A Simulation Model of a Pull Production System for a Flexible PCB Assembly Line

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Abstract

We consider the production system of one model of flexible printed circuits (FPCs) that has the highest production volume. Currently, it operates under a push system, which has flow time higher than the target and high work in process (WIP). The management wants to see if the Kanban system can solve these issues. We develop simulation models of the current push system and the proposed Kanban system to determine the optimal lot size that yields low flow times and low WIP. To combine both measures, we consider the production cost. The optimal lot size is found to be 25 sheets (1 sheet consists of 10 FPCs). At this lot size, the flow time to produce 16,000 FPCs reduces from 59,800 seconds to 52,600 ± 10.10 seconds (-12%), and the WIP level decreases from 409 pieces to 156 pieces (-62%).

Keywords: Kanban System; Stochastic Discrete-Event Simulation; Flexible Printed Circuit Board

1. Introduction

Electronics business is dynamic, complex, highly competitive and continually changing due to advances in technology. Thus, manufacturers need to readily accommodate these modifications. In this study, we focus on the consumer and communication (C&C) product section of a large FCB assembly plant in Thailand. FPCs are used in hard disk drives, mobile phones and digital cameras.

We consider the production of model N that has the highest production volume and is currently produced under the push production control system. Currently, it does not satisfy the output target; the production targets are met only on 5 days out of 21 production days because of high production flow time. The average flow time to produce 16,000 pieces is 59,800 ± 29.30 seconds compared to the target of 54,000 secs (9.7% higher).

Spearman and Zazanis [1] compare push and pull systems. To achieve the same throughput, pull systems with fixed levels of WIP result in lower average WIP (and hence cycle time) than push systems do. In addition, pull systems are more robust in term of setting operating parameters. In push systems, if demand is underestimated, shortages occur; whereas, if production plans overestimate demand, inventory costs increase. A major breakdown occurs if jobs are released to the shop floor at a rate that exceeds capacity. In such cases, output will not be able to increase beyond resource capacity, but WIP levels continues to grow until the mistake is noticed, and corrective actions are taken. The resulting congestion may actually reduce throughput. On the other hand, pull systems automatically match demand, given that the production quota and the number of Kanbans can be adjusted as conditions change.

The optimal level of WIP and flow time are critical for a production system since it represents money saving in the production [2]. Pull production systems has many types of control techniques to achieve these goals, such as Kanban (further explained in the literature review section), constant work in process and the hybrid of these two approaches. Implementation methods should be carefully selected according to the system on hand.

We develop a simulation model of the Kanban manufacturing system for our FCB assembly to determine a good lot size or the production quantity. Simulation is widely used to improve business processes and work flows because it can perform what-if analysis to assess the performance of each alternative [3].

This paper is organized as follows: Section 2 provides a short overview of the Kanban system. The FCB production process is discussed in Section 3. We explain our simulation models and experiments in Section 4. The simulation results are shown in Section 5. Section 6 concludes our paper.

2. Kanban Manufacturing System ([4], [5])

In general, the pull system matches order releases to current customer demand. By limiting WIP, the production rate and flow time remain relatively constant. Pull systems can be further divided by two control techniques: Kanban systems and the constant WIP. In this paper, we will only discuss about Kanban systems.

Kanbans offer one common approach to production authorization in pull systems. Any Kanban not attached to a full container of parts authorizes production. The key decision variables for system control are the number of units authorized per Kanban and the number of Kanbans kept in the system for each part. The total number of units of each part type authorized should be set equal to the replenishment lead-time demand plus some safety stock. The optimal safety factor can be determined by applying a probabilistic inventory control model which is different according to each company policy. The implied cost of a shortage can be identified and verified for logic. The utilization of the workstations, container processing time distribution, and inter-arrival time distribution for Kanbans all determine the number of parts moving through a Kanban system and its inventory levels. The variability of lead-time demand is the dominant factor in specifying the safety stock.

The Kanban system operates without high-level coordination. The control parameters for the system are number of Kanbans for each part type and production quantity. The production line that we consider is dedicated to only one part type. We set the number of Kanbans to one because a curing step in the production is a batch process where setup time is significant. In this study, we use a simulation model to experiment how the production quantity, which will be called a lot size, affect the flowtime and WIP.

3. The FCB Assembly Process

Figure 4 shows the process flow of Model N that consists of 19 processes. The production starts as sheets (1 sheet of FPC contains 10 pieces of FPCs) at 1st piercing process, and they are separated into 10 at the blanking process. The first piercing process uses a piercing die to form a rough product outline of the FPCs. The stiffener pretacking process, temporarily attaches a stiffener (reinforced material) to increase the FPC strength. Laminating process uses vacuum to press stiffeners onto FPCs for more bonding force. In the curing process, FPCs are baked in an oven to complete bonding between stiffeners and FPCs.

