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NAME: Mr. Pakorn Jinorose

THIS THESIS HAS BEEN ACCEPTED BY

.... **THESIS ADVISOR**

(Assistant Professor Pornthep Anussornnitisarn, Ph.D.)

.... **THESIS CO-ADVISOR**

(Miss Suwitchaporn Witchakul, D.Eng.)

.... **DEPARTMENT HEAD**

(Assistant Professor Wisut Supithak, Ph.D.)

APPROVED BY THE GRADUATE SCHOOL ON ....

.... **DEAN**

(Associate Professor Gunjana Theeragool, D.Agr.)

THESIS

AN APPLICATION OF INTERNAL BENCHMARKING FOR MULTIPLE PRODUCT PROCESS MONITORING

PAKORN JINOROSE

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Engineering (Engineering Management)
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Nowadays, the general companies are facing with many obstacles in production. One of them is the companies cannot balance the quantity produced to flow smoothly during processes. It causes more work in process and waiting time during process. The objective of this research is to tracking and monitoring in several dimensions such as by product type, by production line and work center.

This research analyzed the performance of each station by using internal benchmarking methodology that is referred to Hopp and Spearman (2000).

Eventually, the conclusion can be represented by graph which composes of Through put rate , Cycle time that each company are able to apply to monitor and track production line performance before efficiency down or occurring long time of break down case. These also affects to general person who will apply to next advance research for development process in the future.

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Student's Signature Thesis Advisor's signature

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Pakorn Jinorose

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LIST OF ABBREVIATIONS

CT	=	Cycle time
FMS	=	Flexible Manufacturing System
PWC	=	Practical Worst Case
To	=	Raw process time
TH	=	Throughput rate
RB	=	Rate of Bottleneck
WC	=	Worst Case
Wo	=	Critical work in process
WIP	=	Work in process

AN APPLICATION OF INTERNAL BENCHMARKING FOR MULTIPLE PRODUCT PROCESS MONITORING

INTRODUCTION

Nowadays, many factories affected the problem regarding lead time and double handing in process. That affects to minimize profit due to uncontrolled process. If the company cannot know or predict the trend of problem (yield drop) the result leads to occurring big problem approaching. Perhaps the situation will affect to task management and reflex with company profit deeply.

Therefore, if the factory can predict a trend of machine performance line is going to decrease, preventive machine is significant to apply for monitoring and detecting before difficult to maintenance.

An internal benchmarking concept was introduced as alternative method to assess production process performance. A strong point of benchmarking approach inquiries information related to interested performance indicators from external organization. Also internal benchmarking is a tool that measured the performance efficiency by comparing one's business processes and performance metrics to industry bests and/or best practices from other industries productivity in order to adjust and improve production process to serve customers more effective and efficiency. Dimensions typically measured are quality, time, and cost. Improvements from learning mean doing things better, faster, and cheaper.

There are types of benchmarking as following:

1. Internal Benchmarking
2. Competitive Benchmarking
3. Cooperative Benchmarking
4. Strategic Benchmarking

Among the reasons above, the main factor is in production process; machine breakdown, long term in work in process (WIP), bottle neck problem and so on. The good operation line is important for organizations. If the problem is found in the manufacturing process and it is not solved immediately, they may lose the customers. In order to keep the customer, the fast response shall be considered.

The objective of benchmarking is to understand and evaluate the current position of a business or organization in relation to "best practice" and to identify areas and means of performance improvement.

For this research work emphasizes on evaluating line performance by using the relationship among Throughput, Cycle Time and Work in process (WIP) of organization by comparing actual performance to the best case, worst case and practical worst case. Three cases are a sort of internal benchmarking methodology (Hopp and Spearman (2000)). Besides, this research analyzes by using root-cause-analysis and improvement the new production line.

Problem Statement

Developmental operation of organization has influenced to high performance in factory as monitoring and tracking procedure is applied continually in order to analyze operation trend and area problem onward, this will be represented reasonably.

However, all of actual data is difficult to apply if lack of thinking systematically and understand trend truly. Thus questions will be defined to definitely.

1. Can it detect trend?
2. Can it identity problem area?
3. Can it track individual product?

All question of these will be become answer of result in excel data sheet in order to analyze and improve production system by Little's Law also this will be applied benchmarking with other concern correctly.

OBJECTIVES

The purpose of this paper is represented

"The monitoring and tracking process flow in order to analyze trend and problem area by Benchmarking as same as data base"

For this research, the study of production line by using the relationship among WIP, Throughput and Cycle Time. The main objectives of this project are:

1) Diagnose the production line by using internal benchmarking methodology that refers to Hopp and Spearman.

2) Detecting and monitoring production performance by daily

3) Multiple product can be monitored and tracked by data base

Scope

The research and scope of study will be presented as below;

1) Performance of production line can be represented by graph
2) The input data is integer number
3) Study the measurement by using the relationship among WIP, Throughput and Cycle time.

LITERATURE REVIEW

This research represents the best production flow as improvement process, Wastes Elimination, Integration production system. All of them can be applied to process for practice development process. However, these also consists of variable as Little’s Law focusing on throughput rate , work in process , cycle time , lead time all naturally is main factor to reach completed system.

All factories also have target to archive as much as profit possible by eliminate waste in process including improvement process onward. The first observation we can make that these three measures are intimately related by one of the most fundamental principles of operations management.

Moreover, over the past 15 years so, Little's Law has played an increasingly important role in the teaching and practice of operations management. However, the law is usually stated in a modified format to emphasize its applicability to operations.

Principle (Little’s Law): *Over the long-term, average WIP, throughput, and cycle time for any stable process are related according to:*

$$WIP = throughput \times cycle\ time$$

Figure 1 Little’s Law

Source: Little (1961)

Analogously, the behavior of a process flow depends on six parameters

1) Throughput (TH): or throughput rate: The average output of a production Process per unit time (e.g., parts per hour). At the firm level, throughput is defined as the production per unit time that is sold. Therefore, the throughput is the average quantity of good parts produce per unit time. In a line made up of workstations in tandem dedicated to a single family of products and where all products pass through each station exactly once, the throughput at every station will be the same. In more complex plant, where workstations service multiple routing, the throughput of an individual station will be the sum of the throughputs of the routings passing through it.

2) Work in process (WIP): The inventory between the start and end points of a product routing is called work in process. WIP is all products between, but not including, the ending stock points.

3) Cycle Time (CT): The cycle time of a given routing is the average time From release of a job at the beginning of the routing until it reaches an inventory point at the end of the routing. Besides, Cycle time also has another meaning in assembly lines as the time allotted for each station to complete its task. It can also refer to the processing time of an individual machine.

4) Bottleneck rate (r_b): The bottleneck rate of the line, is the rate of the workstation having the highest long-term utilization.

5) Raw process time (T_0): The raw process time of the line is the sum of the long-term average process times of each workstation in the line.

6) Critical WIP (W_0): The critical WIP of the line is the WIP level for which a line with given values of r_b and T_0 but having no variability achieves maximum throughput with minimum cycle time. We show below that critical WIP is defined by the bottleneck rate and raw process time by the following relationship:

$$W_0 = r_b \times T_0$$

It turns out that a wide range of performance is possible for a given (*rb*, *T*0) pair. (Kok, 2001)

We examine how and why this occurs below.

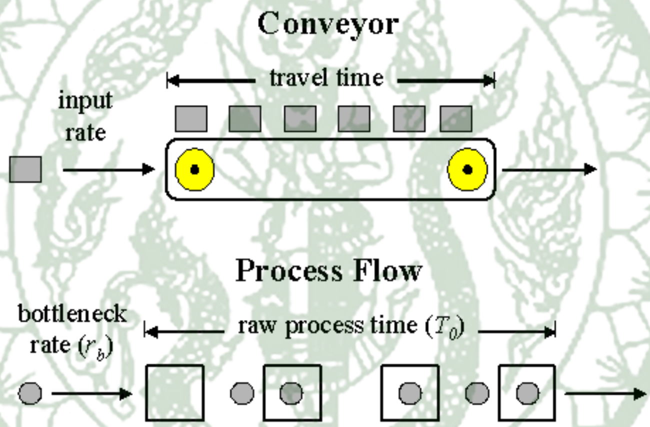

Figure 2 The Conveyor Model of a Process Flow.

Source: Hopp and Spearman (2000)

In Supply Chain Science content text book, it is represented the relationship between Work in process Throughput rate, Cycle time. The performance of any operations system is evaluated in terms of an objective, which could involve making money. The fundamental link between the system objective and its physical operations are the process flows or routings that make up a production or supply chain system (Cachon, 2003)

Benchmarking for Competitive Advantage text book classifies the relationship of measurement process is 3 types

1) Internal Benchmarking
2) External Benchmarking
3) Functional Benchmarking

Benchmarking is an effective structural approach to quality engineering and management. It involves investigating industry's best practices, analyzing and evaluating one's own operation for opportunities and implementing an action plan that includes the structure of goals, objectives and operating targets (Spendolini, 1992)

This research will concentrate on internal benchmarking in order to compare one process flow and also analyze measurement better than other methods, so the result can be represent by graph as below

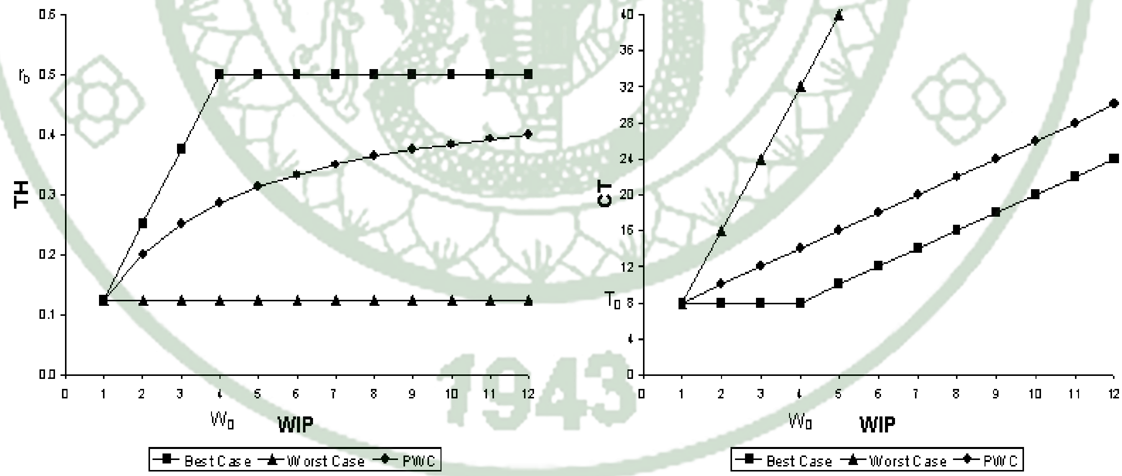

Figure 3 Benchmarking between TH and CT

Source: Hopp (2003)

As graph above can represent the related throughput rate, cycle time, work in process by tracking following as quantities of work in process. Following Rule of (TH > TH PWC), then the flow is in the good region; otherwise it is in the bad region. To illustrate the use of the PWC formula as an internal benchmarking tool.

Generally, research that concerned with benchmarking would operate with single product, but for more advance this research will be applied to multiple product by using Flexible Manufacturing System (FMS) performance measures of Bottleneck model to define problem and reach advanced technical.

We now illustrate these definitions by means of two cases**:**

Balance Line case:

1) The line is stable process. The quantity of machine is the same in each station.

2) The capacity of each station is the same.

3) W_0 is always equal to the number of machine in the line.

4) All stations have equal capacity.

For example, Penny Fab One line consist of four 4 stations; punching, stamping, riming, and burring. Each station takes exactly two hours to perform its operation. The line runs 24 hours per day, with break, lunch etc., covered by spare operators. Hence, the capacity of each station is the same and equals one penny every two hours, or 0.5 penny per hour. Since this is a tandem line with no yield loss, the bottleneck is defined as the slowest workstation. That is

$$r_b = 0.5 \text{ penny per hour}$$

Next, the raw process time is the sum of the processing times at the four stations, so

$$T_0 = 8 \text{ hours}$$

The critical WIP level is given by

$$W_0 = r_b x T_0$$

$$W_0 = 0.5x8 = 4 \text{ pennies}$$

From the equation above, W_0 is equal to the number of machines in the line.
Unbalance Line case:

1) The workstations have different number machines and processing time.

2) The capacity per machine can be calculated by the individual machine capacity times the number of machines, or can be computed directly by dividing the number of machines by the process time.

3) The bottleneck is defined by slowest station in the line. Besides, the bottleneck is the fewest machines

4) The raw process time of the line is still the sum of the process times. Note that adding machines at a station does not decrease T_0, since a job can be worked on by only machine at a time.

5) If W_0 come out to a fraction, it means that there is no constant WIP level that will achieve through of exactly r_b jobs per hour and cycle time of T_0, hours.

6) If the critical WIP level is less than the number of machines can called unbalance line, and therefore some stations will not be fully utilized.

Relationships

The relationships among WIP, throughput, and cycle time in a single production line will depend on the assumptions we make about the line. This will serve to sharpen our intuition about how lines smoothly production and full utilization of resource.

1. Best-Case Performance

We will simulate Penny Fab One. Since the one penny coming out of the line every eight hours, throughput is 1/8 penny per hour. The cycle time is T_0= 8 hours (the cycle time is equal the raw process time), while throughput is ¼ of the bottleneck rate r_b= 0.5

We add the second pennies to the line. After two hours, the first penny completes processing at station 1 and starts on station 2. And second penny starts processing on station 1. Thereafter, the second penny will follow the first, switching station every two hours. Moreover, since two pennies exit the line every eight hours, the throughput increases to 2/8 penny per hour and 50% of the capacity line r_b= 0.5

We add third pennies, the cycle time stay at 8 hours, so throughput increase 3/8 penny per hour, or 75% of capacity line.

We add fourth pennies, all the stations stay busy all the time once steady state has been reached. Because there is no waiting at the stations, cycle time is still T_0= 8 hours. Since the last station is busy all the time, it outputs a penny every other hour, so throughput is 4/8 or ½ penny per hour, which is equals the line capacity r_b= 0.5 are only achieved when the WIP level is set at the critical WIP level.

We add the fifth pennies to the line, since there are only 4 machines in the line, a penny will wait at the first station. Since we measure the cycle time as the time from when a job is release to when it exits the line, it becomes 10 hours, due to the extra two hours of waiting time in front of station 1. Hence, for the first time, cycle time becomes larger than its minimal value T_0= 8. Since all station are always busy, the throughput remains at r_b= 0.5

We add tenth pennies. In steady state, a queue of six pennies persists in front of the first station, meaning that an individual penny spends 12 hours from the time it is released to the line until it begins processing at station 1. Hence, the cycle time is 20 hours. As before, all machine remain busy all the time, so throughput is still r_b= 0.5 penny per hour. It should be clear that each penny we add increases cycle time by two hour with no increase in throughput.

We summarize the behavior of Penny Fab One with no variability for various WIP level. They are following:

1) Penny Fab One run best when there are four penny in WIP. (best case zero-variability)

2) We lose throughput with no decrease in cycle time and we increases cycle time with no increase in throughput.

3) The critical WIP is equal to the number of machines. This is always the case when the line consists of stations with equal capacity. This is balance line.

4) For unbalance line, critical WIP will be less than the number of machine, but still has the property of being the WIP level that achieves maximum throughput with minimum cycle time.

5) While the critical WIP is optimal in the case with zero variability, it will not be optimal in other cases. Indeed, the concept of an optimal WIP level is not even well defined in the presence of variability because, in general, increasing WIP will increase both throughputs (good) and cycle time (bad).

We can apply Little's law to describe the relationship between WIP and cycle time. Since these relationships were derived for perfect lines with no variability, the following expressions indicate the maximum throughput and minimum cycle time for a given WIP level for any system having parameters r_b and T_0.

Law (Best-Case Performance):

The minimum cycle time for a given WIP level *w* is given by

$$CT_{best} = \begin{cases} T_0 & \text{If } w \leq W_0 \\ \frac{w}{r_b} & \text{Otherwise} \end{cases} \quad (1)$$

The maximum throughput for a given WIP level w is given by

$$TH_{best} = \begin{cases} \frac{w}{T_0} & \text{If } w \leq W_0 \\ r_b & \text{Otherwise} \end{cases} \quad (2)$$

2. Worst-Case Performance

We consider the worst. Specifically, we seek the maximum cycle time and minimum throughput possible for a line with bottleneck rate and raw process time. This will help to bracket the behavior and measure the performance of the real line. If a line is closer to the worst case than to the best case, them there are some real problems.

The best-case line with WIP equal to the critical WIP because there is no waiting (queuing) in a line that this achieve the minimum possible cycle time.

