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Laboratory Performance Modeling using Petri Nets in National Standardization Agency in Indonesia

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Abstract
Service providers perform their service to seek customer loyalty, not excluding the product testing laboratory (PTL) as it provides the testing service under National Standardization Agency (NSA) in Indonesia. Early business process observation in one PTL found that the level of work-in-progress (WIP) in some testing job shops performed significantly higher than the others which requires a further operational study. Using workflow data from the PTL, this study modeled the first-come-first-serve (FCFS) as the current scheduling algorithm, proposed an alternative scheduling algorithm, and comparatively analyze the WIP performance through simulation using colored Petri nets (CPN) as business process modeling and simulation tools. The result of this study shows that the shortest flow of processing time (SFPT) algorithm as the alternative scheduling strategy can reduce the maximum WIP level in the laboratory. Although the SFPT scheduling strategy has a relatively small impact in the single item station, the alternative strategy decreases more than one-third of the total WIP in the most complex station in the laboratory.

Keywords: *Colored Petri Nets (CPN); Process Performance; Scheduling; Work-in-Progress (WIP)*

INTRODUCTION

In today's globalization, the national industrial products, services, and other commercialized commodities are challenged to assure their quality itself meets the international standard. In Indonesia, the National Standardization Agency (NSA) is the only governmental agency that assures global challenges related to the quality standards of products in the national markets and enhances the national competitive advantage. In doing so, NSA publishes a national certificate to which product/service meets the standard quality after passing the test that runs by three types of standardization laboratory; product testing laboratory, calibration laboratory, and medical laboratory. While all products/services that spread in the Indonesian market are voluntarily tested, NSA based on national considerations has the authority to decide on which products/services to be mandatorily tested by the laboratory because of the safe usage of the products/services themselves.

The legal framework in health and safety normally obligates all product manufacturers involved in the industry development. Before going to the market, some mandatory products have to meet a certain standard controlled under the product testing laboratory (PTL). PTL through its testing processes aims to assure the products that are available in Indonesia meet international safety standards. Some mandatory tested products have been decided categorically based on a certain level of risk and safety functions on their usage, such as helmets for motorcycle safety and industrial safety, LPG gas stove for cooking safety, etc. Under an appropriate standard management system, PTL operation aims to guide the social responsibility, minimize consumer risk and minimize potential legal consequences behind the usage of the manufactured product.

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From a business sustainability perspective, an effective and integrated system of network planning and management is required in response to reconstructing and evaluating the systemic view of the rational decisions and practical actions (Hassan et al., 2021). In doing so, some process modeling tools are developed and used by process managers to model and manage the business process operation (Mazzuto et al., 2012; Zuhaira & Ahmad, 2021). The modeling and analysis of the business process are also critical to identifying the current business process and understanding the contribution of new processes to the system (Casebolt et al., 2019).

The early observation is conducted to capture the process performance from 32 testing stations in the PTL by using the Colored Petri Net (CPN) tools to model and simulate the business process. The use of CPN tools allows the products/services providers to create a compact representation of states, actions, and events of the modeled system (Glas et al., 2016; Mukhlash et al., 2018). The early result shows that some stations have work-in-progress (WIP) higher than the others and the oven testing station has the highest WIP performance. The dominant use of some stations generates a higher level of WIP because they perform the testing methods for more product types than others. As a consequence, the other testing stations have to wait accordingly to perform which requires workflow evaluation of the current scheduling strategy (Glas et al., 2016)**.** By the use of CPN, the shortest flow processing time (SFPT) scheduling algorithm is developed in accordance to challenge the current first-come-first-served (FCFS) scheduling strategy to minimize maximum WIP in the complex stations.

In the context of process improvement, CPN tools have been used to model and simulate the project execution to describe concurrent activities and simulate the evolvement of processes (Pachpor et al., 2017). The advantage of using Petri net in a project is its dynamic simulation of a performance that can be visualized graphically over time. However, the representation of precedence relationships by using Petri nets becomes easier (Wang et al., 2018).