We have many steps of piercing processes because of the limitation of piercing dies. In the 1st PSA pretacking process, pressure setting adhesive (PSA) is attached on FPCs to be used in a customer's process. In the 2nd piercing process, a piercing die is used form more obvious outline of FPCs. In the 3rd piercing process, another piercing die forms additional outline of FPCs.

In the 1st electrical checking process, the piercing misalignment of FPCs is inspected. In the punching inspection process, the abnormal appearance of FPCs is checked, and no-go ones are separated as scraps. In the FPC setting process, FPCs are set on a fixture to be processed in the next process. Solder printing process prints solder on the FPCs according to the design position. In the surface mounting process, electronic devices, such as resistors and connectors, are placed into the solder printing position. The reflow process uses heat to melt the solder and to make the electronic devices permanently attached on FPCs. In the assembly inspection process, FPCs are inspected to check if electronic device are properly attached.

In the 2nd PSA pretacking process, the pressure setting adhesives are attached on FPCs to be used in the customer processes. In the blanking process, FPCs are separated into individual pieces with a blanking die. In the 2nd electrical checking process, an electrical principal is employed to check the circuit and electronic devices. In the final inspection process, FPCs are inspected for abnormal appearance. If FPCs fail the inspection, they are separated into scraps. Scraping process, no-go FPCs from the production are destroyed or distilled to harvest some useful materials for recycling.

4. Simulation Models

We explain our simulation models in Section 4.1, validation steps in Section 4.2, and experimental setups in Section 4.3.

4.1 Input Models

We model the existing push system on Arena (Rockwell Software Inc. See [6] for overview) as shown in Figure 5. An entity is one sheet of 10 FPCs. The production starts at sheet level (1 sheet of FPC contains 10 pieces of FPCs) at the 1st piercing process, and they are separated into 10 at the blanking process. For the simulation model of current system, the baking quantity at oven cure operation is 1600 pieces. Input models of each process and associated resources are shown in Table 1.

4.2 Model Validation

We use the two-sample t-test to compare the flow times averaged from empirical data with that from the simulation model. We found the p-value of 0.335. It means that the average flow time of the simulation model is not statistically different from the actual data system at 95% confidence level; therefore, our simulation model can adequately represent the current system.

This simulation model is then modified to accommodate the proposed Kanban system by using the Hold module in Arena to control WIP between each process and to make the model work as the pull system.

We also perform a sensitivity analysis to check how our analysis changes when important input parameters change, e.g., operator's wage, electricity charges and raw material prices. Due to space limitation of this paper, the results are not shown here but can be found in [7].

4.3 Experimental Setup

We estimate the system KPIs such as flow time, WIP and production expense. Flow time is defined as the duration that each entity spends in the system. It is the time since the job is released into the system until it departs. WIP is the average amount of work in process in the system. The production cost includes operator wages, electricity charges and cost of opportunity loss for WIP. The lot size is chosen to minimize the production cost (Equation (1)). We try 30 different lot sizes ranging from 1 sheet to 1600 sheets. For each lot size, we perform 30 replications, where one replication is defined as production of 16,000 FPC pieces, i.e., one production day.

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Production expense = [(Operator Wage + Electricity charges) * Flow Time] + [Material Price*(1 + Interest Rate/day)* WIP]
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(1)

where `Operator Wage` is 0.069 Baht/second/line, `Average Electrical Fee` = 0.263 Baht/second, `Material Price` 20.00 Baht/piece, and `Interest Rate` is 0.500%/year.

5. Simulation Results

In this section, we present simulation results for each KPI.

5.1 Flow Time

Figure 1 shows flow times at different production lot sizes. The flow time is minimized at the production lot size of 160 sheets, where the flow time is approximately 45,900 ± 10.10 seconds which is less than the current flow time of 59,800 seconds in the push system (13,900 second less or 23.24 % reduction).

5.2 Work in Process (WIP)

As expected, WIP is minimized at production lot size of 1 sheet (Figure 2); the WIP is 14.4 pieces which is less than the current WIP of 409 pieces in the push system. However, in practice, we cannot implement the lot size of 1 sheet. With the lot size of 160 sheets which yield the minimum flow time, WIP is equal to 772 pieces which is more than the WIP of the push system (363 pieces higher or 89% increase). We also observe that WIP stabilizes when the lot size goes above to 400 sheets.