For the worst case, we must get the longest possible cycle times for the system and somehow increase the waiting time without changing the average processing time (otherwise we would change r_b and T_0) Example, we modified Penny Fab one with four pallets. Instead of all jobs required two hours at each station, suppose that jobs on pallet 1 require eight hours, while pallet 2,3, and4 require zero hour. The average processing time at each station is

8+0+0+0/4 = 2 hours

As before, hence we still have r_b= 0.5 penny per hour and T_0= 8. The slow job on pallet 1 causes all the other jobs to pile up behind it at all times. This is absolute maximum amount of waiting time it is possible to introduce and hence this represents the worst case.

Law (Worst-Case Performance):

The maximum cycle time for a given WIP level w is given by

$$CT_{worst} = wT_0 \qquad (3)$$

The minimum throughput for a given WIP level *w* is given by

$$TH_{worst} = \frac{1}{T_0} \qquad (4)$$

It is interesting to note that both the best-case and worst case performance occur in system with no randomness. There is variability in the worst-case system, since jobs have different process time; but there is no randomness, since all process times are complete predictable. The literature on quality management emphasizes the need for variability reduction, but sometime implies that variability and randomness are synonymous. In case of batching, it is one factor that can push the performance of a line closer to that of the worst case than the best case. Consequently, batching is a true problem in many production systems.

3. Practical Worst-Case Performance

Practical worst case considers an intermediate case, which behaves between the best case and the worst case. This case involves randomness and unlike the previous two cases. In fact, in a sense, it represents the "maximum randomness" case. The worse behavior is a target for improvement.

The practical worst case can be regarded as the maximum randomness case causes every possible to occur with equal frequency. When randomness is introduces into a line, more states become possible. If there is only a little randomness, then the frequency of the spread-out state will be very high, whereas if there is a lot of randomness, then all the states may occur quite often. Hence, we define the maximum randomness scenario to be practical worst case.

In order for all states to be equally likely, three special conditions are required:

1) The line must be balance.
2) All stations must consist of single machine.
3) Process times must be random and occurred according to a specific probability distribution known as exponential distribution. The exponential is the only continuous distribution that has a special property known as memory less property, in which mean that if process times are exponential distributed, there is no need to know about how long a job has been in process to completely define the system state.

Definition (Practical Worst-Case Performance):

The practical worst-case (PWC) cycle time for a given WIP level *w* is given by

$$CT_{pwc} = T_0 + \frac{w-1}{r_b} \qquad (5)$$

The PWC throughput for a given WIP level *w* is given by

$$TH_{pwc} = \frac{w}{(W_0 + w - 1)} x\, r_b \qquad (6)$$

Notice that the behavior of this case is reasonable for both extremely low and extremely high WIP levels. At one extreme, when there is only one job in the system (w=1), cycle time becomes raw process time T_0. At the other extreme, as the WIP level is more than 1 (that is W→∞), throughput approaches capacity r_b, while cycle time increase without bound. Whenever, achieving throughput close to capacity in systems with high variability requires high WIP levels, in order to ensure high utilization of machines. But this also ensures a great deal of waiting and hence high cycle times.

The throughput and cycle time of practical worst case are always between those of the best case and worst case. As such, the PWC provides a useful midpoint that approximates the behavior of many real systems. By collecting data on average WIP, throughput, and cycle time for a real production line, we can determine whether it lies in the region between the best case (green line) and practical worst case(blue line); best region, or between worst case (red line) and practical worst case; bad region, those like in Figure 1 and Figure 2. Better performance that the PWC are good and worse performance are bad. It makes sense to focus our improvement efforts on the bad lines because they are the ones with room for improvement.

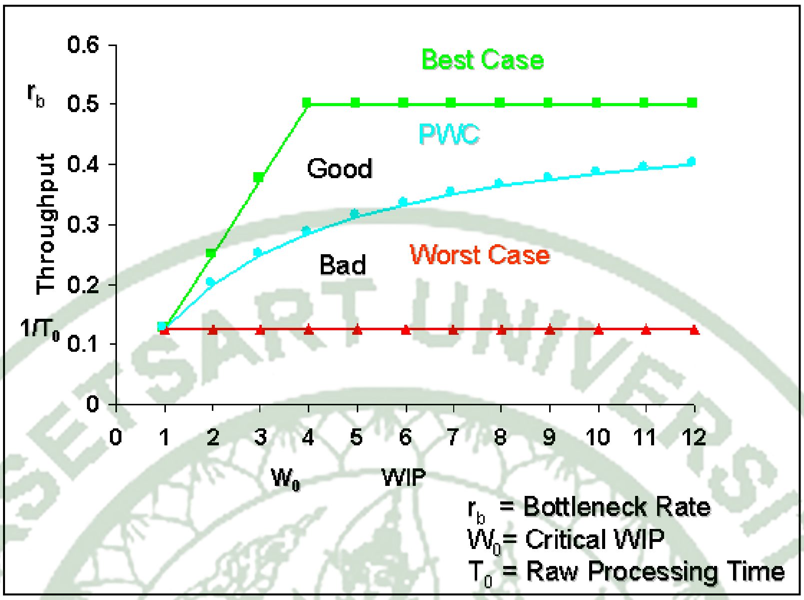

Figure 4 Sample of relationship between Throughput and WIP

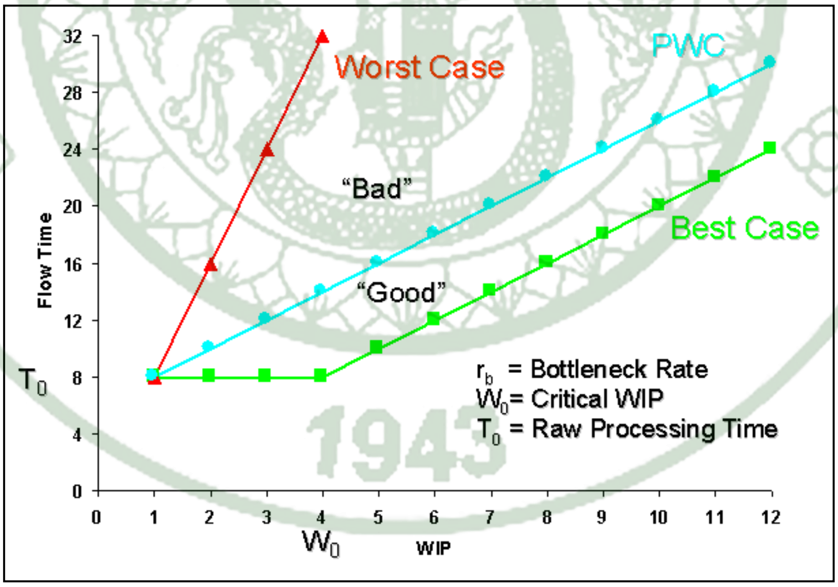

Figure 5 Sample of relationship between Cycle time and WIP

MATERIALS AND METHODS

Materials

The equipment for this research can be categorized into three groups as following;

1. Hardware

Laptop Personal Computer, Lenovo, model Y series, Intel core i5 2.40 GHz and Ram 4 GB, is used to calculate data by graph

2. Software

Microsoft Excel 2007 is used to create indexes and table for this research document.

3. Literatures

3.1) Literatures will be copied from the website of the main library of Kasetsart University.

3.2) Textbooks will come from the International Graduate Program (IGP-IE)

Methods

The item steps that will be explained for research completion as follows in table 1;

Table 1 the Main Process Methodology of this research

Process	Description
1. Research literature review	- Study and more information support about the researches and textbooks.
2. Make a model	- Application model by Excel program.
3. Testing a model	-Try to assume data on computer program and also show the result by graph - Testing relationship between actual data compare process which high speed Monitoring
4. Conclusion and Discussion	- Conclusion and discussion the results and writing to the thesis.
5. Presentation	- Presenting thesis data to the committee.

1. Literature Review

To spend more time to research into related topic or contents with Internal Bench marking also studying the measurement by using the relationship among WIP, Throughput and Cycle time including Flexible manufacturing system (FMS) for composing to trusting testing so on.

2. Make a model

To build up the model by following as Little's Law theory Work in process (WIP) is equel throughput rate multiple by cycle time, also application of Internal Bench marking concept to combine composing method.

In this picture below, this shows the relationship of measures between WIP vary between Throughput rate and Cycle time by separation graph obviously.

In addition to actual data can be calculate the result from Simulated data comparing with theory by disposing good performance in order to check the model is in good region area.

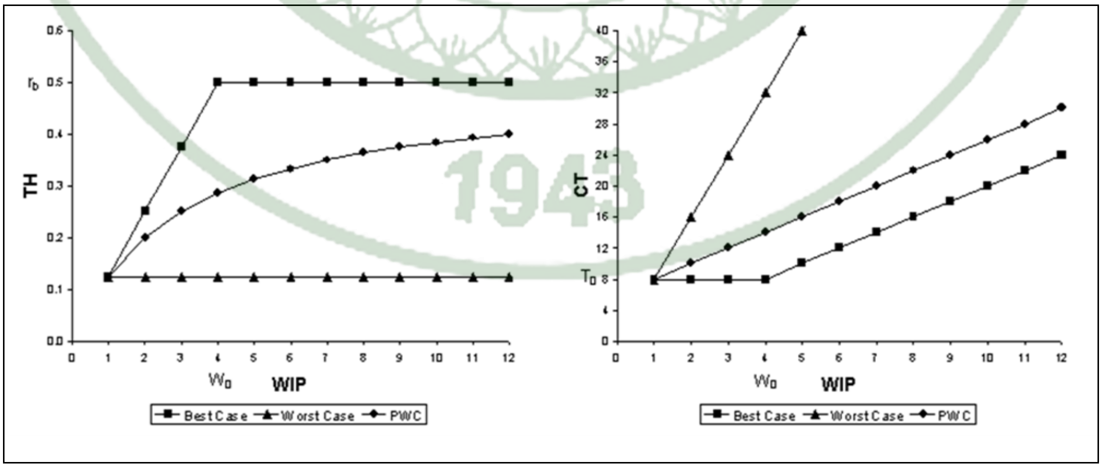

Figure 6 Basic the relationship between measures

Moreover an application of Flexible manufacturing system (FMS) to apply model for divide the data that the demand and production ratio difference in multiple product concept.

For single product can reach actual data apply to model by equation as below The Actual Internal benchmarking concept for a given WIP level w is given by

$$\text{TH (Actual)} = \sum_{i=1}^{N} \frac{Production}{Time\_period(N)} \quad (7)$$

$$\text{WIP (Actual)} = \sum_{\_i=1}^{N} \frac{Input - Output + Buffer}{Time\_period(N)} \quad (8)$$

$$\text{Cycle time (Actual)} = \frac{WIP_{Act}}{TH_{Act}} \quad (9)$$

For multiple products can bring actual data to model by equation as below Equation is based on divided by product ratio; the actual internal benchmarking concept for a given WIP level w is given by

Best case performance

$$CT_{best} = T_o = \%A * T_A + \%B * T_B + \%C * T_C \quad (10)$$

$$TH_{best} = r_b = \%A * r_b(Bottle\_neck) \quad (11)$$

Worst case performance

$$CT_{wc} = W.T_0 = (W_A) * T_0 \quad (12)$$

$$TH_{WC} = \frac{1}{T_0} \quad (13)$$

Practical worst case performance

$$CT_{PWC} = T_O + \left(\frac{W-1}{r_b}\right) = T_0 + \frac{(W_A - 1)}{r_{b_A}} \quad (14)$$

$$TH_{PWC} = T_O + (\frac{W}{W_0 + W - 1}) * r_b = (\frac{(W_A)}{W_0 + (W_A) - 1}) * r_{b_A} \quad (15)$$

In testing model by multiple product can bring actual data apply to model by equation. The Actual internal benchmarking concept for a given WIP level w is given by this equation is based on divided by product ratio at machine.

Best case performance

$$CT_{best} = T_o = \%A * T_A + \%B * T_B + \%C * T_C \quad (16)$$

$$TH_{best} = r_b = \%A * r_{b(a)} + \%B * r_{b(B)} + \%C * r_{b(C)} \quad (17)$$

(19)

Worst case performance

$$CT_{wc} = W.T_0 = (W_A + W_B + W_C) * T_0 \quad (18)$$

$$TH_{WC} = \frac{1}{\%A * T_A + \%B * T_B + \%C * T_C} \quad (19)$$

Practical worst case performance

$$CT_{PWC} = T_O + (\frac{W - 1}{r_b}) = T_0 + \frac{(W_A + W_B + W_C - 1)}{r_b} \quad (20)$$

$$TH_{PWC} = T_O + (\frac{W}{W_0 + W - 1}) * r_b = (\frac{(W_A + W_B + W_C)}{W_0 + (W_A + W_B + W_C) - 1}) * r_b \quad (21)$$

Table 2 Divide ratio data table

Machine	Process	Ratio (%)	CT/ MC (sec)	Second / piece
			Machine 1	
MC 1	Part A	60.0%	148.00	88.8
	Part B	30.0%	150.00	45.0
	Part C	10.0%	144.00	14.4
		Average	147.33	148.2
			Machine 2	
MC 2	Part A	60.0%	160.00	96.0
	Part B	30.0%	170.00	51.0
	Part C	10.0%	165.00	16.5
		Average	165.00	163.5
			Machine 3	
MC 3	Part A	60.0%	220.00	132.0
	Part B	30.0%	212.00	63.6
	Part C	10.0%	230.00	23.0
		Average	220.67	218.6

3. Making data base model by graph

The revision of standing point can be expressed for control Operation research in control scope as questions below

Research Question 1: Can it detect trend?

Research Question 2: Can it identify problem area?

Research Question 3: Can it track individual product?

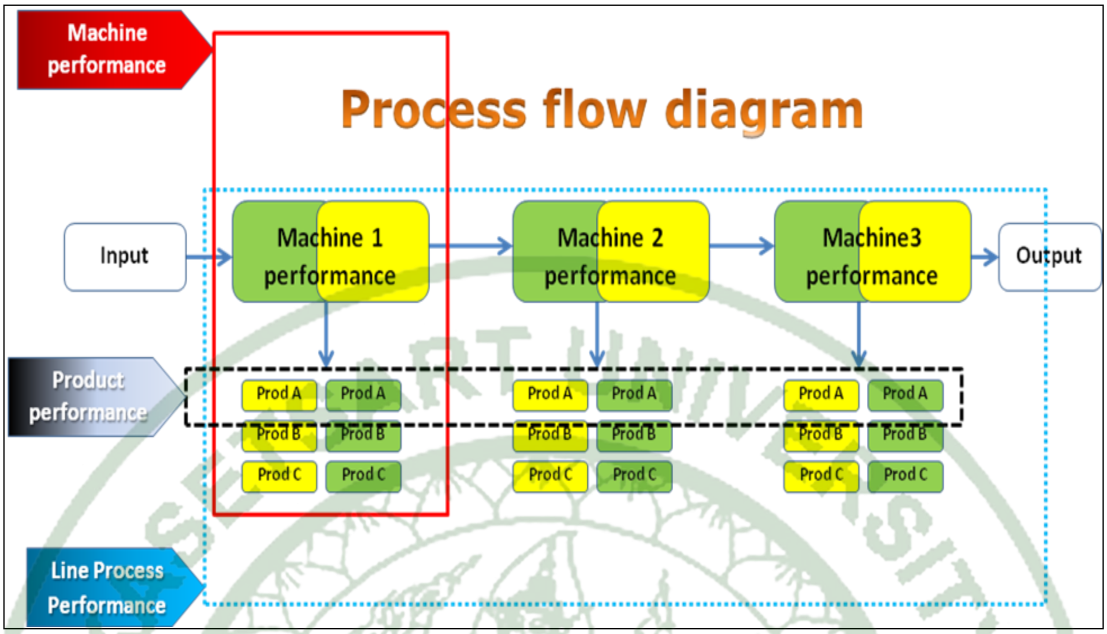

Figure 7 Diagram of development to analyze

This research divided type of detection 2 types

1) Response time to original (% Yield drop detection)

Assume percentage yield drop data into model and compare individual graph (divided by product, machine, and line performance) which indicator are detection fast speed in each experiment.

2) Impact of product ratio (% percentage ratio)

Percentage of product in each product affects to monitor and track the problem to detect.

4. Testing model

To assume data yield drop or down time of machine operation by set date to start yield drop then check and compare the result from graph with indicator can detect and track as fast speed as occurring the problem.

The result of testing will be represented obviously on conclusion and discussion topic by graph and data table for comparing visualization.

5. Conclusion and Discussion

Reporting the results of this study by main program by Microsoft excel 2007 and Microsoft words 2007 for report over all the data.

6. Presentation

This study was marked the presentation to committee by Microsoft power point 2007.

RESULTS AND DISCUSSION

Results

This research composed of the conclusion to two parts following as

1) The result from application program by graph that shows the relationship of Throughput rate, Cycle time and Work in process (WIP) by daily monitoring.