Scholars have studied the case of resource allocation using CPN tools because of its capabilities. Analysis of resources constrained processes with colored Petri nets (Hazra et al., 2018). Some studies aim to solve resource-constrained multiple project scheduling using a timed CPN (Jia & Kefan, 2015; Yu et al., 2009, 2020). Other studies aim to model resource management using a hierarchical CPN (Ji & Ou, 2021; L. L. Zhang & Rodrigues, 2013). The use of hierarchical timed CPN in this study is focused on the analytical approach of the scheduling priority concerning the early observation's results to minimize the maximum WIP in the most complex station. This study would help the PTL to put any cost constraints such as buying a new machine or to extend a new waiting area, aside.

The objective of this study is to analyze the WIP performance of each testing station in the PTL by comparing the current priority scheduling with the SFPT algorithm. This study used hierarchical timed CPN as the analytical tool to model and simulate the complex process operation captured from the PTL. As the limitation of this study, the model represents the testing process of 6 mandatory products to get the National Standard of Indonesia (SNI) certification in one PTL.

Historical data were used in this study collected from 1 January to 30 June 2018. The capacity of the system is assumed sufficient for all simulations.

LITERATURE REVIEW

Business Process Performance

The performance of a company is affected by the quality of its information systems (Dumas et al., 2018). As a result, business processes must be analyzed to identify any discrepancies between the planned and actual business processes (Zuhaira & Ahmad, 2021). The business process can be improved based on the findings of this analysis. The service process is the most important aspect of laboratory service in this study. In reality, there are many differences between the actual and planned business processes, which should be investigated, especially if the business process can be improved using proper analytical approaches. (Mukhlash et al., 2018).

Work-in-Progress (WIP)

Many researchers have investigated the problem of production line control under uncertain machine behavior and proposed various methodologies for increasing throughput while minimizing (WIP) (Bowles et al., 2018; Reyes Levalle et al., 2013; L. L. Zhang & Rodrigues, 2013). Value-added WIP and the costs associated with it have been compromised to reduce average WIP. The term value-added WIP refers to the value of WIP or the cost associated with the value that adds to the product during the production process as labor, material, equipment time, energy, and other resources are added. As a result, it is possible to reduce this cost if WIP queues could be reduced down the production process by containing more and more WIP inventory upstream of the production process (Taylor et al., 2013). Industries have consistently worked to reduce WIP because it incurs inventory costs. However, the workstation with the lowest capacity (the bottleneck) frequently governs the production rate of the entire manufacturing line (Goldratt & Cox, 2004). But to achieve a high throughput rate while maintaining a reasonable cycle time and WIP, it is critical to scrutinize the utilization of the bottleneck workstation.

Shortest Flow Processing Time (SFPT)

The priority dispatching rule is commonly used in real-world job-shop scheduling problems (JSPP) (Zhang et al., 2020). The JSPP problem is a well-known combinatorial optimization problem in computer science and operations research, and it is used in a variety of industries, including manufacturing. Given the inherent complexities of the challenge of allocating resources in the job-shop, proper scheduling (Pinedo, 2012, 2016) and dispatching strategies (Blazewicz et al., 2019; Shi et al., 2019) are frequently used to optimize productivity (Zanchettin, 2022). In project-oriented production, a project planning tool is used to schedule production activities. In practice, heuristic scheduling rules such as Shortest Processing Time (SPT) or Longest Processing Time (LPT) are commonly used. Good rules are derived from expert knowledge, which does not guarantee the best solutions in various situations. They can also be created using system simulation models. Heuristic dispatching rules have the interesting property of being easily usable in conjunction with production models derived using the Petri-net modeling framework (Gradišar & Mušič, 2007). In this study, the SPT is used, and the total processing time is referring the total time of the product flow in the testing procedure and simply used the terms of shortest flow processing time (SFPT).

