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Improvement for enhancing effectiveness of universal power system (UPS) continuous testing process

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Abstract. This experiment aims to enhance the effectiveness of the Universal Power System (UPS) continuous testing process of the Electrical and Electronic Institute by applying work scheduling and time study methods. Initially, the standard time of testing process has not been considered that results of unaccurate testing target and also time wasting has been observed. As monitoring and reducing waste time for improving the efficiency of testing process, Yamazumi chart and job scheduling theory (North West Corner Rule) were applied to develop new work process. After the improvements, the overall efficiency of the process possibly increased from 52.8% to 65.6% or 12.7%. Moreover, the waste time could reduce from 828.3 minutes to 653.6 minutes or 21% , while testing units per batch could increase from 3 to 4 units. Therefore, the number of testing units would increase from 12 units up to 20 units per month that also contribute to increase of net income of UPS testing process by 72%.

1. Introduction

In recent global business, industrial processes need to be improved in order to ensure the quality in both national and international levels as well as to reduce waste and excessive costs of production for price competitiveness. Therefore, several methods have been applied to encourage the success of process improvement such as work study, time study, and work scheduling [1, 2]. Electrical and electronic industry is one of the major industrial businesses in Thailand, which has played an important role for years. Similar to other countries, the electrical appliance industries in Thailand have been controlled by the government as adopting international and national standards to ensure the quality and safety of the products. Normally, there are several tasks testing required in order to achieve the industrial standards before distributing to the customers, which would take a long time to complete the production process and lead to excessive costs in addition to the products [3, 4]. Electrical and Electronic Institute is the independent organization that is responsible for testing electrical appliances, that includes Universal Power System (UPS) regarding to TIS 1291-3-2555 standard. Initially, there was only one operator in UPS continuous testing process with the average work efficiency was about 52.8%. Therefore, waste time can be observed in this testing process and work target could not meet its requirements.

This study aims to enhance the effectiveness of UPS continuous testing process of Electrical and Electronic Institute by improving the overall efficiency while reducing waste time in testing process. Yamazumi chart and job scheduling theory (North West Corner Rule) were adopted by determining the standard time and developing new testing process. After the improvement, the developed work

process would enhance the effectiveness of the operator who contributes to the well-organize work plan of the institute.

2. Methodology

For Electrical and Electronic Institute, the major problem of UPS testing process was the testing target could not met its requirement on time. Therefore, time Study was applied to analyse the standard time of well-trained operator with normal pace. Work study and time study are related to the work ability per unit of time (second or minute) regarding to work standard. Time study can be further used to develop work schedule and work plan.

2.1. Yamazumi Chart

Comparison of cycle time (the time from the beginning to the end of process) and takt time (the average time between the start of production of one unit and the start of production of the next unit) were shown in Yamazumi Chart. Both cycle time and takt time were used to rearrange and develop the appropriate work plan to improve the effectiveness and also reduce wastes in the production line [5]. Yamazumi chart is therefore commonly and effectively used for time study in several production processes such as assembly line, forming process and also for production flow analysis [6-8].

2.2. North West Corner Rule (NCR)

Job scheduling method namely the North West Corner Rule (NCR) was also applied for evaluating a basic feasible solution to rearrange new operation process of UPS testing. Theoretically, NCR is a heuristic approach which is used to solve the problem by permutation in order to control the daily-used resources based on the demand and managing the demand, which does not override the supply such as the optimal delivery plan (from factories to warehouses) in supply chain model [9-11].

2.3. UPS testing process

UPS testing process is responsible for issuing the certificate of TIS 1291-3-2555 [12] to manufacturers in order to guarantee the quality of the products before distributing them to the customers. All UPS products with requirement of this standard should be performed by testing process according to the specification and label provided by the manufacturer. Normally, there were 3 units of UPS per batch required for testing. The average values of testing time spending in each task per unit and per batch were assessed. Details of testing are as given in Table 1 [13] and Appendix A.

To improve the effectiveness of UPS testing process, details of research methodology are as follows:

- Analyse initial work process and develop new one by rearranging daily tasks with consideration of standard time as well as feasible and optimal solution (NCR method) and limitation of each task. Moreover, new testing process should not influence on the results of UPS testing and should be applicable to all UPS products with requirement of TIS 1291-3-2555.
- Consider the possibility to increase testing unit from 3 units to 4 units per batch.
- Assess standard time of each testing task before and after improvement by measuring time of work (10 times), averaging time of work per unit and per batch, estimating standard time and cycle time with consideration of overall allowance.
- Comparison of effectiveness in terms of efficiency and waste time before and after improvement.