2) The result of this research can represent that percentage of production ratio and down time including yield down on process have affected to line performance and fast speed to detect decreasing trend of line performance.

The result from testing 72 Experiments

To set example model by setting production flow as three machines continually and 3 products is produced to process flow.
Furthermore, ratio production in each machine will be assumed into model for applying the operation result.

For understanding clearly, Little’s Law theory WIP = TH / CT; these can be applied to model by Internal Bench marking concept as following as below.

This example composed of Machine 1, Machine 2, and Machine 3 meanwhile each machine will be into assumed data as table by divided quantity of production by ratio production (Percentage).

Table 3 Data process

MC No.	Process	Ratio	CT/ MC (sec)	Sec / piece	No. mc	Cap pcs /day / mc	Process Time To	CT each product (sec)	Rate of bottleneck Pcs/day	Pcs/day/part (Rb)	Rate of Bottle neck	Process Time To	Wo (pcs)
	MC1												
	Part A	60.0%	148.00	88.8	2	194.6	0.00257	44.5		233		0.0043	9.00
MC 1	Part B	30.0%	150.00	45.0	2	192.0	0.00260	22.2	388.7	117	0.0013	0.0086	4.50
	Part C	10.0%	144.00	14.4	2	200.0	0.00250	7.4		39		0.0257	1.50
	Total			148.2		586.6		74.1				0.03859	15.0
	MC2				2								
	Part A	60.0%	160.00	96.0	2	180.0	0.00278	49.1		211		0.0047	1.67
MC 2	Part B	30.0%	170.00	51.0	2	169.4	0.00295	24.5	352.3	106	0.0014	0.0095	3.33
	Part C	10.0%	165.00	16.5	2	174.5	0.00286	8.2		35		0.0284	10.00
	Total		147	163.5		524.0		81.8				0.04258	15.0
	MC3				3								
	Part A	60.0%	220.00	132.0	3	130.9	0.00255	43.7		237		0.0042	1.67
MC 3	Part B	30.0%	212.00	63.6	3	135.8	0.00245	21.9	395.2	119	0.0008	0.0084	3.33
	Part C	10.0%	230.00	23.0	3	125.2	0.00266	7.3		40		0.0253	10.00
	Total		221	218.6		392.0		72.9				0.03795	15.0

Note To = Raw process time , Wo = Wip in process

Now this table was revealed the relationship of content and this is a linkage of main calculation table.

1. Testing Benchmarking model for multiple product at line performance
2. Testing Benchmarking model for multiple product at product performance
3. Testing Benchmarking model for multiple product at machine performance

The first identify in each variables, As below equation will show the method to calculate variable as follows T_0, W_0, TH_{best}, TH_{PWC}, TH_{WC} only Machine 2

This for calculation example; raw process time (T_0)

Raw process time of each product that arrange by percentage of product (MC2)

$$T_0 = \text{Sum of total machine time in process}$$

$$T_0 = 0.0043+0.0086+0.0257$$

$$= 0.03859 \text{ day}$$

This for calculation example, Critical work in process (W_0)

$$W_0 = r_b x T_0$$

$$W_0 = 388.7 \text{ X } 0.0386$$

$$W_0 = 15 \text{ pieces}$$

To build the model perfectly, this need to find out variable that relate with cycle time and work in process (WIP)
Significant variable to calculate as these

- Throughput rate (Best case) , (Worst case) ,(Practical worst case)
- Cycle time (Best case) , (Worst case) ,(Practical worst case)

1) To find the value of Throughput rate following as internal bench marking concept as below

$$TH_{best} = r_b \qquad (1)$$

$$TH_{best} = 388.7\_pcs$$

$$TH_{worst} = \frac{1}{T_0} \qquad (2)$$

$$TH_{worst} = \frac{1}{0.03859} = 25.9\_piece / day$$

$$TH_{pwc} = \frac{w}{(W_0 + w - 1)} x r_b \qquad (3)$$

Give the work in process is assumed data; w = 33 pieces

$$TH_{pwc} = \frac{33}{(15 + 33 - 1)} x 399.7$$

$$TH_{pwc} = 272.9\_piece / day$$

According to detail as data table 3, it can be adjusted following by user requirement or depending on actual data need to insert to model, so the program can be also utilized in development of problem for monitoring and tracking by time series.

2) To find the value of cycle time (CT) following as internal bench marking concept as below.

$$CT_{best} = \begin{cases} T_0 & \text{If } w \leq W_0 \\ \frac{w}{r_b} & \text{Otherwise} \end{cases} \quad (4)$$

$$CT_{best} = 0.039\_day$$

$$CT_{worst} = wT_0 \quad (5)$$

Give the work in process is assumed data; w, target (Not over) = 90 pieces

$$CT_{worst} = 90 * 0.039$$

$$CT_{worst} = 3.47\_day$$

$$CT_{pwc} = T_0 + \frac{w-1}{r_b} \quad (6)$$

Give the work in process is assumed data; w = 33 piece

$$CT_{pwc} = 0.0257 + \frac{33-1}{388.7} = 0.11\_day$$

Table 4 Summary of example result

Variable	Result	Unit
TH (Actual)	388.7 (If no loss time)	Pcs / day
TH (Best case)	388.7	Pcs / day
TH (Worst case)	25.9	Pcs / day
TH (Practical worst case)	272.9	Pcs / day
CT (Actual)	0.039 (If no loss time)	Day / 1 pcs
CT (Best case)	0.039	Day / 1 pcs
CT (Worst case)	3.47	Day / 1 pcs
CT (Practical worst case)	0.11	Day / 1 pcs

	Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	BNR(rb) (Pcs /day)	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389
	RPT (DAY)	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
	Wo (CWIP) WIP target	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
TH	TH best	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389	389
	TH wc	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
	TH pwc	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6	272.6
CT	CT best	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	CT wc	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47
	CT pwc	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	Actual CT	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
WIP	Target WIP	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
	Daily WIP (out-in)	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
	Throught put rate1	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387	387

Figure 8 The relationship function of model

For clearly hypothesis, model will be tested based on condition affection such as yield drop and ratio production by multiple product.

The result will be divided to experiment to test which condition affect or influence to line process performance as shown below

Assume percentage yield down (%)

1) Testing by Throughput rate, Cycle time in each product of one machine

- Data is set into model as table 3 as above
- Bottleneck process is Machine 2 (Red sketch color)
- Ratio of work load are Part A : 60%, Part B :30% and Part C: 10%

In another application case, ratio product can adjust by depending on user

The result shows as graph both through put rate and cycle time
As graph 9 relationship between throughput and cycle Product A.
Assume data percentage of yield drop as Table 4

% Yield drop		Date															
Product		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	Time	100%	100%	100%	100%	100%	100%	100%	100%	100%	96%	92%	88%	85%	82%	78%	75%
B	Time	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
C	Time	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%	97%	96%	95%	94%	93%	92%

% Yield drop		Date														
Product		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A	Time	72%	69%	66%	64%	61%	59%	56%	54%	52%	50%	48%	46%	44%	42%	41%
B	Time	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
C	Time	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total	91%	90%	89%	88%	87%	86%	85%	85%	84%	83%	83%	82%	81%	81%	80%

Figure 9 Percentage ratio of yield drop for all product in one machine

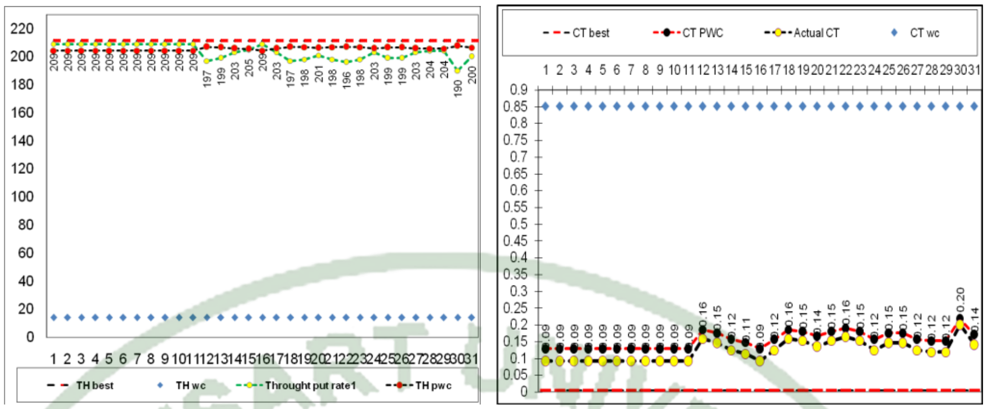

Figure 10 Relationship between Throughput and CT Product A

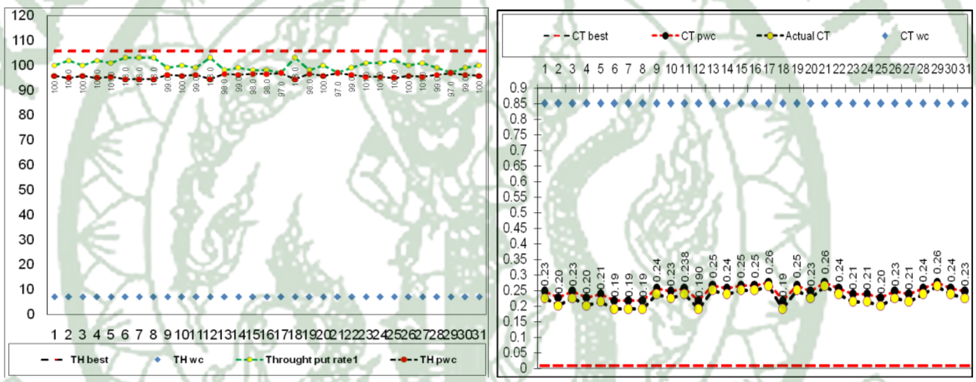

Figure 11 Relationship between Throughput and CT Product B

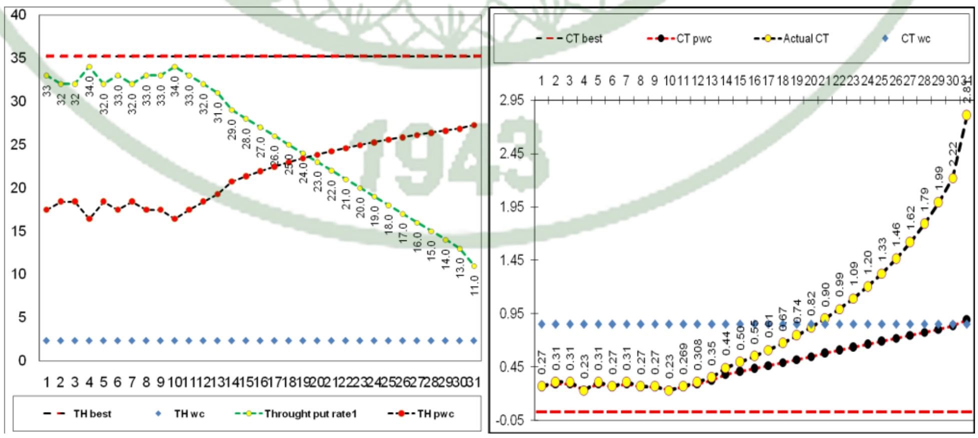

Figure 12 Relationship between Throughput and CT only product C

Based on all graphs as above are shown the relationship between through rate, cycle time and work in process in daily performance, focusing on product A, B, C respectively.

Both graphs are compared to monitor the trend which one can detect the trend.
On Figure 3 found Actual throughput rate line is lower than PWC line at 12^{th}
On Figure 4 found Actual Cycle time line is more than PWC line at 7^{th}
On Figure 5 found Actual Cycle time line is more than PWC line at 3^{rd}

This can be shown the result of monitoring and tracking between Throughput and cycle time at different time detection by cycle time while also product C is found detect on 3^{rd} as fast detect that another parameter.

Addition of tracking by individual graph that separated by line performance for each product line performance, machine line performance, original line performance, there are many graphs as below.

Example: Assume data from and percentage yield down (%)

2) Testing by machine line performance for all product

- Data is assumed data to simulate on table 23 as above
- Bottleneck process in process ; is Machine 2
- Ratio work load is ; Part A : 60%, Part B : 30%, Part C:10%

Step to find variable as same as example 1; in additional graph for monitoring Throughput, cycle time product: A, B, C on table.

