its maximum capacity. Over the similar issue, there is a need to formulate an effective lean process on, as suggested by Puvanasvaran *et.al.* (2009), employee's development aspect regarding how to unlock the infinite potential of the workforce. The same case goes to equipment utilization by planning the production rate of existing machine up to their maximum capacity to promote On Time in Full (OTIF). Besides that, customer demand nowadays consists of multiple product packages with different process parameters. This makes the number of product loaded in each production with respect to maximum capacity is very important. In addition of that, setup and adjustment time are increasing accordingly with the product mix in manufacturing company and this will adversely affect the OEE value (Mileham *et.al.*, 1997).

1.1 Objectives

a. To quantify the planning efficiency of production in affecting the utilization of machine with constant cycle time.
b. To demonstrate usage of OEE data for the planning of production section.

2.0 LITERATURE REVIEW

Tajiri and Gotoh (1992) classified major losses into six groups in OEE computation. Breakdown losses, setup and adjustment losses are the downtime losses determining the availability of a machine whereas minor stoppage and reduced speed losses are classified as speed losses. Rework and yield losses are defined as quality losses that determine the quality ratio of an equipment.

In details, the availability factor measures the time loss due to breakdowns, set-up, adjustment, and other stoppages (Jonsson and Lesshammar, 1999). It is traditionally calculated using the Nakajima's (1988) formula as shown below. In this formula, loading time refers to the equipment's total length of operation after any deduction of planned activities that may have disrupted production, for examples like scheduled maintenance, official production breaks, process improvement initiatives or equipment tests etc.:

$$A = \frac{(\text{Loading time} - \text{Downtime})}{\text{Loading time}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Formula 1 is usually used in loading time-based OEE or conventional OEE, which focuses on losses after loading time. This so-called loading-time approach always results in overestimation of availability and may not reflect the real equipment utilization (Sermin Elevli and Biro Elevli, 2010). The losses neglected in loading time-approach are shown in Figure 1.

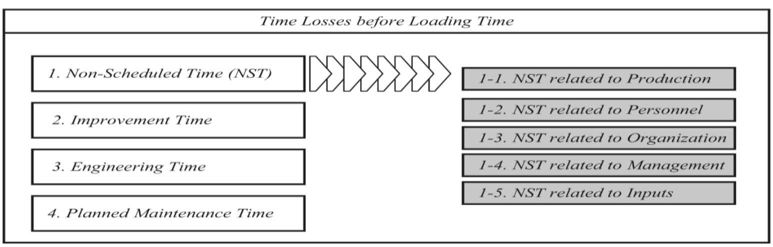

Figure 1: Losses ignored by OEE (Andrew Starr, Farhad Anvari and Rodger Edwards, 2010)

Upon the reason, calendar time-based approach is more preferable than loading time-based approach since it measures the availability over the total calendar time a company owns the equipment. According to Sermin Elevli and Biro Elevli (2010), the total time available for production has to be defined as the maximum amount of time unit available in the observed period and hence is a constant.

On the other hand, there is a new element called planner factor had been implemented by Francis Wauters and Jean Mathot (2007) into OEE computation. Planning factor (Pf) was defined in term of time unit and visualized as the countermeasure of external losses (planned downtime) in loading-time approach as shown in Figure 2 below:

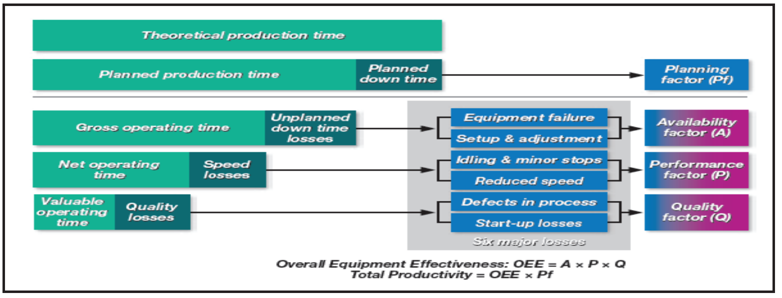

Figure 2: Introduction of planning factor in OEE (Francis Wauters and Jean Mauthot, 2007)