Table 1. UPS testing process before improvement.

Testing Title (TIS1291-3-2555)	Testing Process	Details	Testing Time (min)		
			Per unit		Per batch
			Average	STD time[a]	
Day 1					
6.3.2	Input testing		30.5	33.3	91.6
5.2.2h	Harmonic	On current	6.20	6.8	18.6
6.3.3	Inrush current		21.9	23.9	65.8
6.3.4.1	Output Testing 1		9.5	10.4	28.6
6.3.4.3	Output Testing 3	Off current	10.7	11.6	32.1
6.3.4.2	Output Testing 2	On current	8.9	9.7	26.6
6.3.4.4	Output Testing 4	Off current, increasing load[b]	8.0	8.7	24.0
		Cycle time			**287.2**
Day 2					
6.3.5.1	Overload 1	On current	11.4	12.5	34.3
6.3.5.2	Overload 2	Off current	9.7	10.6	29.2
6.3.6.1	Linear load 1		8.5	9.2	25.4
6.3.6.2	Linear load 2		4.9	5.4	14.8
6.3.6.4/6.3.5.1	Overload 3	On current	6.6	7.2	19.9
6.3.6.4/6.3.5.2	Overload 4		6.7	7.3	20.0
6.3.8.1	Non-linear load 1		17.5	19.0	52.5
6.3.8.2	Non-linear load 2	Off current, increasing load[b]	13.3	14.5	40.0
		Cycle time			**235.9**
Day 3					
6.3.8.1/6.3.8.3	Linear/Non-linear		15.7	17.1	47.1
6.3.7.1	Step load 1	On current	6.7	7.3	20.1
6.3.8.4	Step load 2		15.3	16.7	45.9
6.3.8.6	Step load 3		16.1	17.6	48.4
6.3.9.1	Energy storage	Off current, increasing load[b]	12.3	13.4	37.0
		Cycle time			**198.4**
Day 4					
6.3.10	Efficiency 1		16.8	18.3	50.3
6.3.10	Efficiency 2	On current	14.7	16.0	44.0
6.3.10	Efficiency 3		21.8	23.8	65.5
6.3.10	Efficiency 4	Off current, increasing load[b]	10.2	11.1	30.6
		Cycle time			**190.3**
Day 5					
6.3.5.3	Short circuit 1	Off current, final tasks	7.5	8.1	22.4
6.3.5.4	Short circuit 2		7.5	8.2	22.4
		Cycle time			**44.8**

[a] STD time is the standard time calculated by adding 9% of overall allowance (5% of personal allowance and 4% of fatigue allowance) to average time [5].
[b] Battery power is exhausted after testing and needs to be charged up to 8 hours before performing next day testing process.

3. Process Improvement

Daily work period of the operator is at 8 am to 5 pm or 540 minutes per day with no overtime required. Excluding the breaks, the network time or actual takt time is 435 minute per day. The cycle time of each work day is much lower than net time of work that causes waste time as shown by Yamazumi Chart in Figure 1. For Day 5, short circuit testing should be moved to other work days due to low cycle time in order to complete all testing tasks within 4 days if possible. However, rearranging

this testing should be well considered as it could cause damage of UPS and also battery power exhausted after testing.
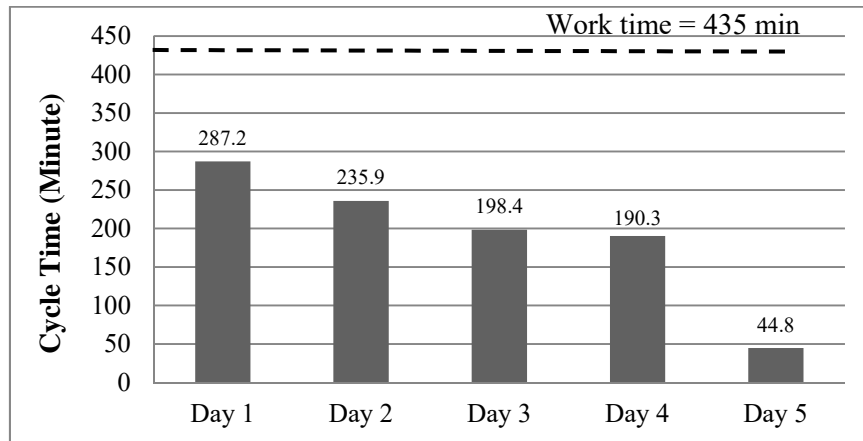

Figure 1. Comparison of Cycle time and net time of work on each work day.