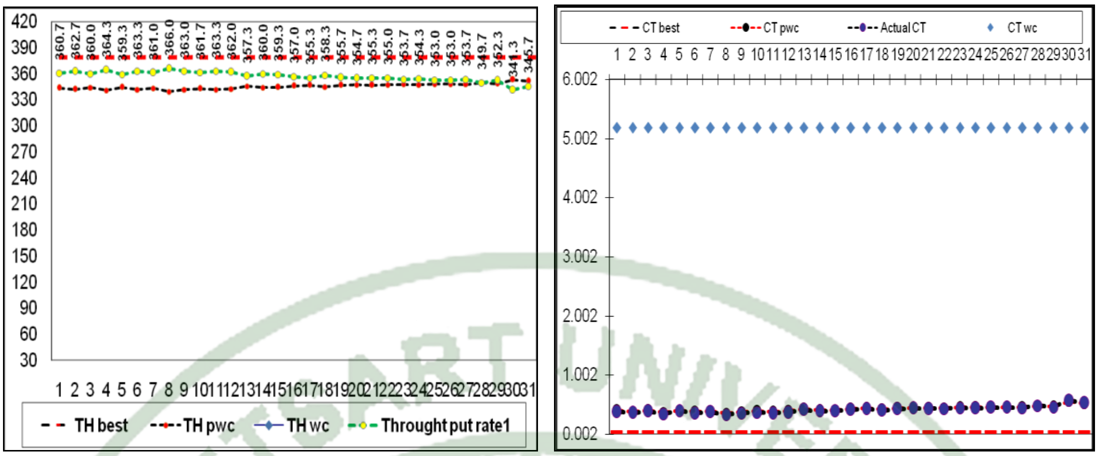

Figure 13 Performance Production lines between Throughput and cycle time

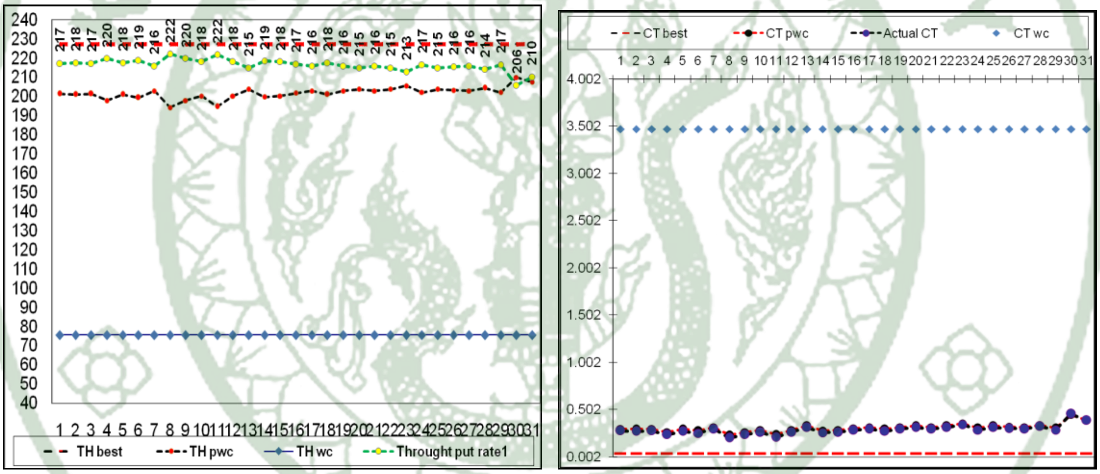

Figure 14 Relationship performance lines between Throughput and CT Product A

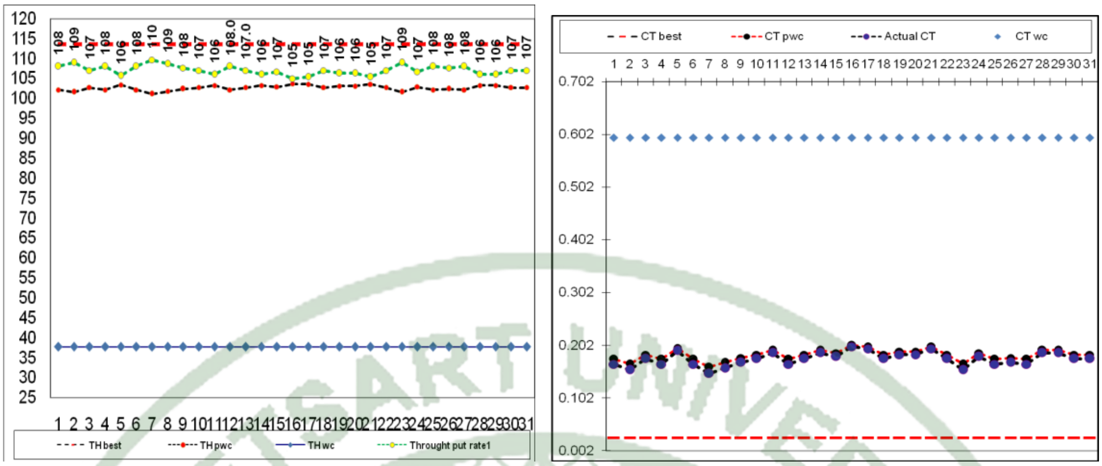

Figure 15 Relationship performance lines between Throughput and CT Product B

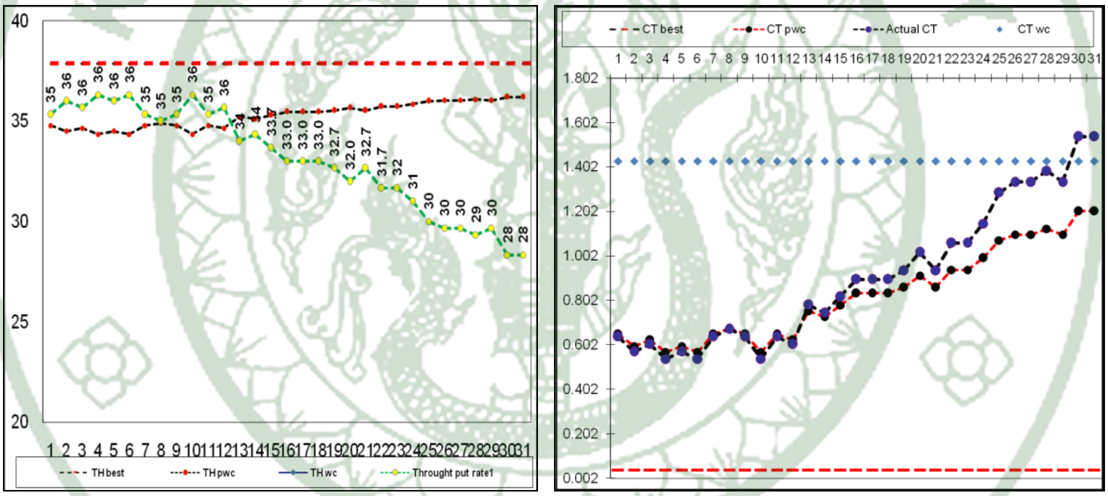

Figure 16 Relationship performance lines between Throughput and CT Product C

Based on all graphs as above are shown the relationship between through rate, cycle time, work in process by daily, focusing on Product A, B, C

Both graphs are compared to monitor the trend which one can detect the decreasing trend.

On Figure 6 found Actual throughput rate line is lower than PWC line at 28^{th}

On Figure 7 found Actual throughput rate line is lower than PWC line at 30^{th}

On Figure 9 found Actual throughput rate line is lower than PWC line at 12^{rd}

This can be shown the result of monitoring and tracking between Throughput and cycle time at different time detection by cycle time graph in product C , the result of product C found area to detect on 12^{rd} as fast detect than another graph.

3) Testing by machine line performance for each product

Example: assume data from and % yield down

- Data is assumed into model following as table 23
- Bottleneck process is Machine 2
- Ratio of work load are Part A : 60%, Part B : 30% and Part C :10%

Step to find variable as same as example 1; additional graph for monitoring And result will be shown to graph for easier visualization and tracking including monitoring for detection throughput, cycle time product A, B, C