Colored Petri Nets Tools

The IT industry is crucial in assisting enterprise executives and BPM consultants in redesigning, improving, and managing business processes (Davenport, 2013). Various software systems and support tools have been designed and developed and are further regarded as BPM enablers (Luo et al., 2009; Zuhaira & Ahmad, 2021). A business process management system (BPMS) or tool integrates software system capabilities for workflow management, modeling, redesigning, reengineering, process analysis, business intelligence, monitoring and measuring, improvement, process enactment, and enterprise application integration. A BPM tool is essentially a software system that supports a BPM life cycle, its methods, and techniques for redesigning and improving business processes in an efficient and timely manner (Hildebrandt et al., 2019; Mazzuto et al., 2012; Shaw et al., 2007).

The operational business process is a complex system that necessitates the modeling of business processes to gain a better understanding. Colored Petri Nets (CPN) is a model for describing complex manufacturing and logistics processes such as transportation, inventory, order processing, warehousing, distribution, and production. CPN extends the classical PN formalism with data, time, and hierarchy. This extension makes it possible to model a complex system in detail. CPN is a powerful toolset that supports process design and analysis. Some features of CPN can be used for performance analysis such as comparing design alternatives using simulation. Time plays an important role in capturing the duration of an activity or process. The duration might be deterministic or stochastic. Time is also important in performance analysis as an indicator to predict the flow time, service levels, or other performance parameters. Timed Petri net (TPN) is one such tool that can develop a design of a methodology for managing an operation as well as to evaluate the performance in the network regarding the overall operating system and the specific stationary system (Mazzuto et al., 2012). By the use of this application, the manager will be able to pursue the coordinated action of certain strategic levers (Yee, 2005).

Timed Petri nets can show how the processes would react to changes in one or more of its constituent parameters. A simulation tool inside PN makes it possible to explain the dynamics, variables, and parameters that characterize the process. As a challenge, the use of PN in industrial applications can become very complex and difficult to handle (Mazzuto et al., 2012). In some cases, a model tends to become large because it might capture the number of interactions. The hierarchy concept in hierarchical timed Petri net (HTPN) is needed to deal with this type of complexity. HTPN approach helps the modeler to structure a model as well as to communicate the design and analysis (Van Der Aalst et al., 2013).

The early observation leads this study to focus the analysis on the WIP performance and the scheduling priority. By using the testing process data from PTL under NSA, this study concerned with the application of the HTPN tool in analyzing the WIP performance behavior of the station-based system by comparing the FCFS as the current scheduling priority and the SFPT as the proposed scheduling solution. This study aims to model and analyze the performance of WIP in the product testing system, because maintaining the level of WIP is important to control the inventory level in the stations, especially when the complexity level of PTL's stations is different.

RESEARCH METHOD

Problem Description

The scoop will be limited to the six mandatory products to be tested in the product testing laboratory (PTL), especially for the technical products concerning the risk of product usage. From the early observation, the WIP performance was found inefficient in that the majority of stations need to wait for the complex operation held in a few stations to be tested. To cover this issue, this study analytically compares two different scheduling methods, the current FCFS and the SFPT comparative approach using business process modeling and simulation methodology. To study this case, the testing procedure and the item orders in this system will be modeled using hierarchical timed CPN.

Model Development

Conceptually, the hierarchical model of timed CPN is constructed to capture the full testing procedural system and the hierarchy consists of two levels. The first level is the whole view of the testing workflow of the six mandatory products in the PTL. Table 1 below is the list of mandatory products tested in the PTL. And the second level of the hierarchy is focusing the view on the item workflow in the two categories of the station, the single arrival station, and the multi arrival station. Both levels are connected, the first level is to compute the PTL's workflow, and the second level is to study the priority comparison between FCFS and SFPT algorithms.

Table 1. List of mandatory products tested in PTL

No	Items	Processing time (h)	Item symbol
1	Half-face helmet	15	A
2	Full-face helmet	16	B
3	Industrial helmet	29	C
4	Inner tube for motorcycle	40	D
5	PVC pipes	67	E
6	Hose – LPG gas stove	120	F

The first hierarchy is captured by the full network model in the PTL and is described in Figures 1a and 1b. Both figures map the testing workflow of six mandatory products, not including the scheduling analysis. These figures aim to draw that some stations look busier than the others.