In other words, the more planned downtime in the schedule, the lower is the planning factor perceived. Application of planning factor in loading-time approach OEE computation is actually similar to the concept of OEE in calendar-time approach.

$$\text{Planning factor} = \frac{\text{Available production time}}{\text{Theoretical production time}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Concerning utilization of OEE measurement, Dal *et.al*. (2000) point out that OEE measure can provide topical information for daily decision making by utilizing largely existing performance data, such as preventive maintenance, material utilization and etc. Although OEE was originally designed to monitor and control performance, Dal (1999) suggests that the role of OEE goes far beyond the task of just monitoring and controlling. At certain extent, this is concurrent with the point of view from Robert M. Williamson (2006) which states that the OEE data could be used individually to track out the quantified loss reasons categorized by specific equipment-related loss. In that, OEE data format such as availability, performance ratio, and quality ratio could be analyzed and used individually.

3.0 METHODOLOGY

The study was carried out in a manufacturing cell consists of 6 Autoclaves which cure several panel types, at constant cycle time due to optimized and fixed curing recipe for each panel type. This causes 100% of quality ratio on the manufacturing cell as well. Besides that, the dimensions of Autoclaves are different from each other contributes to different maximum capabilities. Time data is collected from the computerized record system for duration of 9 weeks. Within this system, beginning and ending time of all curing processes are automatically to ensure the accuracy and reliability of data since it reduces the possibility of human bias and fatigue issues.

Since the total calendar-time approach is similar with conventional definition of planning factor, new definition of planning factor is shown in the Formula 3 below:

$$\text{Planning factor} = \frac{\text{Total amount of product cured}}{\text{Maximum amount of product can be cured}} \quad \text{....................................(3)}$$

The reason of defining planning factor as such in this study is due to the condition where the amount of product loaded into the Autoclave is always less than the maximum capacity of the Autoclaves can afford. This is neglected and not being quantified in conventional OEE. The mechanism of obtaining the availability is visualized in Figure 3.

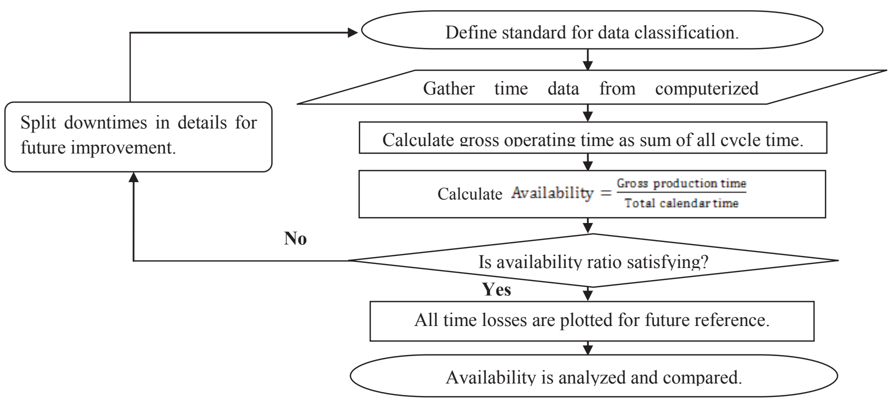

Figure 3: Use of availability to examine non-value-added activities of a production line

4.0 RESULT AND DISCUSSION

The standard of classification is based on the purpose of curing. Note that only curing process runs with panels loaded is considered as uptime. This definition is match with a point saying "if the output is (for a longer period, for instance 3 minutes) zero, the installation produces nothing and hence the unused segment of time, during the examined period, are downtime losses" (Francis Wauters and Jean Mathot, 2007). The standards established are shown below:

Table 1: Standard established to classify uptime and downtime

Classification	Description	Reason
Uptime	Manufacturing production	Upon customer demand
	Engineering runs	To optimize machine utilization
Downtime	Set up	Availability of Autoclaves is affected without producing panel / making profit.
	Loading and Unloading	
	Stop run	
	Breakdown	
	Test run without panel loaded	

There are 23 hours of scheduled downtime per each month contributing to the lower operating time, and hence higher availability in loading time-approach. The availability for Autoclave 1-6 in January and February are calculated in both loading time approach and total calendar time approach as shown in Table 2. Note that the availabilities deviate by 2-3% for both approaches. The raw data and the visualization of the downtime composition are shown in Appendix A, B and C respectively.

Table 2: Availability of Autoclave 1-6 calculated in both approaches.

Description	AC1		AC2		AC3		AC4		AC5		AC6	
	Jan	Feb	Jan	Feb	Jan	Feb	Jan	Feb	Jan	Feb	Jan	Feb
Running time (VA)	515	485	561	532	457	502	502	434	452	462	509	441
Engineering run	-	9	8	-	51	47	11	29	7	79	74	66
Uptime	515	494	569	532	508	549	513	463	459	541	583	507
Total time duration	744	696	744	696	744	696	744	696	744	696	744	696
Scheduled uptime	721	673	721	673	721	673	721	673	721	673	721	673
Availability (Calendar-time	69.2%	71.0%	76.5%	76.4%	68.3%	78.9%	69.0%	66.5%	61.7%	77.8%	78.3%	72.8%
Availability (Loading-time	71.4%	73.4%	79.0%	79.0%	70.5%	81.6%	71.2%	68.8%	63.6%	80.4%	80.8%	75.3%

Prior to evaluating the planning factor in this study in term of products or WIP loaded per each production, the capability of Autoclaves in term of maximum panel number loaded is summarized in Table 3 below:

Table 3: Maximum number of panel could be loaded per curing slot in each Autoclave.

	Maximum loading (panel)					
Product	AC1	AC2	AC3	AC4	AC5	AC6
A320 Leading Edge (8552)	72	72	12	72	0	0
A320 Trailing Edge	66	66	11	66	0	0
A320 Aileron	30	30	10	30	0	0
A320 Underwing	6	6	6	6	0	0
A320 Falsework	6	6	6	6	0	0
A320 Overwing	8	8	4	8	0	0
A320 Spoiler	15	15	2	20	0	0

The data in table 3 depends on the size of the Autoclave and the types of package being cured. Using the formula 3 shown above and the raw data obtained, the planning factor in term of production unit is shown in table 4.

Table 4: Planning Factor (Pf) by Autoclave number and by month.

Loading		Autoclave						Pf by Month (%)
		AC 1	AC 2	AC 3	AC 4	AC 5	AC 6	
Jan	Maximum	1273	1777	640	1458	530	586	89.85
	Actual	1117	1701	568	1339	423	480	
Feb	Maximum	1306	1574	519	1067	513	532	90.76
	Actual	1216	1486	495	988	356	461	
Total	Pf by Autoclave (%)	90.46	95.11	91.72	92.16	74.69	84.17	90.28

The OEE values of 6 Autoclave in 59 days for January and February are then calculated from using total calendar-time approach and incorporating planning factor in new definition. Note that the availability here is computed over 59 days and are different as in Table 2. The OEE are compared in Table 5 shown below.

Table 5: Average OEE values for 6 Autoclaves

Average OEE		Autoclave					
		AC1	AC2	AC3	AC4	AC5	AC6
Primary data	Availability	70.08%	76.50%	73.49%	67.83%	69.49%	75.72%
	Performance ratio	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	Quality ratio	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	OEE	70.08%	76.50%	73.49%	67.83%	69.49%	75.72%
Real Value	Planning Factor	90.46%	95.11%	91.72%	92.16%	74.69%	84.17%
	Total OEE	63.39%	72.76%	67.41%	62.51%	51.90%	63.73%

Traditional approach considers only the time available, speed, and the amount of good products produced but not the maximum capacity of the machine (Autoclave) in OEE computation. This could be imagined in an extreme case where an autoclave is capable of curing 100 units products in single curing slot, run all the time without breakdown, at ideal speed and all products are in good quality, but is only fed by 1 unit of input. The OEE value for this case should be 100% x 100% x 100 x (1unit/ 100 units) = 1% only but not 100% as calculated in traditional approach. Conclusion from that is that planning factor in terms of production amount should be incorporated in OEE computation.