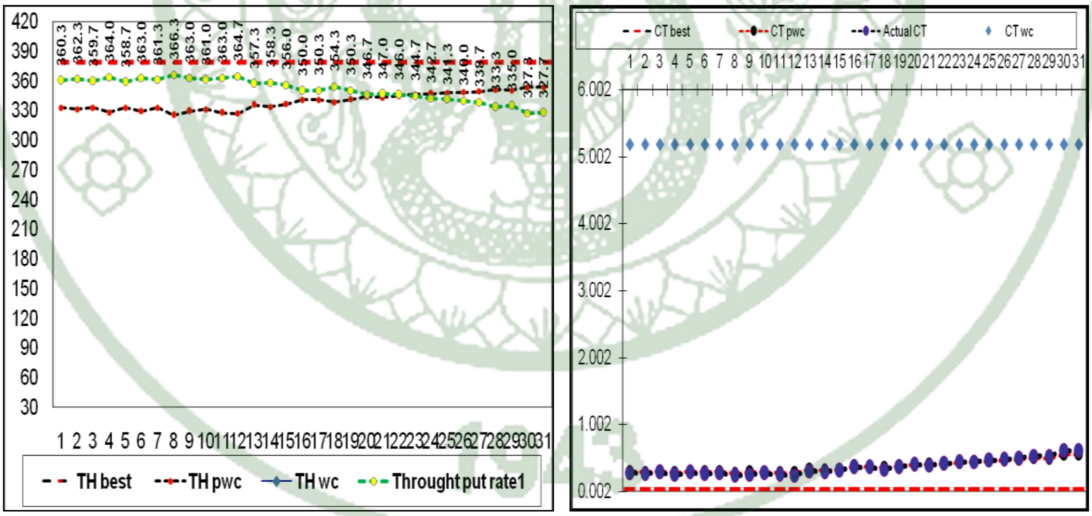

Figure 17 Performance Production lines between Throughput and cycle time

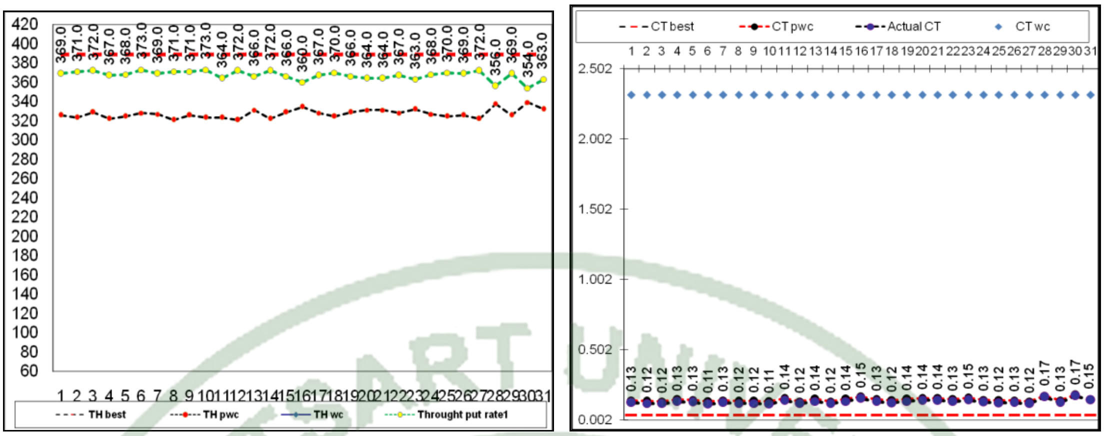

Figure 18 Performance Production between Throughput and cycle time Machine 1

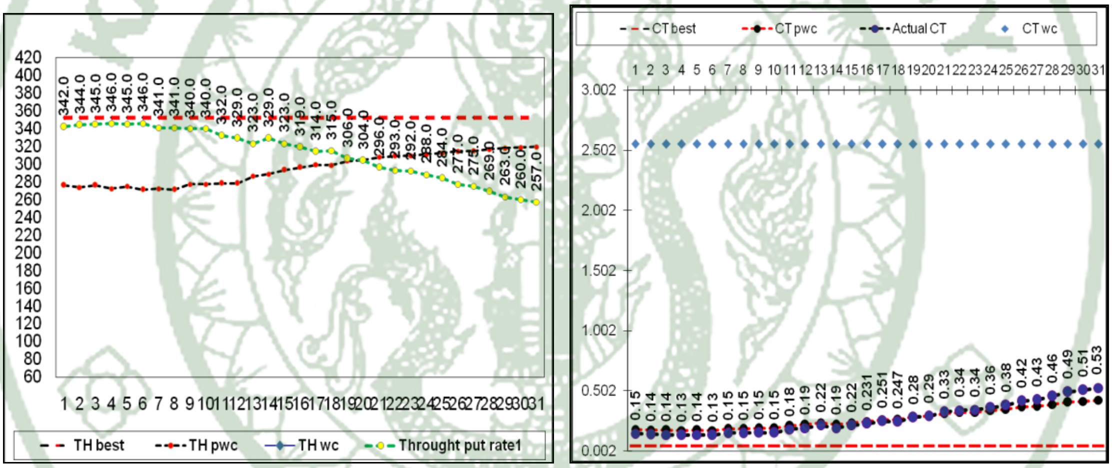

Figure 19 Performance Production between Throughput and cycle time Machine 2

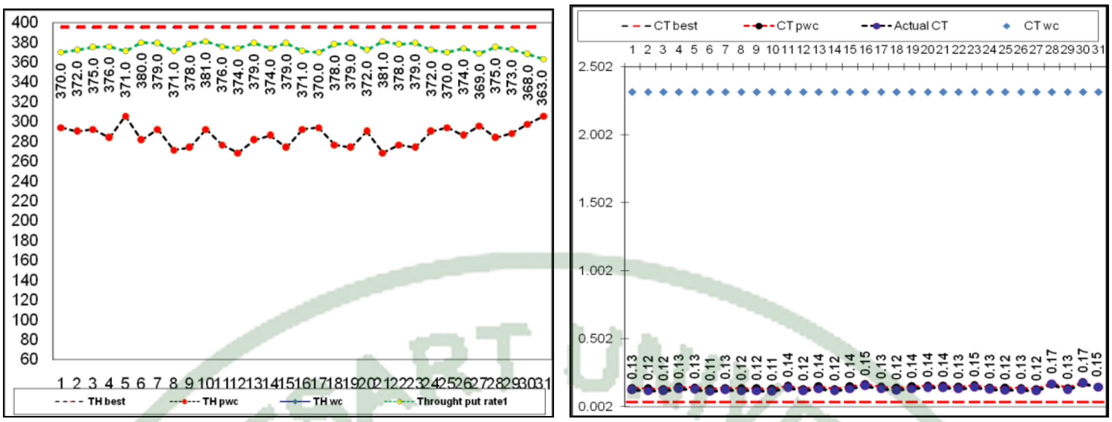

Figure 20 Performance Production between Throughput and cycle time Machine 3

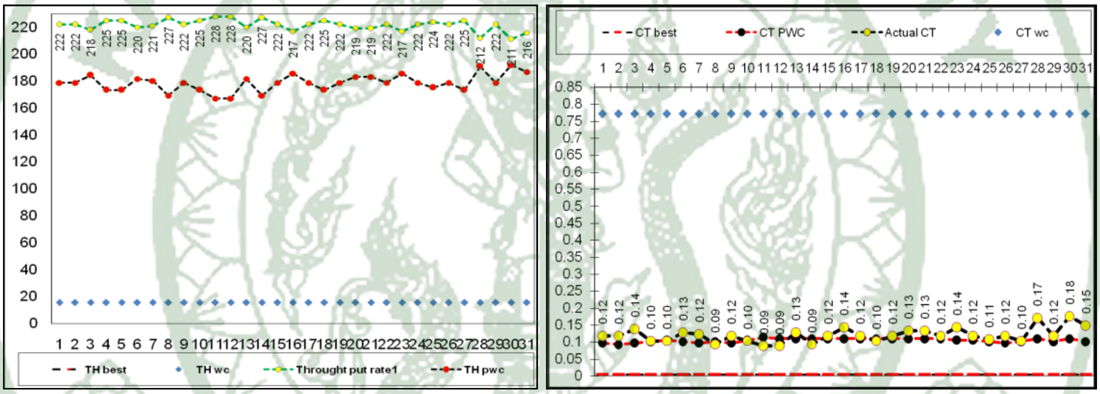

Figure 21 Performance Machine 1 between Throughput and cycle time Part A

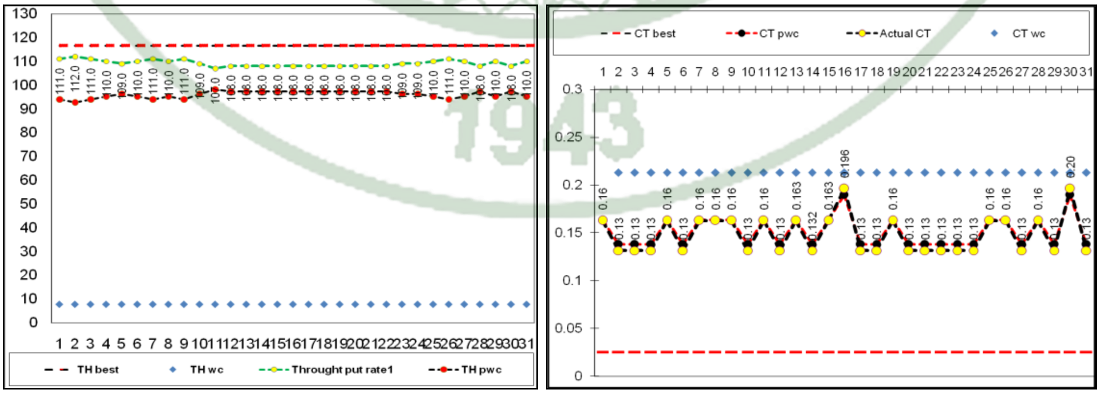

Figure 22 Performance Machine 1 between Throughput and cycle time Part B

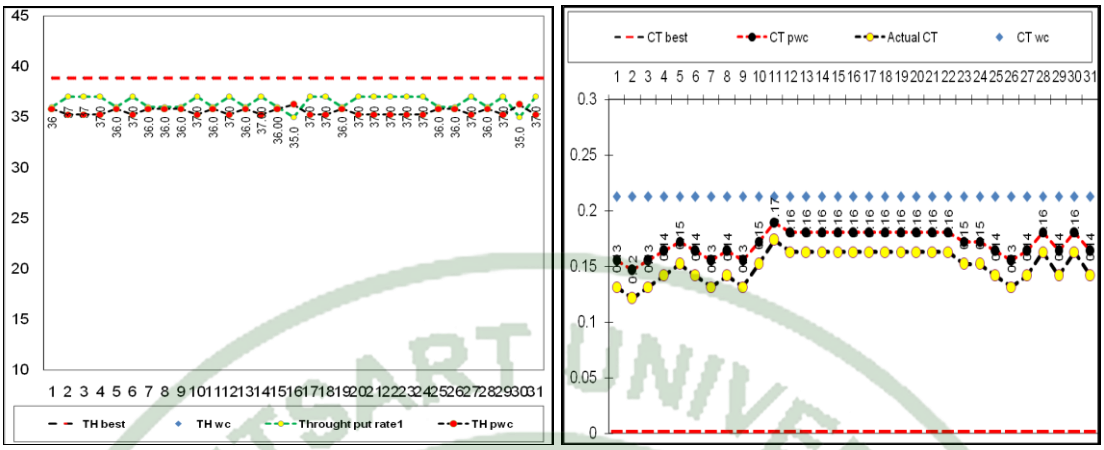

Figure 23 Performance Machine 1 between Throughput and cycle time Part C

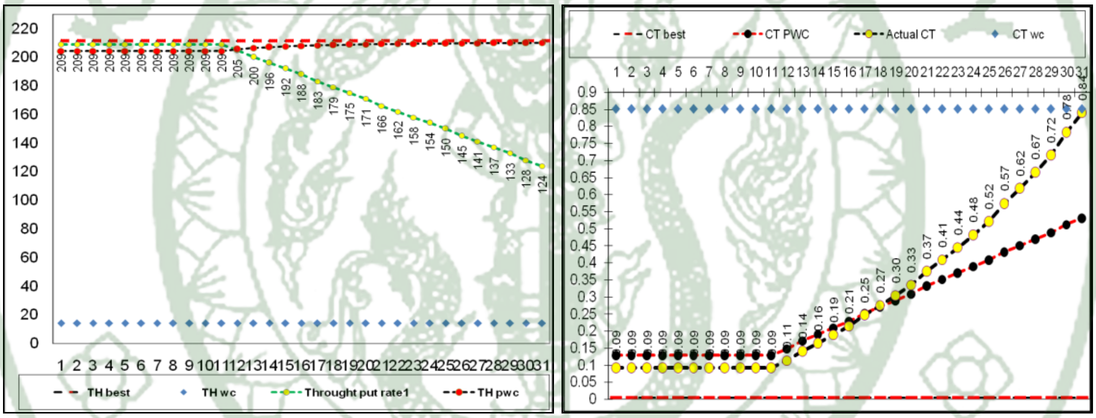

Figure 24 Performance Machine 2 between Throughput and cycle time Part A

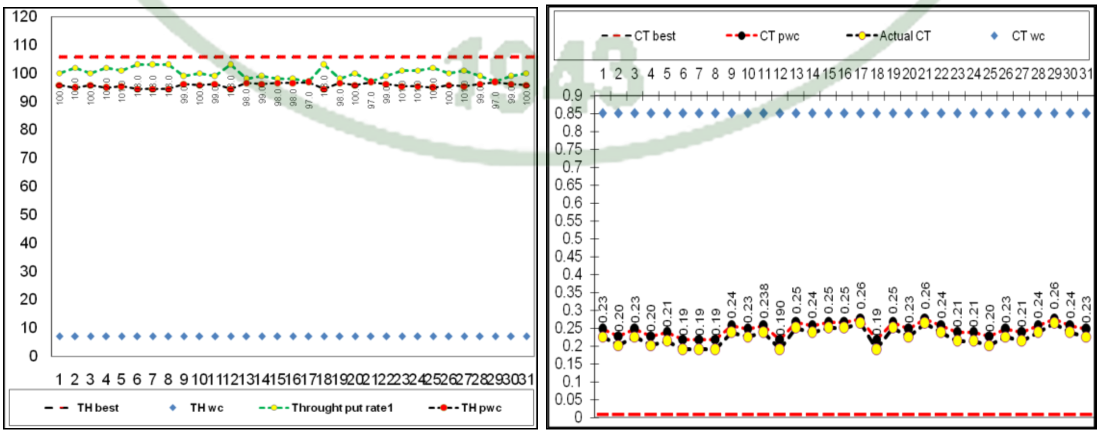

Figure 25 Performance Machine 2 between Throughput and cycle time Part B

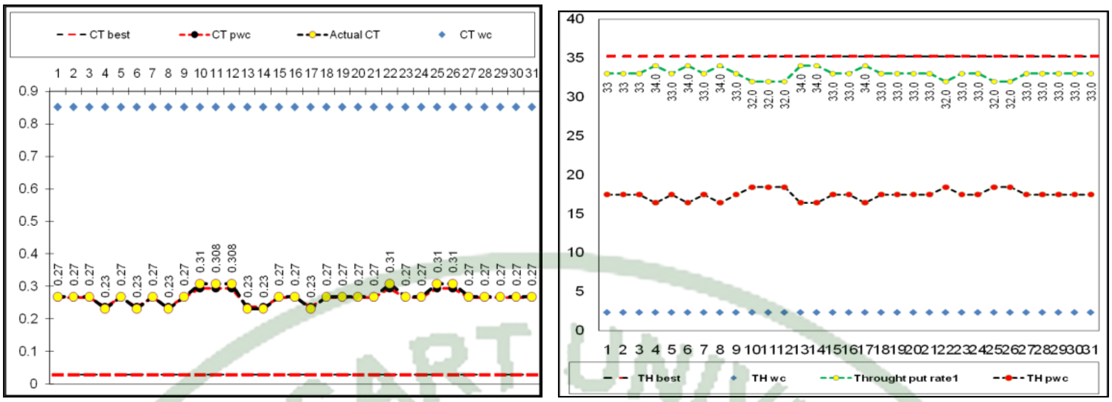

Figure 26 Performance Machine 2 between Throughput and cycle time Part C

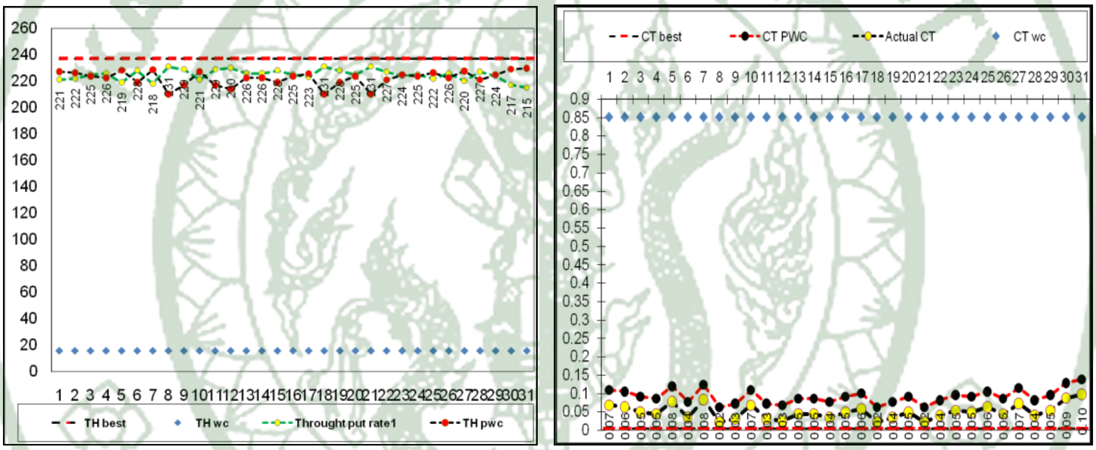

Figure 27 Performance Machine 3 between Throughput and cycle time Part A

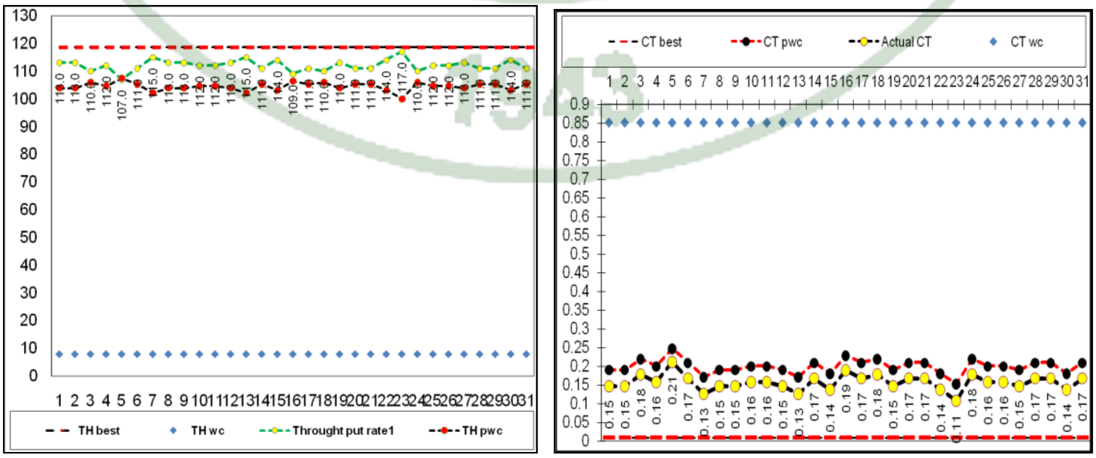

Figure 28 Performance Machine 3 between Throughput and cycle time Part B

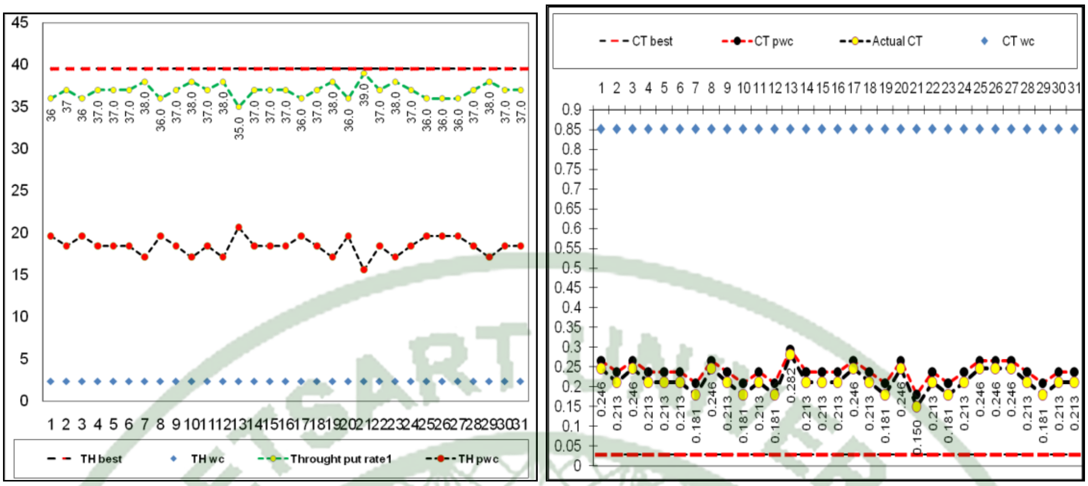

Figure 29 Performance Machine 3 between Throughput and cycle time Part C

Testing result based on all graphs as above are shown the relationship between through rate, cycle time, work in process by daily, focusing on Product A, B, C and shown production line performance that composed of machine 1,2,3

All graphs are compared to monitor the trend which one can detect the trend.
On Figure 9 found Actual throughput rate line is lower than PWC line at 20^{th}
On Figure 11 found Actual cycle time line is higher than PWC line at 1^{th}
On Figure 12 found Actual throughput rate line is lower than PWC line at 5^{rd}
On Figure 16 found Actual throughput rate line is lower than PWC line at 1^{rd}
On Figure 15 found Actual throughput rate line is lower than PWC line at 3^{rd}
On Figure 13 found Actual throughput rate and cycle time line is over than PWC line at 12^{rd} as same production date.

For this testing can be represented performance of this production line Example 3 Performance line cannot detect the problem trend as same as graph on figure 16 and 11. That found the problem going to decrease from at 1^{rd} so, more explanation can detect trend of problem as fast as main line production performance.

At this time to clear concept of model by internal benching which parameter detect or monitor trend of bad region; data will be applied to model 72 experiments as below condition.

After the result of example 22, these will be represented to each graph by process and product type, next to clearly experiment that % ratio product production and yield drop have affected to line performance conditionally.

1) For example that will be tested, ratio of production composed of 10, 20, and 30 %
2) For example that will be tested, ratio of production composed of 40, 50, and 60 %
3) For example that will be tested, ratio of production composed of 60, 70, and 80 %

Following as pattern by step increment increasing 10%

Table 5 Separation % ratio product in each machine

Condition 1	**Ratio Machine**		
Product	**Machine 1**	**Machine 2**	**Machine 3**
Product A	10.0%	20.0%	30.0%
Product B	20.0%	30.0%	40.0%
Product C	70.0%	50.0%	30.0%
Condition 2	**Ratio Machine**		
Product	**Machine 1**	**Machine 2**	**Machine 3**
Product A	40.0%	50.0%	60.0%
Product B	30.0%	30.0%	20.0%
Product C	30.0%	20.0%	20.0%
Condition 3	**Ratio Machine**		
Product	**Machine 1**	**Machine 2**	**Machine 3**
Product A	60.0%	70.0%	80.0%
Product B	30.0%	20.0%	10.0%
Product C	10.0%	10.0%	10.0%

Table 6 Pattern for experiment

Product	Machine 1	Machine 2	Machine 3
Product A	MC1: Product A (1)	MC2: Product A (4)	MC3: Product A (7)
Product B	MC1: Product B (2)	MC2: Product B (5)	MC3: Product B (8)
Product C	MC1: Product C (3)	MC2: Product C (6)	MC3: Product C (9)
Relationship (Machine , Product)	Machine 1 Product A,B,C (10)	Machine 2 Product A,B,C (11)	Machine 3 Product A,B,C (12)

Table 7 Comparing index performance

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
1	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	2% yield drop														
	B	30%	20%	10%	2		30	30	21			21			15			15		
	C	10%	10%	10%	3															
2	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1				31			31								
	B	30%	20%	10%	2	2% yield drop	30	30							17			17		
	C	10%	10%	10%	3															
3	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1															
	B	30%	20%	10%	2	2% yield drop 2%	30	30		Undetected			Undetected		22			22		
	C	10%	10%	10%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
4	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1															
	B	30%	20%	10%	2	2% yield drop	30	30	21			21			15			15		
	C	10%	10%	10%	3															
5	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1															
	B	30%	20%	10%	2	2% yield drop	30	30		Undetected			Undetected		17			17		
	C	10%	10%	10%	3															
6	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1															
	B	30%	20%	10%	2	2% yield drop 2%	30	30		Undetected			Undetected		23			23		
	C	10%	10%	10%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
7	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	2% yield drop	30	30		22			22			14			14	
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															
8	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	2% yield drop	30	30		Undetected			Undetected		23			23		
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															
9	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	2% yield drop 2%	30	30		Undetected			Undetected		21			21		
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
10	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	2% yield drop	16	16		13			13		15	14	22	15	14	22
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															
11	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	2% yield drop	15	16		18			18		15	17	23	15	17	23
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															
12	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	2% yield drop 2%	16	16		19			19		15	24	21	15	24	21
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
13	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1															
	B	30%	20%	10%	2	4% yield drop	20	20		13			12		12			12		
	C	10%	10%	10%	3															
14	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1															
	B	30%	20%	10%	2	4% yield drop	20	20		20			20		12			12		
	C	10%	10%	10%	3															
15	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1															
	B	30%	20%	10%	2	4% yield drop 2%	20	20		Undetected			Undetected		16			16		
	C	10%	10%	10%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
16	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	4% yield drop	20	20	15				13			12			12	
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															
17	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	4% yield drop	20	20		Undetected			Undetected		13			13		
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															
18	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	4% yield drop 2%	20	20		Undetected			Undetected		16			16		
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
19	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	4% yield drop	20	20	15			15			12			12		
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															
20	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	4% yield drop	20	20		Undetected			Undetected		16			16		
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															
21	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	60%	70%	80%	1	4% yield drop 2%	20	20		Undetected			Undetected		13			13		
	B	30%	20%	10%	2															
	C	10%	10%	10%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			**CT**			**TH**			**CT**		
22	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	60% 30% 10%	70% 20% 10%	80% 10% 10%	1 2 3	4% yield drop	12	12		Undetected			Undetected		12	12	16	12	12	16
23	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	60% 30% 10%	70% 20% 10%	80% 10% 10%	1 2 3	4% yield drop	12	12		Undetected			Undetected		12	13	16	12	13	16
24	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	60% 30% 10%	70% 20% 10%	80% 10% 10%	1 2 3	4% yield drop 2%	12	12		Undetected			Undetected		12	16	15	12	16	15

Table 7 (Continued)

NO	Ratio product % product ratio; 40, 50, 60 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
25	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	2% yield drop	30	30	16			16			17			17		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
26	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	2% yield drop	30	30	18			18			15			15		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
27	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	2% yield drop 2%	30	30	18			18			17			17		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 40, 50, 60 %						Single product (Original)		Machine line performance						Product line performance					
									TH			**CT**			**TH**			**CT**		
28	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	2% yield drop	30	30	23			23			17			17		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
29	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	2% yield drop	30	30		Undetected			Undetected		16			16		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
30	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	2% yield drop 2%	30	30		Undetected			Undetected		23			23		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
31	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1															
	B	30%	30%	20%	2	2% yield drop	30	30		22			22			15			15	
	C	30%	20%	20%	3															
32	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1															
	B	30%	30%	20%	2	2% yield drop	30	30		Undetected			Undetected		19			19		
	C	30%	20%	20%	3															
33	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1															
	B	30%	30%	20%	2	2% yield drop 2%	30	30		Undetected			Undetected		21			21		
	C	30%	20%	20%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 60, 70, 80 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
34	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	2% yield drop	16	16		10			10		17			17		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
35	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	2% yield drop	16	16		16			16		17	16	23	17	16	23
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
36	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	2% yield drop 2%	16	16		17			17		15	19	21	15	19	21
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 40, 50, 60 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
37	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	4% yield drop	20	20		11			11		13			13		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
38	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	4% yield drop	20	20		12			12		12			12		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
39	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	4% yield drop 2%	20	20		12			12		13			13		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 40, 50, 60 %						Single product (Original)		Machine line performance						Product line performance					
									TH			**CT**			**TH**			**CT**		
40	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1															
	B	30%	30%	20%	2	4% yield drop	20	20		16			16		13			13		
	C	30%	20%	20%	3															
41	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1															
	B	30%	30%	20%	2	4% yield drop	20	20		22			22			13			13	
	C	30%	20%	20%	3															
42	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1															
	B	30%	30%	20%	2	4% yield drop 2%	20	20	31			31			16			16		
	C	30%	20%	20%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 40, 50, 60 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
43	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	4% yield drop	20	20		16			16		12			12		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
44	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	4% yield drop	20	20		Undetected			Undetected		14			14		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
45	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	4% yield drop 2%	20	20		Undetected			Undetected		15			15		
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 40, 50, 60 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
46	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	4% yield drop	12	12		11			11		12	13	13	13	12	13
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
47	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	4% yield drop	12	12	11			11			15	13	16	15	13	16
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															
48	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	40%	50%	60%	1	4% yield drop 2%	12	12	11			11			12	14	15	12	14	15
	B	30%	30%	20%	2															
	C	30%	20%	20%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 10, 20, 30 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
49	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1	2% yield drop	31	31		16			16			27			27	
	B	20%	30%	40%	2															
	C	70%	50%	30%	3															
50	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1	2% yield drop	31	31		10			10			19			19	
	B	20%	30%	40%	2															
	C	70%	50%	30%	3															
51	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1	2% yield drop 2%	31	31		9		9				15			15	
	B	20%	30%	40%	2															
	C	70%	50%	30%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 10, 20, 30 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
52	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	10% 20% 70%	20% 30% 50%	30% 40% 30%	1 2 3	2% yield drop	30	30	Undetected			Undetected			19			19		
53	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	10% 20% 70%	20% 30% 50%	30% 40% 30%	1 2 3	2% yield drop	30	30	Undetected			Undetected			17			17		
54	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	10% 20% 70%	20% 30% 50%	30% 40% 30%	1 2 3	2% yield drop 2%	30	30	22			22			18			18		