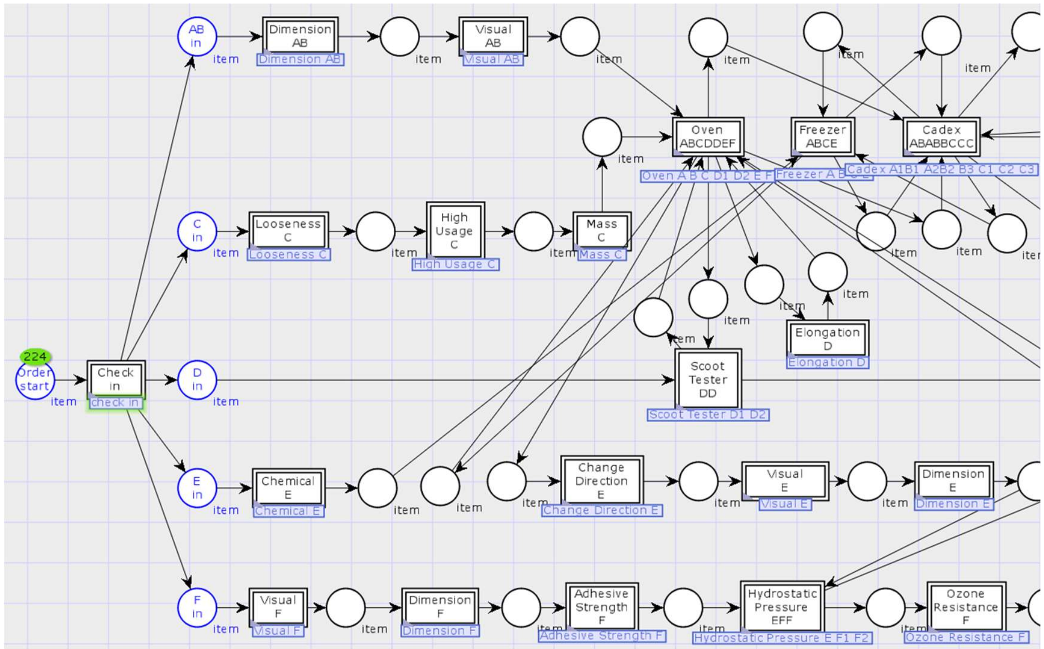

Figure 1a. The full network model of PTL

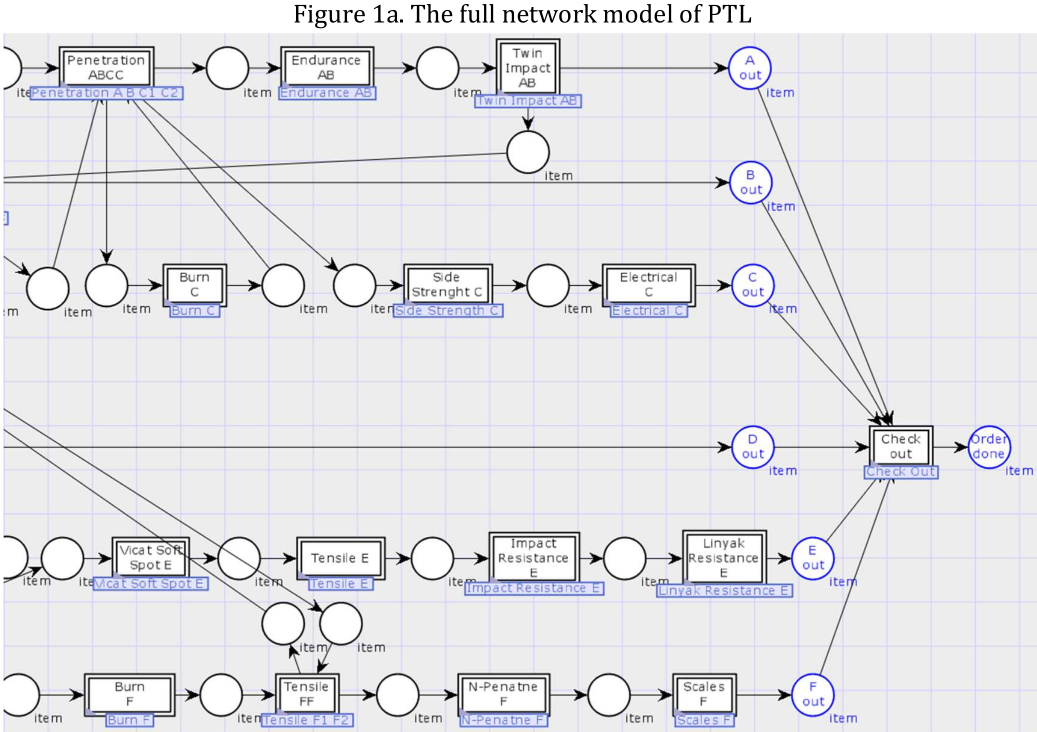

Figure 1b. The full network model of PTL (cont.)

The second level of hierarchy captured the specific process inside each station in PTL. Tables 2a and b below are the lists of the single- and the multi-testing stations in the PTL. The similarity of the single arrival station is the workstation only waits for one single item arrival to be tested. In contrast, the similarity of the multi-arrivals station is the workstation test more than one item, and some items are repeatedly arrived in the station to be retested.

Table 2a. The single arrival stations

NO	SINGLE ARRIVAL STATIONS	ITEM
1	Looseness	C
2	High Usage	C
3	Burn C	C
4	Side Strength	C
5	Electricity	C
6	Elongation	D
7	Chemical	E
8	Visual E	E
9	Dimension E	E
10	Vicat Soft Spot	E
11	Tensile UTM	E
12	Impact Resistance	E
13	Linyak Resistance	E
14	Directional Change	E
15	Visual F	F
16	Visual F	F
17	Adhesive Strength	F
18	Ozone Resistance	F