From the net time of work, it can be assumed that the total work time of the operator is 1740 minute per batch. As there are 3 units per batch, the unit time is therefore 580 minute which is also used as the standard time (the time required by an average skilled operator). To evaluate the efficiency of the testing process, it can be calculated by [6]:

$$\text{Efficiency} = \frac{\text{Cycle Time(per day)}}{\text{Net time of work(per day)}} \quad (1)$$

The efficiency of Day 1, Day 2, Day 3, and Day 4 are 66%, 54.2%, 45.6%, and 43.8%, respectively. Thus, the average efficiency of the process is about 52.8% which is relatively low. From analysis, it can be noted that low efficiency and waste times (about 4.2 hours per day on average) would be caused by the limitations of individual testing task and also the specification of battery used.

Initially, the testing process has been performed regarding to the testing category based on TIS 1291-3-2555. Waste time could then caused by several movements and battery power exhausted. To improve the efficiency of the process and to increase the testing units per batch, work scheduling method was applied by using North West Corner Rule (NCR). Standard time was applied in NCR table where Demand was the standard time of each task and Supply was the actual work time of the operator. Daily demand or total standard time from several testing tasks of each work day were rearranged to not exceed the supply or actual work time to control overtime wage. Moreover, each task rearranged should not affect other tasks or overall process. The conditions applied are as follows:

1. Rearrange testing tasks to complete within 4 work days
2. Rearrange testing tasks with the same load to perform on the same day
3. Rearrange similar testing tasks to perform continuously
4. Rearrange testing tasks that cause exhausted battery power to perform last
5. Rearrange short circuit testing to perform in the last step if possible due to risk of damage

From NCR method, the appropriate work schedule was developed by considering 4 units per batch. Details are as shown in Table 2 and comparison of cycle time before and after improvement is shown by Yamazumi chart in figure 2.

Table 2. UPS testing process after improvement.

Testing Process	Details	Cycle time (min)	
		Estimated[a]	Actual[b]
Day 1			
Input testing		133.1	122.7
Harmonic		27.0	18.9
Inrush current	On current	95.6	46.3
Output Testing 1		41.6	37.2
Output Testing 3		46.6	41.7
Output Testing 2	Off current	38.7	43.2
Output Testing 4[c]		34.9	40.4
	Cycle time	**417.4**	**350.3**
Day 2			
Overload 2	Off current	42.4	25.6
Overload 1		49.8	85.3
Linear load 1		36.8	24.5
Linear load 2	On current	21.5	27.0
Step load 1		29.1	27.0
Efficiency 1		73.1	60.8
Efficiency 2		63.9	46.6
Efficiency 4[c]	Off current	44.5	27.1
	Cycle time	**361.1**	**324.2**
Day 3			
Linear/Non-linear		68.36	49.8
Step load 2		66.71	49.2
Step load 3	On current	70.33	49.0
Efficiency 3		95.14	74.9
Non-linear load 1		76.21	73.5
Non-linear load 2[c]	Off current	58.08	77.2
	Cycle time	**434.8**	**373.5**
Day 4			
Overload 3	On current	28.91	2.9
Overload 4		28.99	10.2
Short circuit 1		32.48	25.3
Short circuit 2	Off current	32.79	25.2
Energy storage[c]		53.76	27.1
	Cycle time	**176.9**	**90.7**

[a] Estimated cycle time = STD time (Table 1) × 4 units.

[b] Actual cycle time was evaluated from average cycle time measured from each task.

[c] Battery would be exhausted after testing and required charging up to 8 hours before next day testing process.
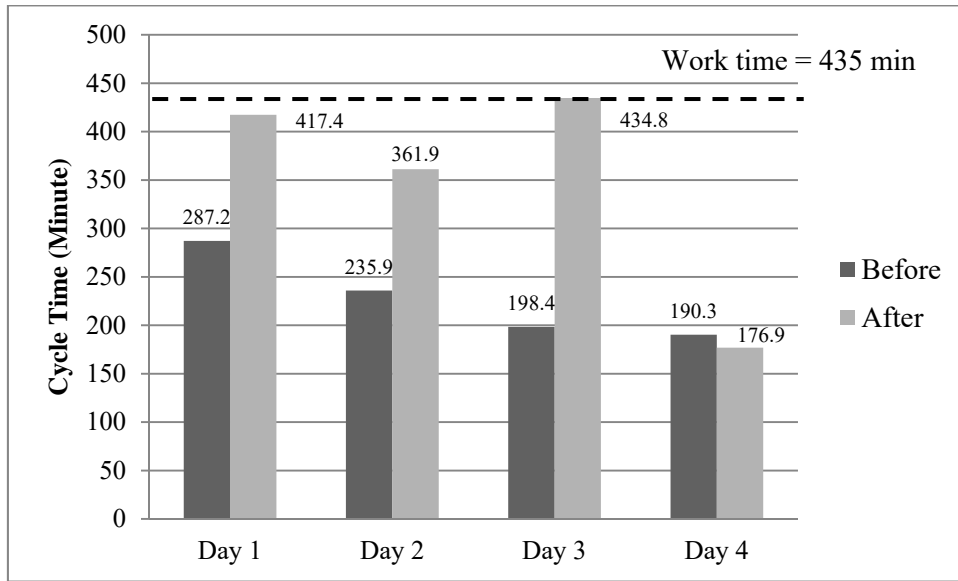
Figure 2. Comparison of estimated cycle time before and after improvement.