Table 7 (Continued)

NO	Ratio product % product ratio; 10, 20, 30 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
55	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1															
	B	20%	30%	40%	2	2% yield drop	30	30		31			25			15			15	
	C	70%	50%	30%	3															
56	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1															
	B	20%	30%	40%	2	2% yield drop	30	30		15			25			15			15	
	C	70%	50%	30%	3															
57	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1															
	B	20%	30%	40%	2	2% yield drop 2%	30	30		30			30			23			23	
	C	70%	50%	30%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 10, 20, 30 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
58	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	10% 20% 70%	20% 30% 50%	30% 40% 30%	1 2 3	2% yield drop	15	15		10			16		27	20	15	27	20	15
59	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	10% 20% 70%	20% 30% 50%	30% 40% 30%	1 2 3	2% yield drop	15	15		16			16		19	17	18	19	17	18
60	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	10% 20% 70%	20% 30% 50%	30% 40% 30%	1 2 3	2% yield drop 2%	15	15		13			13		15	15	23	15	15	23

Table 7 (Continued)

NO	Ratio product % product ratio; 10, 20, 30 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
61	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1															
	B	20%	30%	40%	2	4% yield drop	20	20		12			12			18			18	
	C	70%	50%	30%	3															
62	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1															
	B	20%	30%	40%	2	4% yield drop	20	20		11			11			15			15	
	C	70%	50%	30%	3															
63	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1															
	B	20%	30%	40%	2	4% yield drop	20	20		10			10			13			13	
	C	70%	50%	30%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 10, 20, 30 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
64	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1															
	B	20%	30%	40%	2	4% yield drop	20	20												
	C	70%	50%	30%	3					31		31			14			14		
65	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1															
	B	20%	30%	40%	2	4% yield drop	20	20		21			21			13			13	
	C	70%	50%	30%	3															
66	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1															
	B	20%	30%	40%	2	4% yield drop	20	20		16			16			14			14	
	C	70%	50%	30%	3															

Table 7 (Continued)

NO	Ratio product % product ratio; 10, 20, 30 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
67	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	10% 20% 70%	20% 30% 50%	30% 40% 30%	1 2 3	4% yield drop	20	20		20			20			12			12	
68	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	10% 20% 70%	20% 30% 50%	30% 40% 30%	1 2 3	4% yield drop	20	20		17			17			12			12	
69	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A B C	10% 20% 70%	20% 30% 50%	30% 40% 30%	1 2 3	4% yield drop	20	20		20			20			16			16	

Table 7 (Continued)

NO	Ratio product % product ratio; 10, 20, 30 %						Single product (Original)		Machine line performance						Product line performance					
									TH			CT			TH			CT		
70	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1	4% yield drop	13	13	10			10			18	15	13	18	15	13
	B	20%	30%	40%	2															
	C	70%	50%	30%	3															
71	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1	4% yield drop	13	13		12			12		14	13	14	14	13	14
	B	20%	30%	40%	2															
	C	70%	50%	30%	3															
72	Prod	M1	M2	M3	M	Experiment	TH Line	CT Line	MC1	MC 2	MC3	CT 1	CT 2	CT3	A	B	C	A	B	C
	A	10%	20%	30%	1	4% yield drop	13	13	12			12			12	12	16	12	12	16
	B	20%	30%	40%	2															
	C	70%	50%	30%	3															

Discussion

Nowadays, a time always depends on the profit; especially production line should operate process smoothly by lack of waste time that is importance for production line balancing. Performance production line is measurement to indicate production line good or bad, in addition to tracking and monitoring is once method to detect area problem of production line, so these lead to protection occurring problem to escalated situation that uncontrolled.

According to application model for detect the problem that can be applied to daily management by leader, foreman in shop floor to daily detect performance line process.

All analysis can be applied to deep development simulation of program to understand, monitoring and tracking a technology for real time by using network operation.

CONCLUSION AND RECOMMENDATION

Conclusion

Internal Benchmarking methodology can bring to factory and detect problem In multiple product and line process that was divided for detect the problem which product or machine is indicator, that problem should be improved line process Immediately for protection uncontrolled factor occur.

Table 8 Comparison monitoring result

Comparison failure detection performance	TH (Found)	CT (Found)	% Found	
Product > Machine	45	45	62.5%	*68.75%
Product > Original data	54	54	75%	
Machine > Original data	46	46	63.8	49.95%
Machine > Product	26	26	36.1	
Original > Machine	25	25	34.7	29.85%
Original > Product	18	18	25	

Note: 1) Original data is original line performance

1) Machine is Machine line performance

2) Product is Product line performance

As data shown in table 8, to compare methods to detect trend of failure found, the result is shown both thought put rate and cycle time by percentage.

Table 9 Tracking and monitoring date table

Day	5-10	10-15	15-20	21-25	25-31
Throughput and Cycle time	3	46	16	7	0

Note: Number in table is many days that Actual line and Practical worst case line overlap

As data shown in table 9, to summary tracking date in period times which period time can be found failure performance and the conclusion which type of speed up detection is respectively following as

1) Product line performance can be fastest detect than machine line Performance line and line process performance by time measure detection by ranking score

- Product line performance
- Machine line performance
- Line process performance respectively

2) Line process that has occurred the percentage yield drop and loss time while on process; model can detect trend line down as bench marking concept.

3) Percentage of product ratio is once factors to line performance directly

The result as above can explain; product line performance can detect in best detection and observation by product line as result is 72 experiments testing.

Recommendation

This principle can be applied to performance line production to improve the ability of development to enhance production line performance.

However, this research can be applied to external benchmarking to gain more operation performance and maximize profit in target business.

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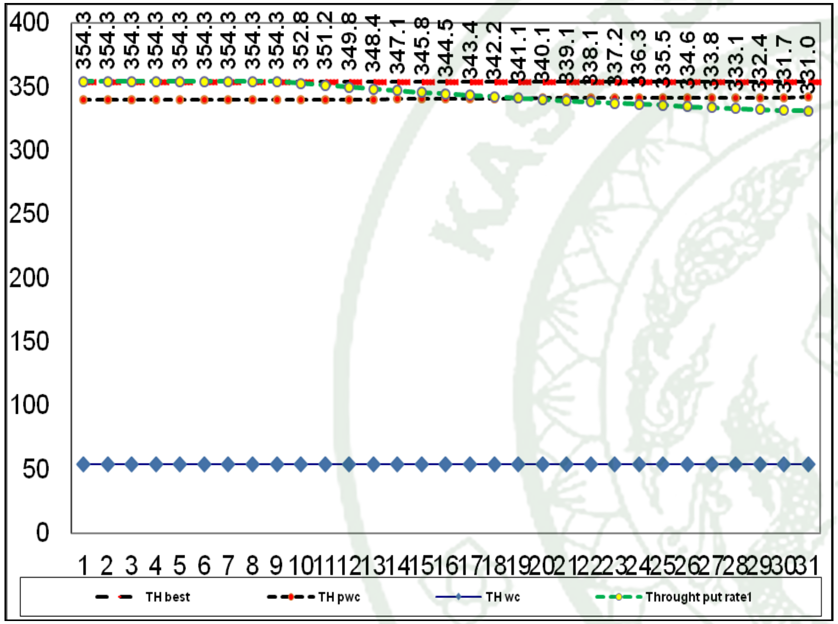
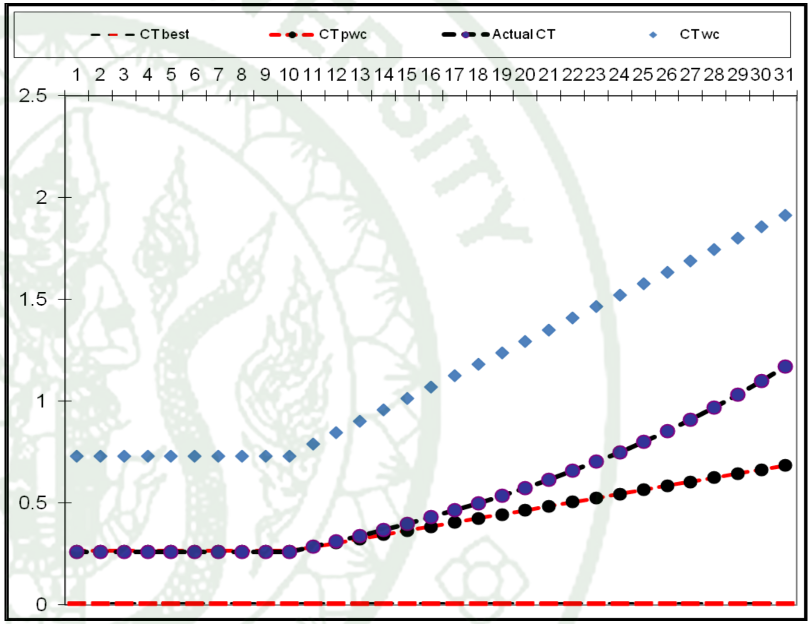
APPENDIX

Detection performance graph

Original product line > Machine line performance



Throughput rate

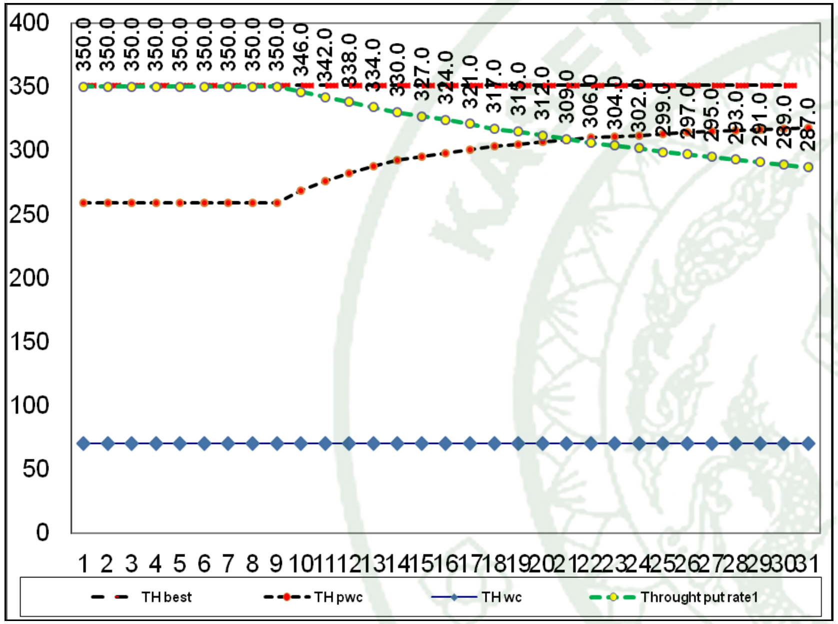


Cycle time

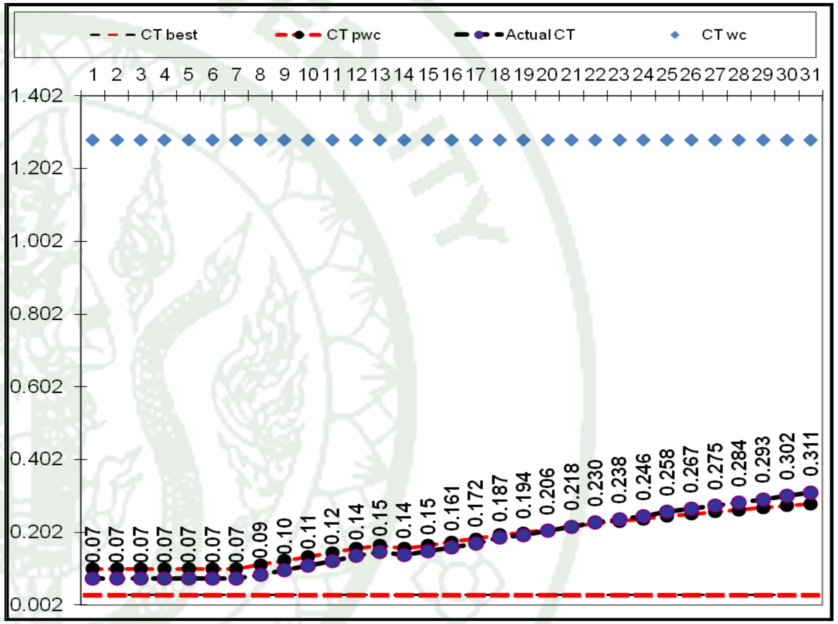
Appendix Figure 1 Original product line detection; example 41

In this case; focusing on multiple product at machine 1, 2, 3

Condition only 2% yield drop for machine 1, 2 and 3 by ratio product at (60%, 70%, 80%)



Throughput rate

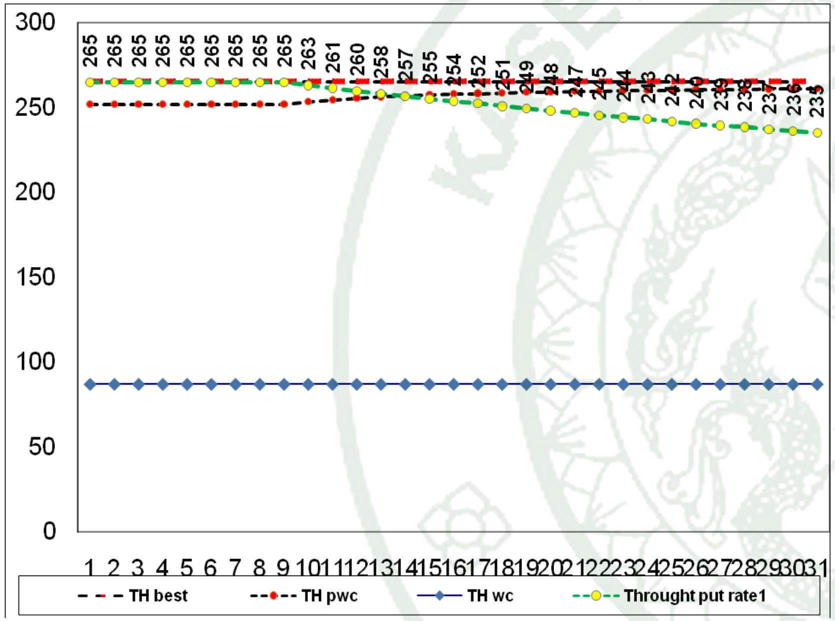


Cycle time

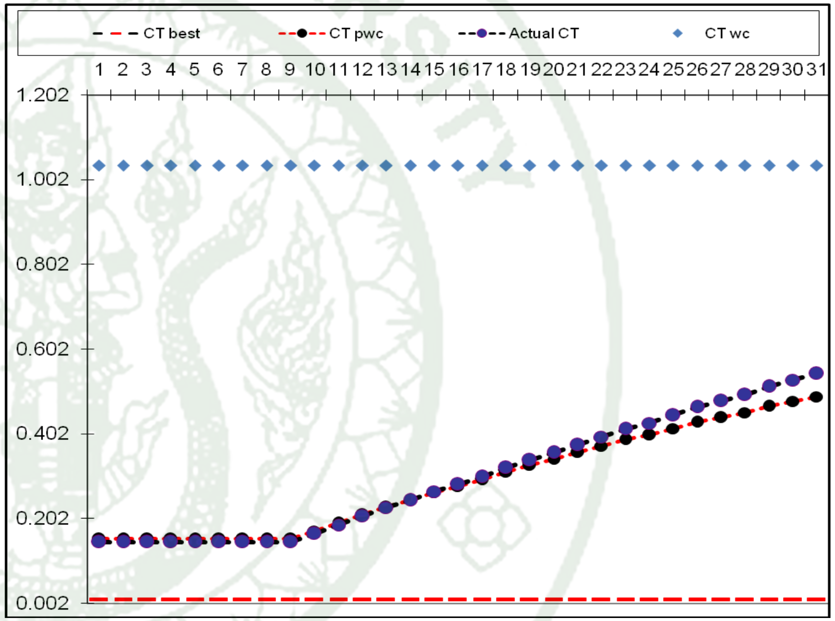
Appendix Figure 2 Machine line performance detection; on example 41