If we consider both flow time and WIP simultaneously, we cannot select the production lot size because they are conflicting objectives. We should have one more KPI that combine both KPIs. The production expense helps us to select a good production lot size that minimizes the production expense.

5.3 Production Cost

From Figure 3, the production cost is minimized at a lot size of 25 sheets. The total cost is 23,873 Baht which is less than that for the current system of 31,775 Baht.

6. Conclusion

We model the proposed Kanban system to determine a good production lot size for the FCB assembly line that produces a single product model. We consider flow time, WIP and production cost. Our proposed lot size is 25 sheets, resulting in the minimum production cost of 23,873 Baht to produce 16,000 FPCs. This Kanban system can decrease both production flow time and WIP level comparing to the current push system. The flow time is reduced from 59,800 seconds to 52,600 seconds (12% reduction) which meets the management target. Moreover, the WIP level is reduced from 409 pieces to 156 pieces (62% reduction). A more complete details of this paper can be found in [7].

Acknowledgement

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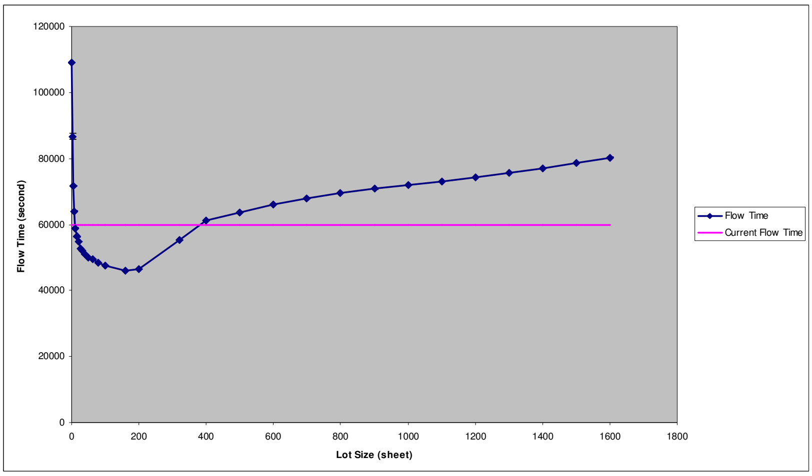

Figure 1: Flow time when the production lot sizes are varied.

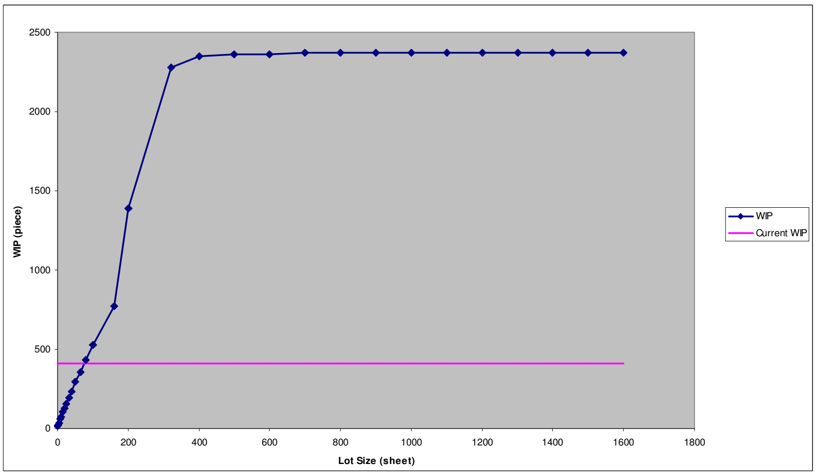

Figure 2: WIP when the production lot sizes are varied.

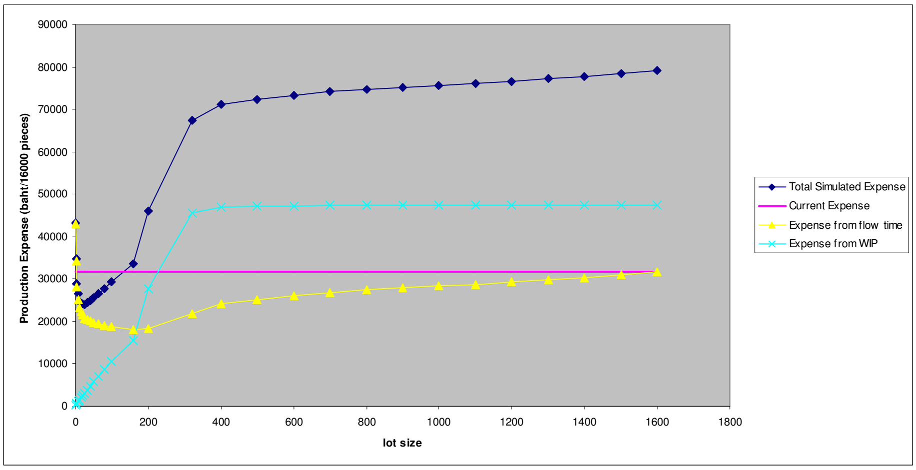

Figure 3: Production cost when the production lot sizes are varied.