19	Burn F	F
20	N-Pentane	F
21	Scales	F

Table 2b. The multi-arrival stations

NO	MULTI ARRIVAL STATION	ITEM	TOTAL ITEM
1	Dimension	A, B	2
2	Visual	A, B	2
3	Endurance	A, B	2
4	Twin Impact	A, B	2
5	Scoot	D1, D2	2
6	Tensile 30Kgf	F1, F2	2
7	Hydrostatic	F1, F2, E	3
8	Freezer	A, B, C, E	4
9	Penetration	A, B, C1, C2	4
10	Cadex	A1, A2, B1, B2, B3, C1, C2	7
11	Oven	A, B, C, D1, D2, E, F	7

The comparative scheduling strategy and the workflow model in all the single arrival testing stations are modeled by CPN as the same as captured in figures2 (a and b). The figures capture product C in the workstation that tests the looseness of the product. These figures aim to draw the comparative scheduling algorithms between the current FCFS and the alternative SFPT strategies.

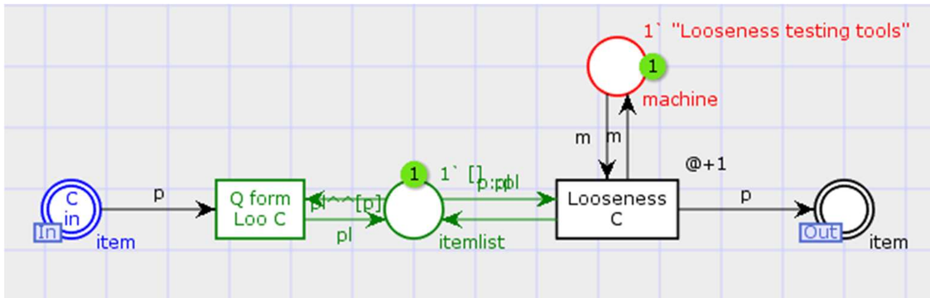

Figure 2a. The current FCFS process model in the single arrival testing station

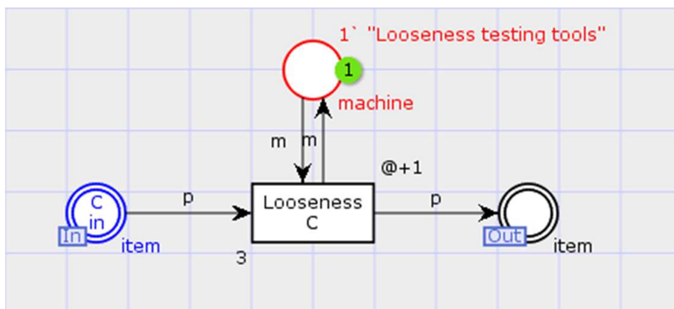

Figure 2b. The alternative SFPT process model of the single arrival testing station