In this case; focusing on multiple product at machine 1, 2, 3

Condition only 2% yield drop for machine 1, 2 and 3 by ratio product at (60%, 70%, 80%)



Throughput rate

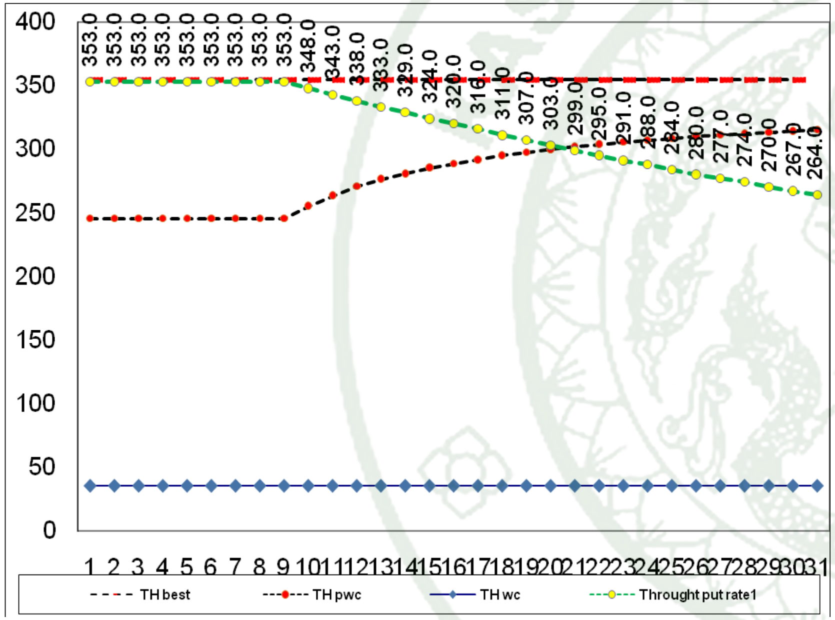


Cycle time

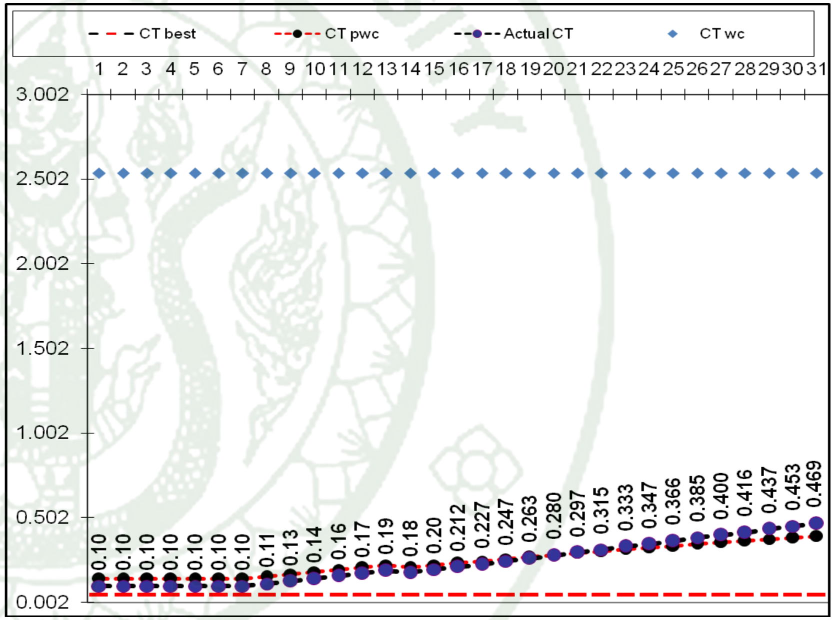
Appendix Figure 3 Product line performance detection; on example 4

In this case; focusing on multiple product at machine 1, 2, 3

Condition only 2% yield drop for machine 1, 2 and 3 by ratio product at (60%, 70%, 80%)



Throughput rate



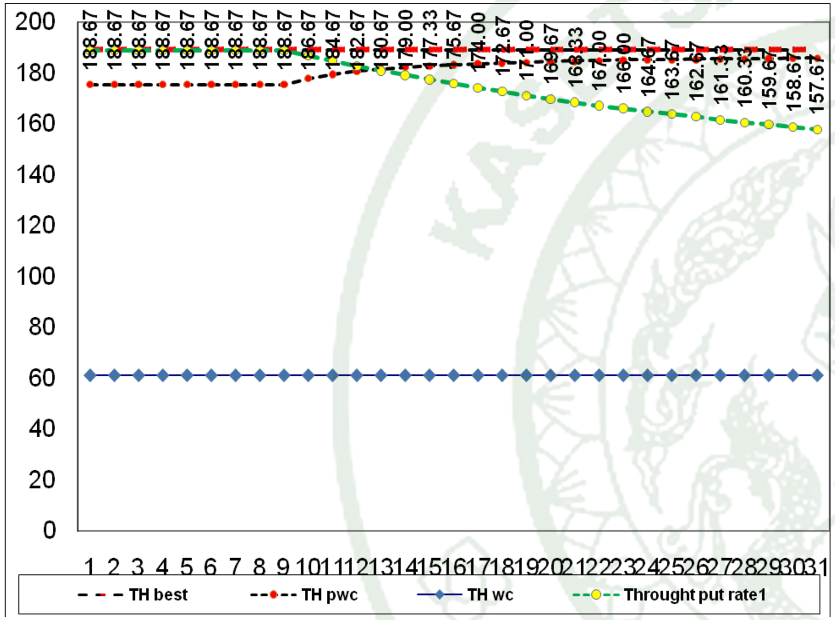
Cycle time

Appendix Figure 4 Machine line performance detection; on example 4

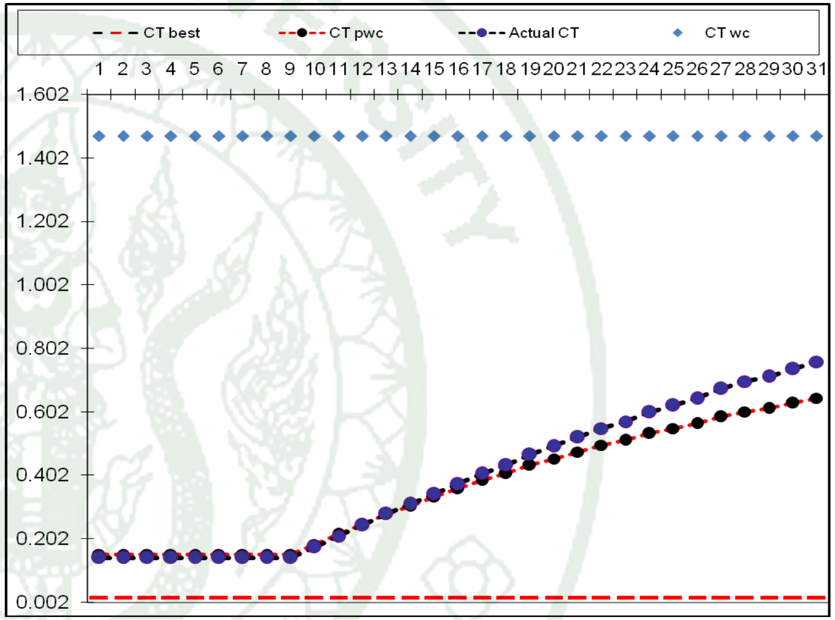
In this case; focusing on multiple product at machine 1, 2, 3

Condition only 2% yield drop for machine 1, 2 and 3 by ratio product at (60%, 70%, 80%)

Condition machine line performance detection; on example 4



Throughput rate

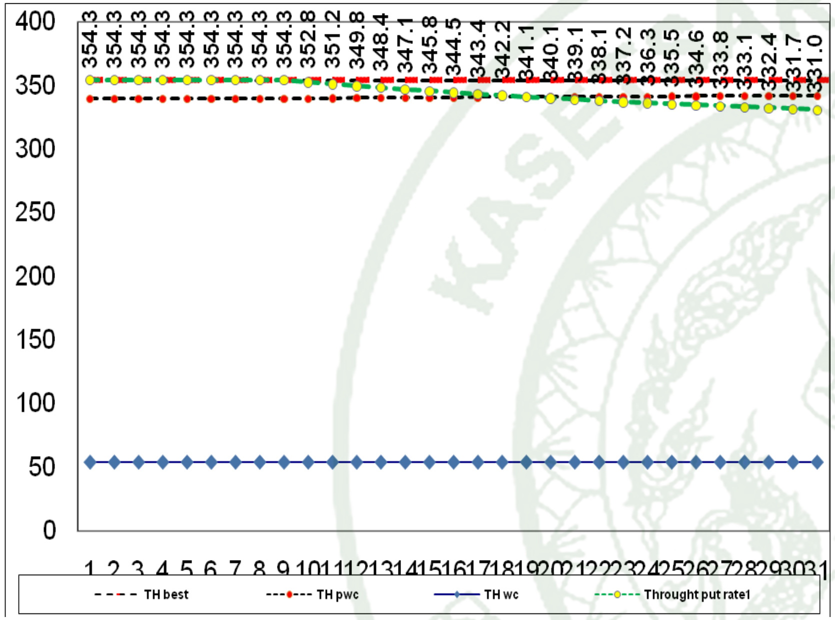


Cycle time

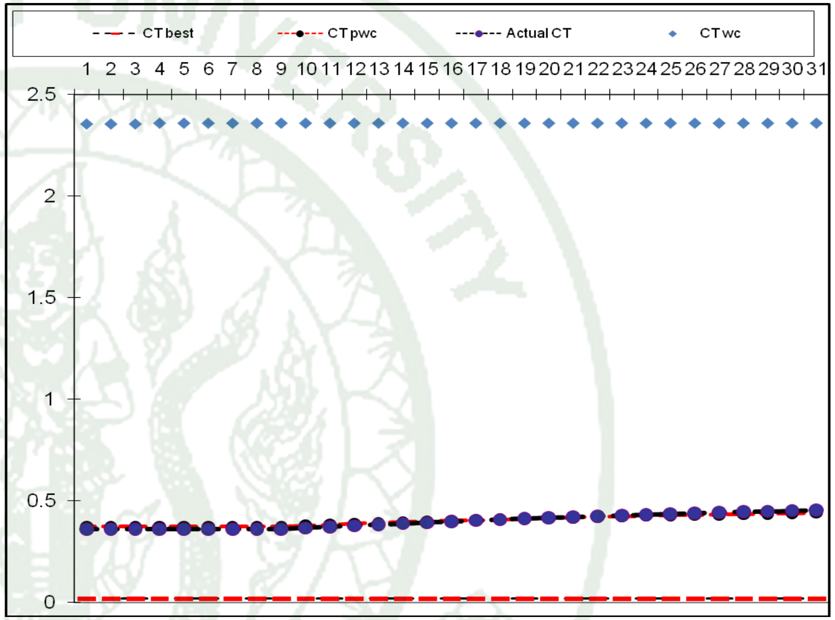
Appendix Figure 5 Product line performance detection; on example 37

In this case; focusing on multiple product at machine 1, 2, 3

Condition only 4% yield drop for machine 1, 2 and 3 by ratio product at (40%, 50%, 60%)



Throughput rate

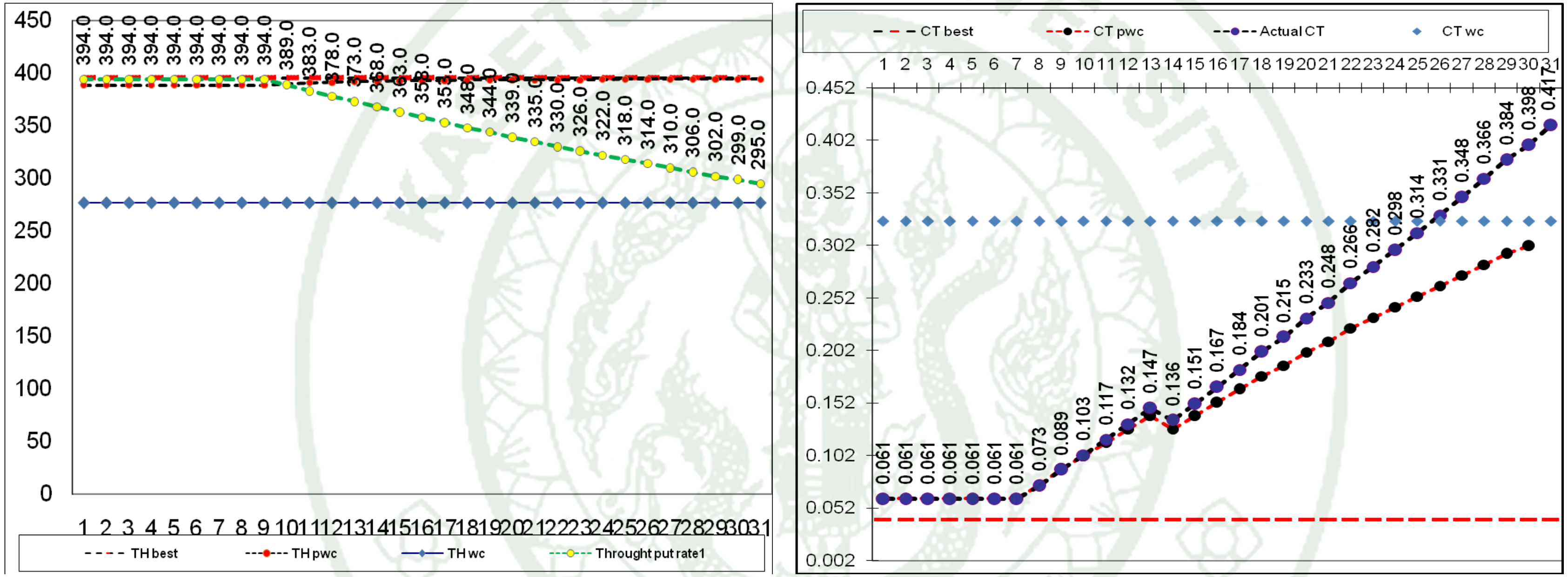


Cycle time

Appendix Figure 6 Machine line performance detection; on example 37

In this case; focusing on multiple product at machine 1, 2, 3

Condition only 4% yield drop for machine 1, 2 and 3 by ratio product at (40%, 50%, 60%)



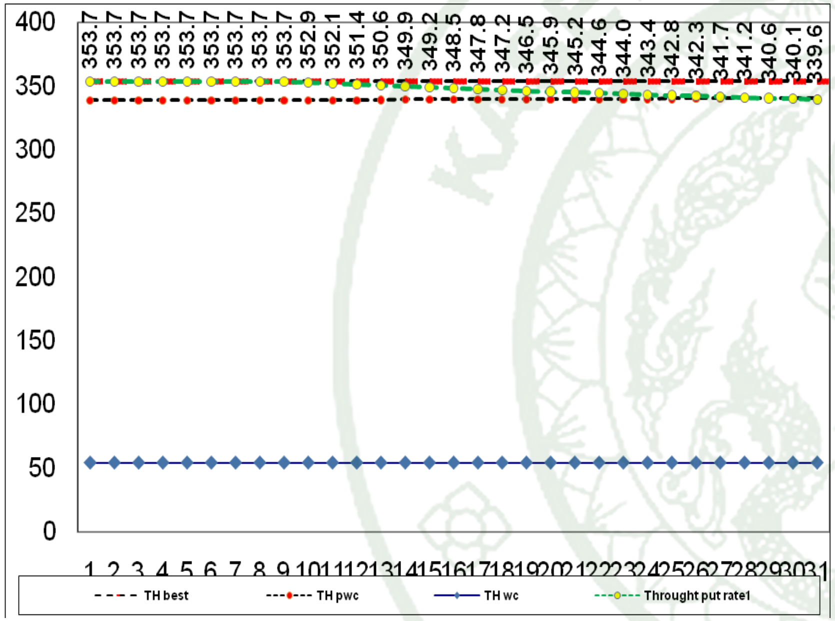
Throughput rate

Cycle time

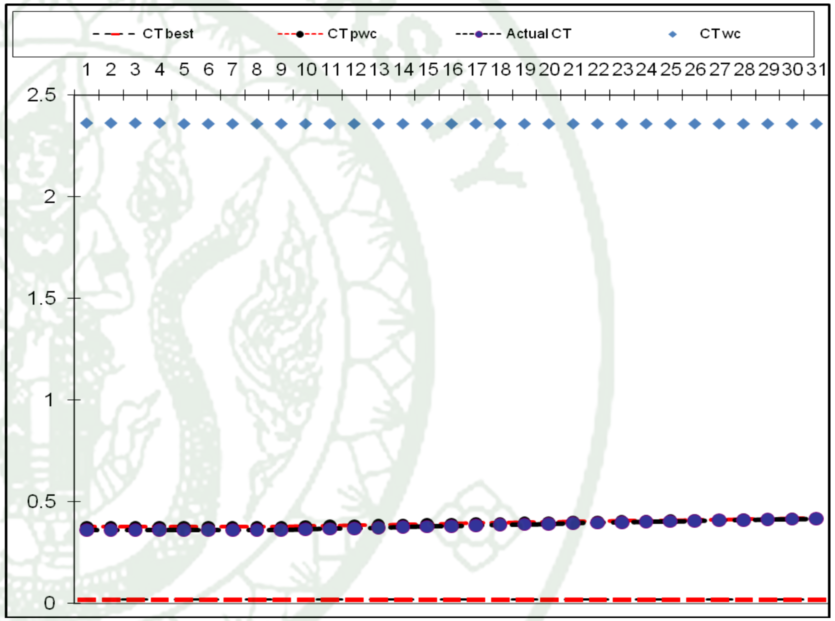
Appendix Figure 7 Product line performance detection; on example 51