After improvement, the operator could perform well in all testing tasks with less waste time. From equation (1) using actual cycle time, the efficiency after improvement of Day 1, Day 2, Day 3, and Day 4 are 80.5%, 74.5%, 85.9%, and 20.8%, respectively. The overall efficiency after improvement is 65.6% or increasing 12.7% on average. For Day 4, the efficiency would decrease after improvement as several tasks could be shifted to other workdays. Therefore, the operator can manage the paperwork to do on this day.
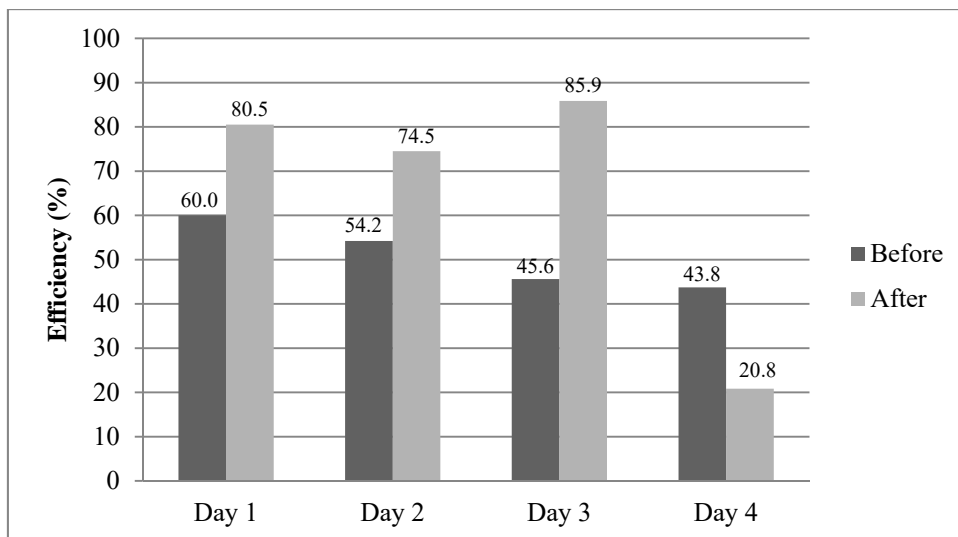

Figure 3. Comparison of efficiency before and after improvement.

To estimate waste time, net time of work and actual cycle time per batch were compared. Details of waste time before and after improving process are as illustrated in figure 4. From study, it can be noted that overall waste time of the process can be decreased from 828.3 minutes to 653.6 minutes or about 21%.
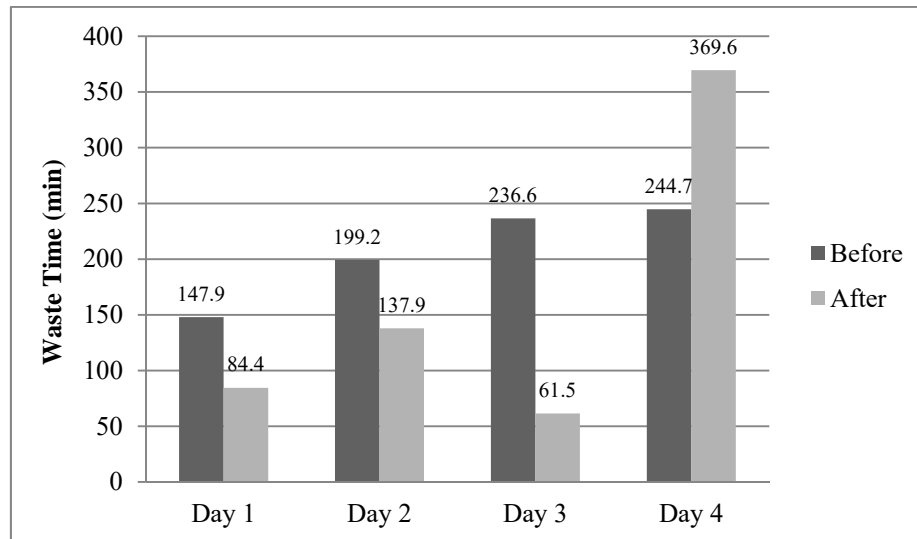

Figure 4. Comparison of waste time before and after improvement.