CPN Simulation

The simulation tools in CPN captured the product testing process in each station which starts from the incoming item, queueing area, item processing, and resource that are used in the station. The station will be named by the resource or machine operated in the station. In doing so, the log file that captured the process record in the PTL is required to evaluate WIP performance for each station.

FINDINGS AND DISCUSSION

WIP Performance Table in Multi-Arrival Stations (the second level of the hierarchical CPN model)

After applying the SFPT priority using CPN simulation tools, both the average WIP and the max WIP are changed in several testing station. Totally, in multi arrival stations, the average value of WIP in 5 stations and the maximum value WIP in 3 stations are affected by the implementation of SFPT priority. The table 3 below shows the overview of the WIP performance which comparing the FCFS and SFPT priority. The table also sum up the WIP performance in the total 11 multi arrival stations in the system. From the table, the highest gap is showed in the oven station which reduce 35% of average value of WIP and 36 value of maximum WIP. As the most complex testing station in the system, the oven testing station have the highest impact by the implementation of SFPT priority in the PTL.

TABLE 3. THE OVERVIEW OF WIP PERFORMANCE IN MULTI-ARRIVAL STATIONS

CAT.	No	Testing Stations	Total Served Item	Minimized Average WIP (%)			Minimized Max WIP (item)		
				FCFS	SFPT	**GAP**	FCFS	SFPT	**GAP**
MULTI ARRIVAL STATION	1	Dimension (item A and B)	130	1	1	**0%**	1	1	**0**
	2	Visual (item A and B)	130	1	1	**0%**	1	1	**0**
	3	Endurance	130	1	1	**0%**	1	1	**0**
	4	Twin Impact	130	1	1	**0%**	1	1	**0**
	5	Scoot	112	6.6	6.39	**3%**	35	35	**0**
	6	Tensile (30kgf)	18	1	1	**0%**	1	1	**0**
	7	Hydrostatic	43	1.88	1.95	**-4%**	5	6	**-1**
	8	Freezer	159	1.72	1.47	**15%**	7	4	**3**
	9	Penetration	138	1	1	**0%**	1	1	**0**
	10	Cadex	304	1.05	1	**5%**	2	2	**0**
	11	Oven	280	40.1	26.1	**35%**	97	61	**36**

Based on the gap between both scheduling priorities, the WIP performance of Hydrostatics Pressure testing station can be seen in figure 3 below. The maximum value of WIP is not significantly improved when using SFPT priority. The reason is because the item quantity and its flows of sequences are similar whether they use the SFPT or FCFS priorities, As the WIP calculation, each arrival item will bring one (1) point of WIP to the station and each departure item will bring minus one (-1) point of WIP.

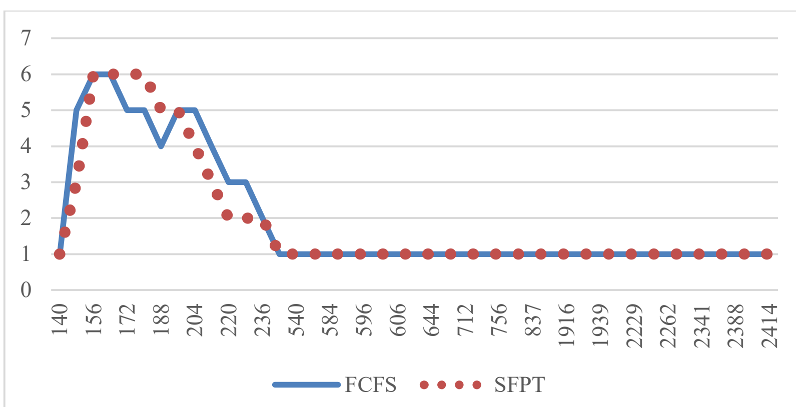

Figure 3. The WIP Performance of the Hydrostatic Pressure testing station

In this Freezer testing station, the maximum level of WIP is reduced 3 items, from 7 items in the current FCFS priority to 4 items when using SFPT priority using the same WIP calculation. The figure 4 shows the WIP performance in the Freezer testing station.