In this case; focusing on multiple product at machine 1, 2, 3

Condition only 2% yield drop for machine 1, 2 and 3 by ratio product at (10%, 20%, 30%)



Throughput rate



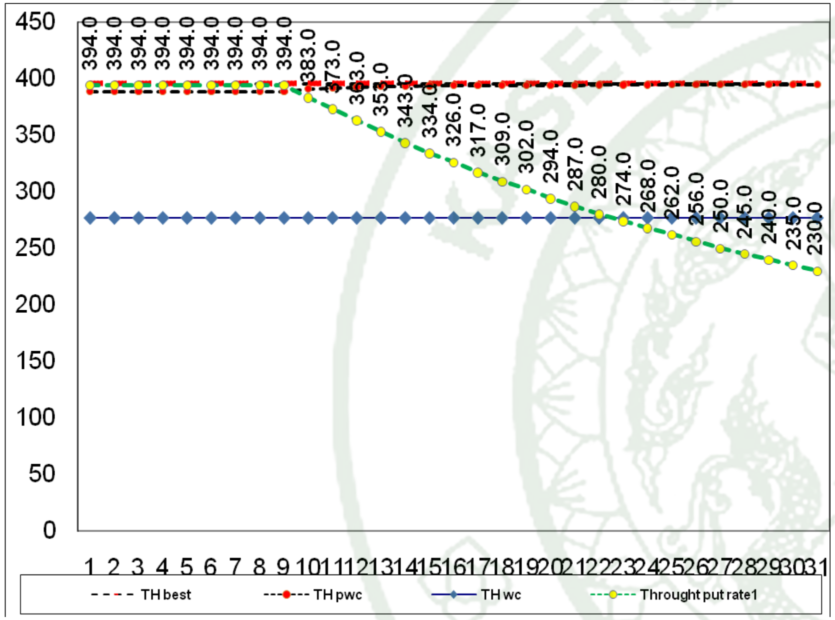
Cycle time

Appendix Figure 8 Machine line performance detection; on example 51

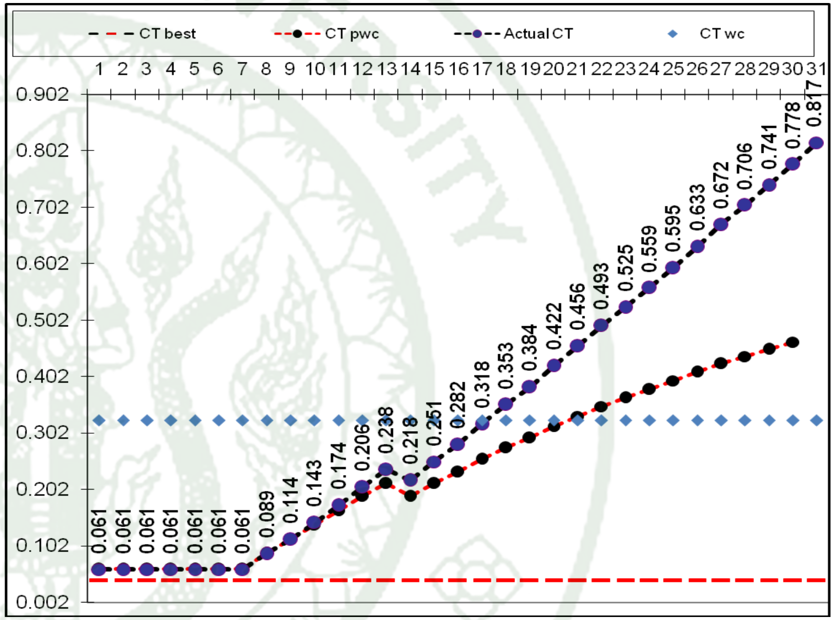
In this case; focusing on multiple product at machine 1, 2, 3

Condition only 2% yield drop for machine 1, 2 and 3 by ratio product at (10%, 20%, 30%)

Machine line performance > Original product performance



Throughput rate

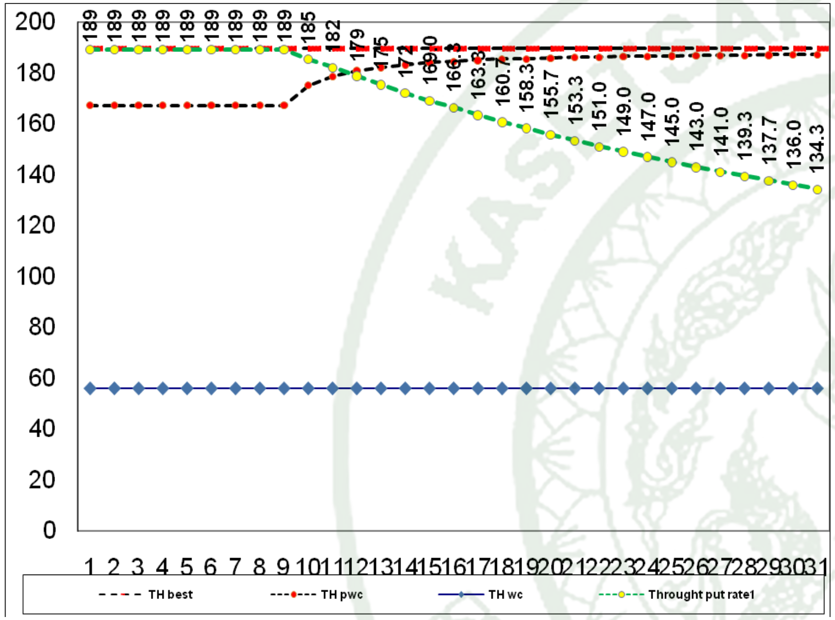


Cycle time

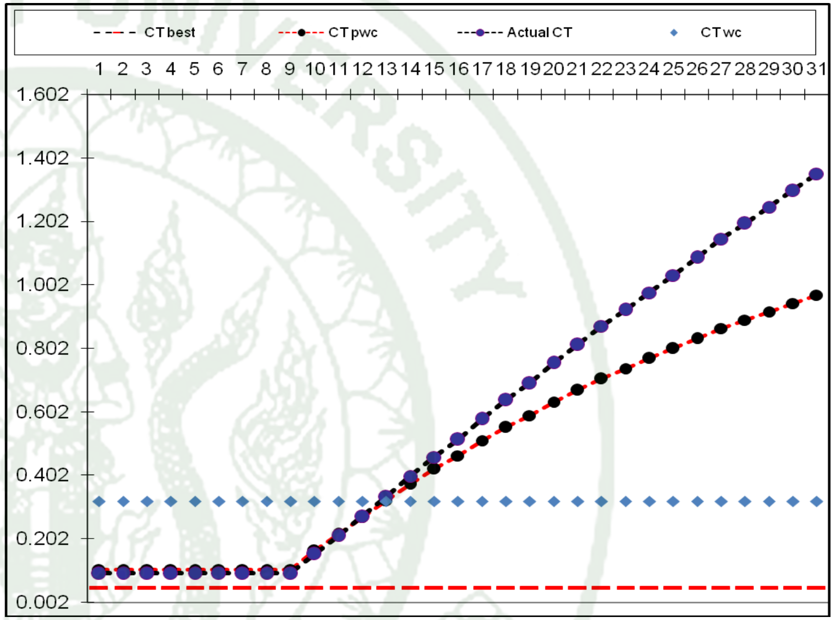
Appendix Figure 9 Machine line performance detection; on example 63

In this case; focusing on multiple product at machine 1, 2, 3

Condition only 4% yield drop for machine 1, 2 and 3 by ratio product at (10%, 20%, 30%)



Throughput rate



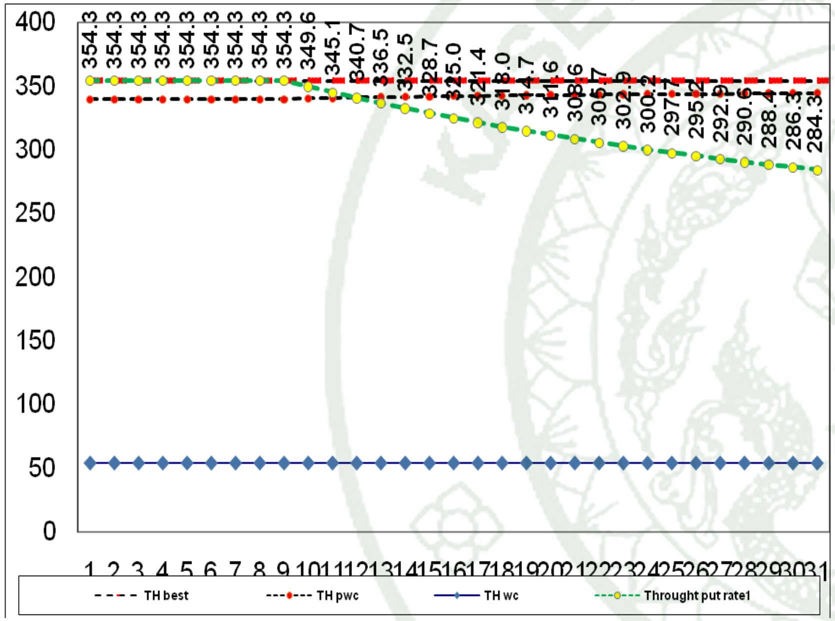
Cycle time

Appendix Figure 10 Product line performance detection; on example 63

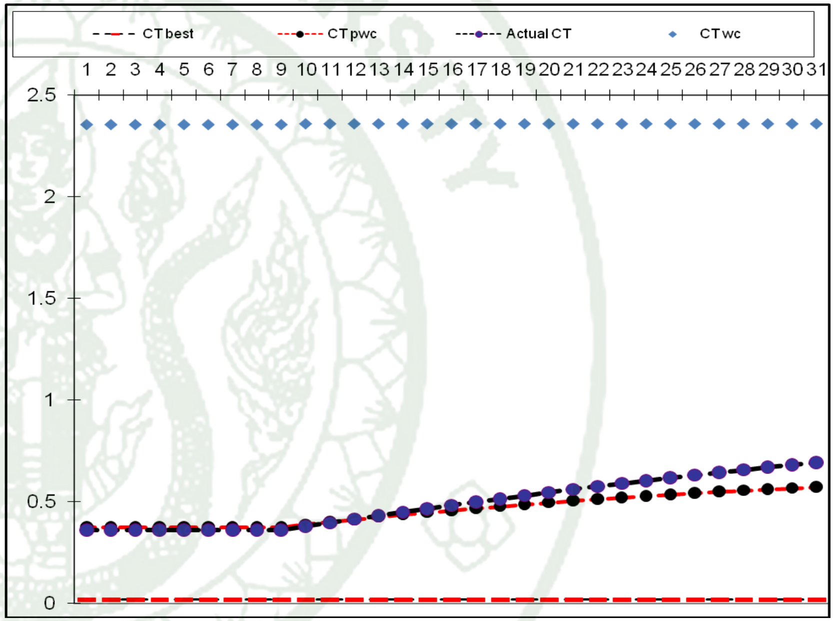
In this case; focusing on multiple product at machine 1, 2, 3

Condition only 4% yield drop for machine 1, 2 and 3 by ratio product at (10%, 20%, 30%)

Original line performance > Product line performance



Throughput rate

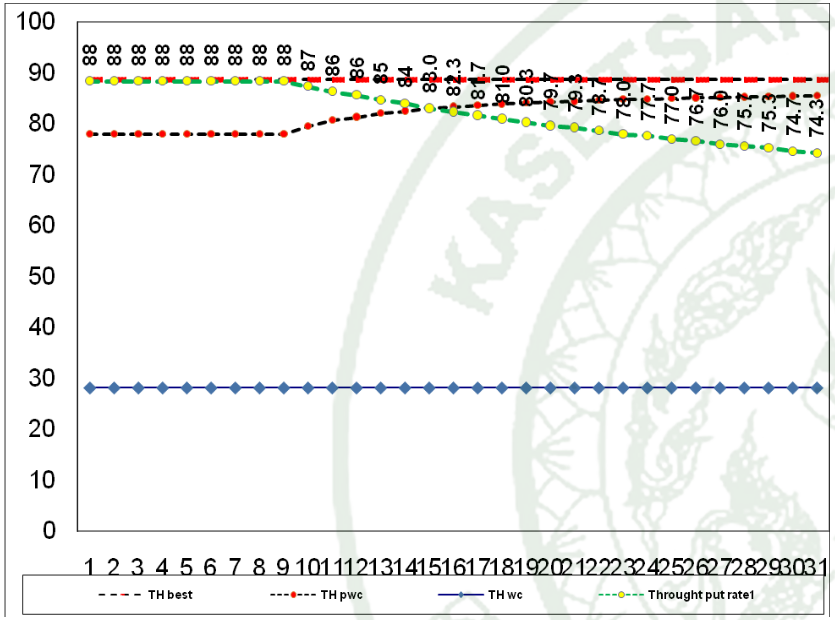


Cycle time

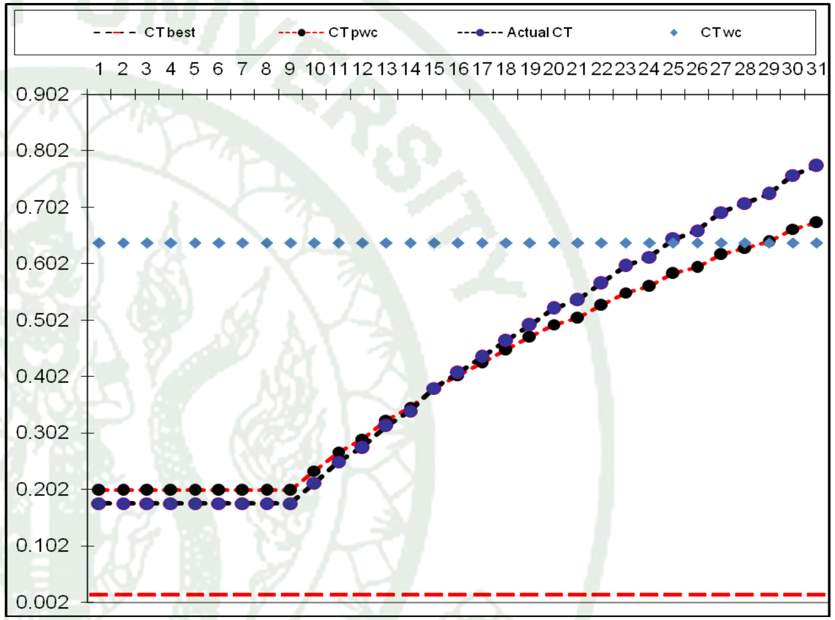
Appendix Figure 11 Original line performance detection; on example 47

In this case; focusing on multiple product at machine 1, 2, 3

Condition only 4% yield drop for machine 1, 2 and 3 by ratio product at (40%, 50%, 60%)



Throughput rate



Cycle time

Appendix Figure 12 Product line performance detection; on example 47

In this case; focusing on multiple product at machine 1, 2, 3

Condition only 4% yield drop for machine 1, 2 and 3 by ratio product at (40%, 50%, 60%)

CURRICULUM VITAE

NAME : Mr. Pakorn Jinorose

BIRTH DATE : June 25, 1984

BIRTH PLACE : Phayao, Thailand

EDUCATION :

YEAR	INSTITUTE	DEGREE/DIPLOM
2006	Naresuan University	B.Eng (Industrial Engineering)

POSITION/TITTLE : Logistics Engineer

WORK PLACE : Aisin Takaoka Foundry Bangpakong

SCHOLARSHIP/AWARDS : International Graduate Program in Industrial Engineering, Kasetsart University Scholarship 2011 - 2013