4. Discussion

Improvement of UPS continuous testing process can enhance the overall efficiency of the process and work day can be reduced from 5 days to 4 days. Moreover, the units of testing per patch could increases from 3 units to 4 units. Normally, the operator works about 20 day per month and receives wage about 9,000 Baht per month. Before improving process, work day per batch would take about 5 days. Therefore, work ability of this process should be 4 batches or 12 units per month. Assuming the institute earns 10,000 Bath per units of testing, the income from UPS testing should be 120,000 Baht per month. Excluding operator wage, the net income from UPS testing process would be 111,000 Baht. After improving process, work day per batch would take about 4 days and work ability should be 5 batches or 20 units per month. The total income from UPS testing process would be 200,000 Baht per month and the net income would be 191,000 Baht per month that increases 80,000 Baht or 72%.

5. Conclusion

Electrical and Electronic Institute provides UPS testing service for electrical appliance manufacture in order to obtain TIS 1291-3-2555 standard before distributing to the customers. However, the UPS continuous testing process has been observed low efficiency as the cycle time is much lower than work time of the operator. Initially, testing process would take about 5 days and there were 3 units of testing per batch. This study aims to enhance the effectiveness of the UPS testing process by reducing waste time and increases the overall efficiency of the operation process. Yamazumi chart and job scheduling theory namely North West Corner Rule were adopted by determining the standard time and then developing the new testing process with consideration of applicability to all UPS products with requirement of TIS 1291-3-2555. The developed testing process was performed by rearranging all tasks to be completed within 4 work days, rearranging tasks with the same load to perform on the same day, rearranging similar tasks to perform continuously, rearranging tasks that cause exhausted battery power to perform last and rearranging short circuit testing to perform in the last step.

Moreover, unit of testing per batch could be increased from 3 units to 4 units. After improvement, the overall efficiency would increase from 52.8% to 65.6% or increasing 12.7%. Also, waste time of the process could be decreased by 21% after improvement. Moreover, the institute could earn more net income from UPS testing process due to increasing testing unit by about 72% and the delivery target could be met.

Acknowledgement

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Appendix

A. Details of Testing Tasks

Electrical and Electronic Institute provides UPS electric testing service mainly in Chapter 6.3 of TIS 1291-3-2555 standard (Test of UPS operation according to Manufacturer's Specifications) [12]. Details of testing title (Table 1 and 2) are briefly described as follows:

Testing Title	Details
5.2.2h	Test of total input harmonic distortion
6.3.2	Test of input voltage and frequency tolerance band
6.3.3	Test of UPS inrush current
6.3.4.1	Test of static output characteristic (normal mode/no load)
6.3.4.3	Test of static output characteristic (stored energy mode/no load)
6.3.4.2	Test of static output characteristic (normal mode/full load)
6.3.4.4	Test of static output characteristic (stored energy mode/full load)
6.3.5.1	Test of static output characteristic (normal mode/overload)
6.3.5.2	Test of static output characteristic (stored energy mode/overload)
6.3.5.3	Test of static output characteristic (normal mode/short circuit)
6.3.5.4	Test of static output characteristic (stored energy mode/short circuit)
6.3.6.1	Test of dynamic output characteristic (normal to stored energy mode/resistance linear load)
6.3.6.2	Test of dynamic output characteristic (stored energy to normal mode/resistance linear load)
6.3.6.4	Test of operation mode change (normal to bypass mode if applicable)
6.3.7.1	Test of output dynamic load characteristic (linear step load)
6.3.8.1	Test of UPS output (output tolerance/non-liner load/normal mode)
6.3.8.2	Test of UPS output (output tolerance/non-liner load/stored energy mode)
6.3.8.3	Test of UPS output (linear load /normal to stored energy mode)
6.3.8.4	Test of UPS output (non-linear step load/normal mode/rated $\leq$ 4.0 kVA)
6.3.8.6	Test of output (non-linear step load/stored energy mode)
6.3.9.1	Test of stored energy time
6.3.10	Test of input efficiency and power factor