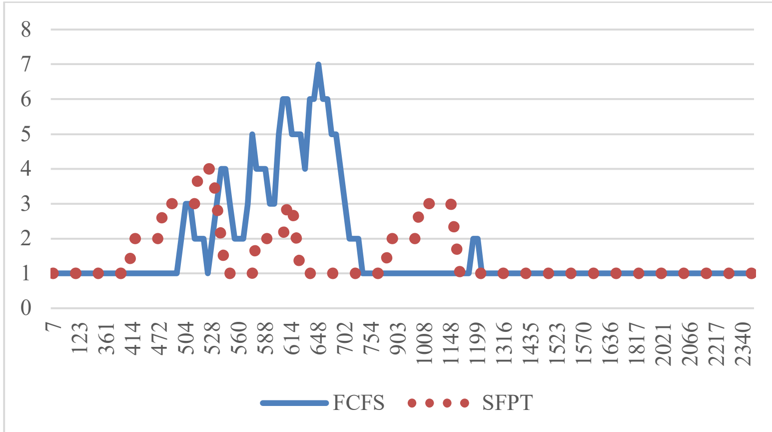

Figure 4. The WIP Performance of the Freezer testing station

The most impacted station by the alternative priority is the Oven testing station. The maximum WIP is 97 for FCFS priority and 61 for SFPT priority as described in figure 5 below. The level of WIP is reduced 36 items and the SFPT has the biggest impact to this station using the same WIP calculation. The reason is because the oven serves all the item with more variety of processing time. This station is the most complex stations over all the stations because it has to serve 7 items with the diverse processing time ranging from 4 to 24 for hours.

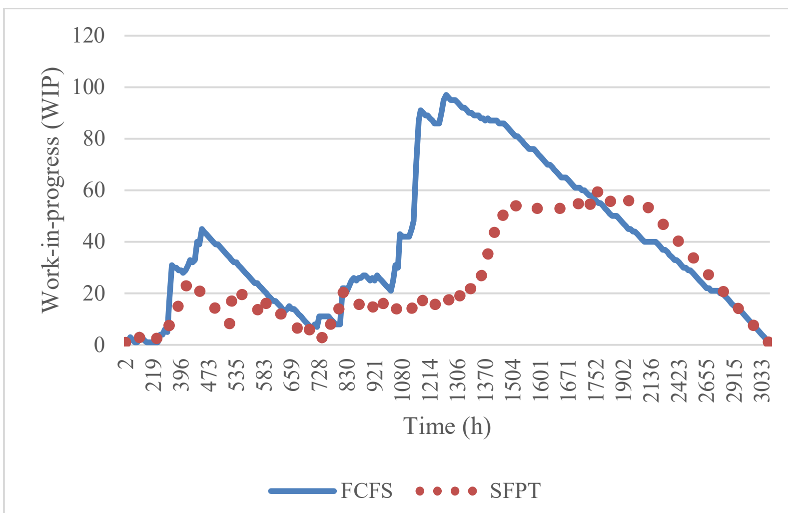

Figure 5. The WIP Performance of the Oven testing station

WIP Performance of the PTL (as the first level of the hierarchical CPN model)

The WIP performance of the system is presented in the next figure. The calculation is based on the item arrival to and item departure from the system. The data used for the WIP performance of the system is 224 items on arrival and 224 items on departure. For the WIP calculation, each arrival item will bring one (1) point of WIP to the system and each departure item will bring minus one (-1) point of WIP.