Once the availability is obtained, it can actually be used individually to schedule preventive maintenance of equipment, which is essential to ascertain TPM and prevent serious issue of breakdown. This method is somehow similar to that used in the study which was performed by Ireland and Dale (2001) in their implementation of Total Preventive

Maintenance (TPM) in a rubber products-manufacturer company, which used OEE to set losses targets to be reduced and classification system to prioritize the improvement activities.

The baseline of planning the preventive maintenance is to minimize the frequency (number) of preventive maintenance after every period of Mean time between failures (MTBF). In that, breakdown time is estimated using the average availability and the percentage of breakdown time in downtime (Appendix E). Recalling back to Appendix B and C, the largest portion of downtime in every Autoclave especially Autoclave 5 is the breakdown (categorized as "others" in the pie chart). The data in Table 5 and Appendix D are further analyzed as shown in table below:

Table 6: The summary of Mean Time Between Failures (MTBF) for all Autoclaves

Description	AC1	AC2	AC3	AC4	AC5	AC6
Total time available (Hour)	1416	1416	1416	1416	1416	1416
Availability (%)	70.08%	76.50%	73.49%	67.83%	69.49%	75.72%
Downtime (Hour)	423.60	332.69	375.42	455.56	432.06	343.81
Breakdown percentage	35.47%	43.51%	58.79%	60.19%	57.61%	49.93%
Breakdown time (Hour)	150.24	144.75	220.72	274.19	248.91	171.67
Non-breakdown time (Hour)	1265.76	1271.25	1195.28	1141.81	1167.09	1244.33
Number of breakdown occurs	3	2	6	8	12	10
Mean Time Between Failure	421.92	635.63	199.21	142.73	97.26	124.43
No. of PM suggested	4	3	7	9	14	11

In Appendix 6, the non-breakdown time is the duration of, regardless of in classification of uptime or downtime, which is not in the breakdown condition. It is divided by the average number of breakdown time from historical data to get the MTBF (Mean time between failures) and the preventive maintenance (PM) is planned and scheduled after every MTBF.

Once the average MTBF is calculated, the frequency of preventive maintenance can be planned accordingly. For an example, the number of preventive maintenance in Autoclave 2 should be planned every 678.81 hours, that is, 3 times within 59 days being observed. The number of preventive maintenance in Table 9 above shows that the number of PM is slightly more than frequency of breakdown. Only through the increasing preventive maintenance, the number of breakdown will be reduced and hence contribute to larger availability in the future. As a conclusion, the availability of OEE data could be used to estimate MTBF and hence scheduled the frequency of MTBF accordingly.

5.0 CONCLUSION

As a conclusion, both of the objectives are achieved. The planning factor, which is evaluated as the ratio of production amount planned over the total capacity, enables the autoclaves with invariably fixed and constant curing time to be fully utilized through promotion of On Time in Full (OTIF). On the other hand, the conventional definition of planning factor in term of time unit is not essential for total calendar-time approach because both are similar and overlapping to each other. In addition of that, the estimation of Mean Time Between Failures (MTBF) and scheduling of preventive maintenance using availability data have been demonstrated in this study. This could be a reference in the future to propose another way to estimate the MTBF from reliable data such as availability and average number of breakdown in the history. The combined usage of this breakdown percentage in downtime composition along with the availability is the basis of estimation of MTBF. The more data collected, that is, the longer is the time horizon, more accurate will the estimation be.

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