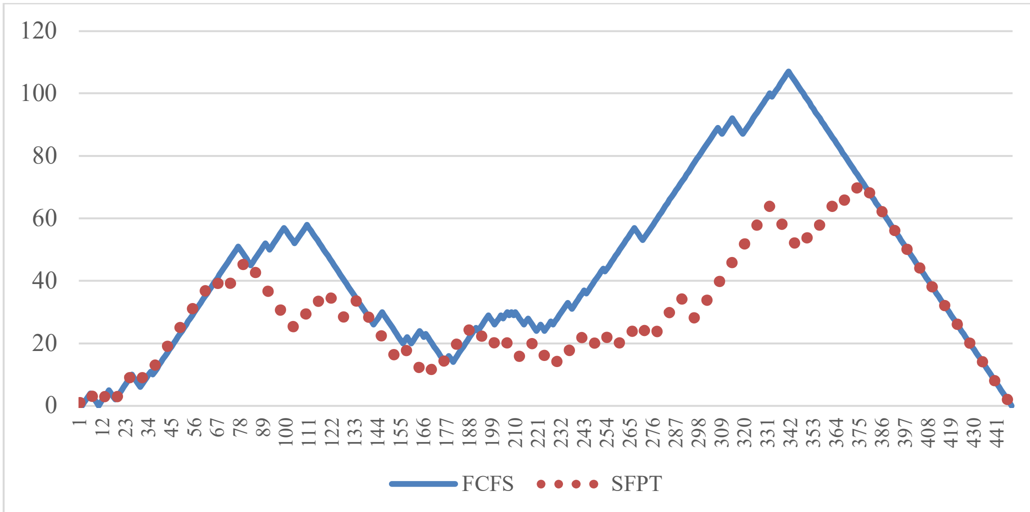

Figure 6. The WIP performance of the product testing laboratory (PTL)

Figure 6 describes the comparison of WIP performance between two scheduling priorities implemented in the PTL. The WIP performance of the current scheduling priority (FCFS) is represented by the blue line. The WIP performance of the alternative scheduling priority (SFPT) is represented by red dots. The maximum WIP on the FCFS priority is 107 and for the SFPT priority is 71. The gap between the maximum item from each priority is 36 items. This simulation result shows that the implementation of SFPT algorithm as the alternative scheduling priority is effective to reduce the maximum WIP of current scheduling practice in the PTL.

CONCLUSION

This study has shown that a particular testing workflow can be modeled and simulated using hierarchical timed colored Petri net (CPN). A particular performance also can be comparatively evaluated using the log file extracted form operational data in the product testing laboratory (PTL). The result of the study also shown the expected process performance based on particular business operations issue.

Focusing on simulation result, this study aims to describe that the priority rule in firing the shortest flow processing time (SFPT) can reduce the average work-in-progress (WIP) in the most complex stations. SFPT priority have a relatively small impact on the WIP in the singular item processing. The biggest impact of SFPT priority on the WIP performance can be seen in the oven testing station because the WIP is decreased as much as 35% on average value and 36 items on maximum value. In the overall system view, the maximum WIP on the current FCFS priority is 107 items, while the maximum WIP on the alternative SFPT priority is decreased to 71 items, and the gap of WIP between both scheduling priorities is 36 items.

As the recommendation, this study suggest the process manager in the PTL to implement SFPT scheduling priority due to the gap in the WIP performance. Even though the implementation of SFPT policy is not affect all the station significantly, this policy is significantly affecting the most complex station in the system. In aggregate level, this policy will also significantly affect the WIP performance of the PTL.

The contribution of this study can be seen as the effective use of business process modeling and simulation tools can intervene on some process management issue especially for the PTL under National Standardization Agency (NSA) in Indonesia. From the other side, the application of SFPT priority would gain some concern about the priority of customers products in PTL's operation.

LIMITATIONS & FURTHER RESEARCH

As the limitations, this study focuses on the performance level of work-in-progress (WIP) as a process indicator using hierarchical CPN in one mandatory product testing laboratory (PTL) under national standardization agency (NSA) in Indonesia. The further analysis might be to extending the performance analysis to some degree under the production or financial managerial areas such as relating the WIP to production waste or inventory cost.

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