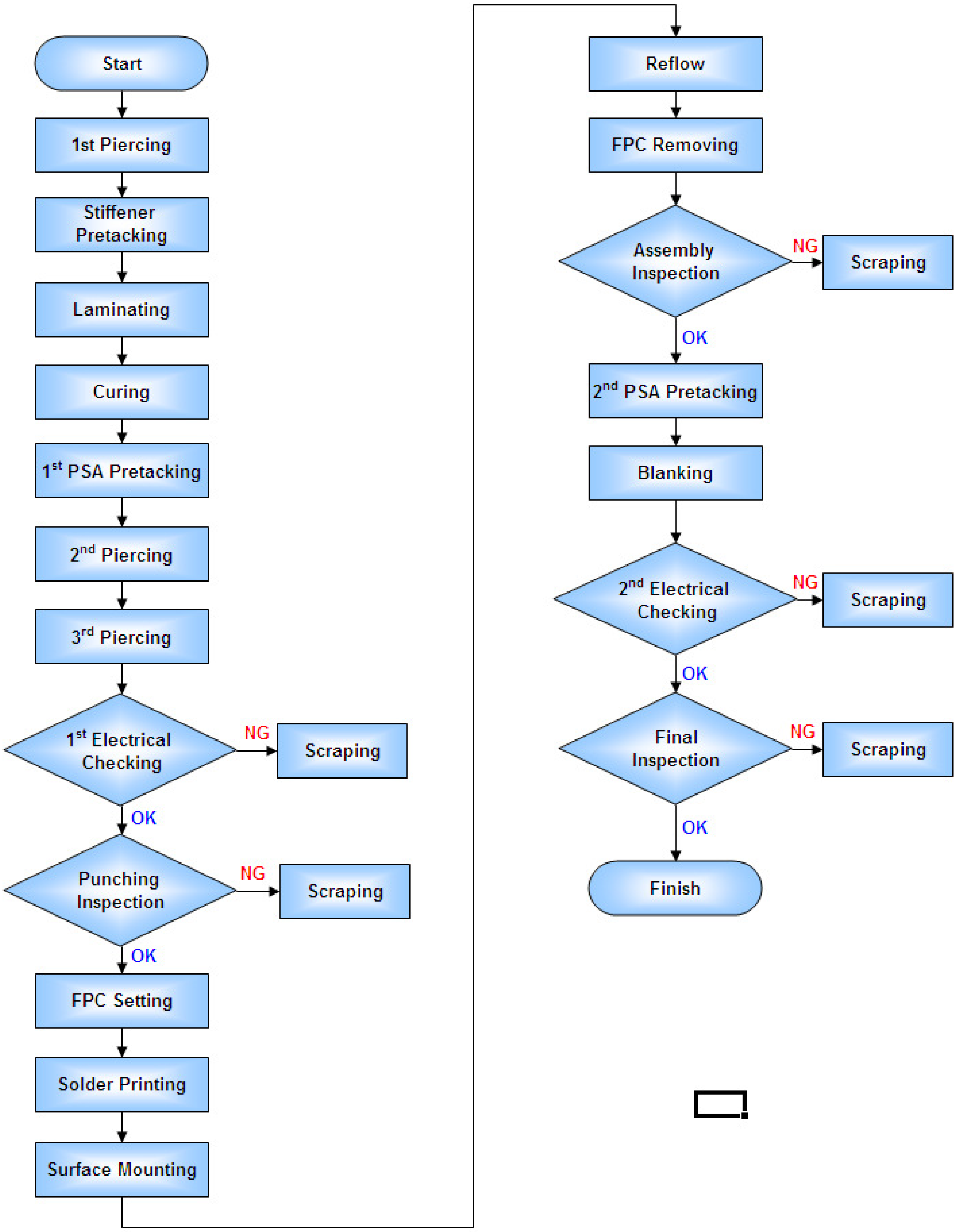

Figure 4: Process flow diagram.

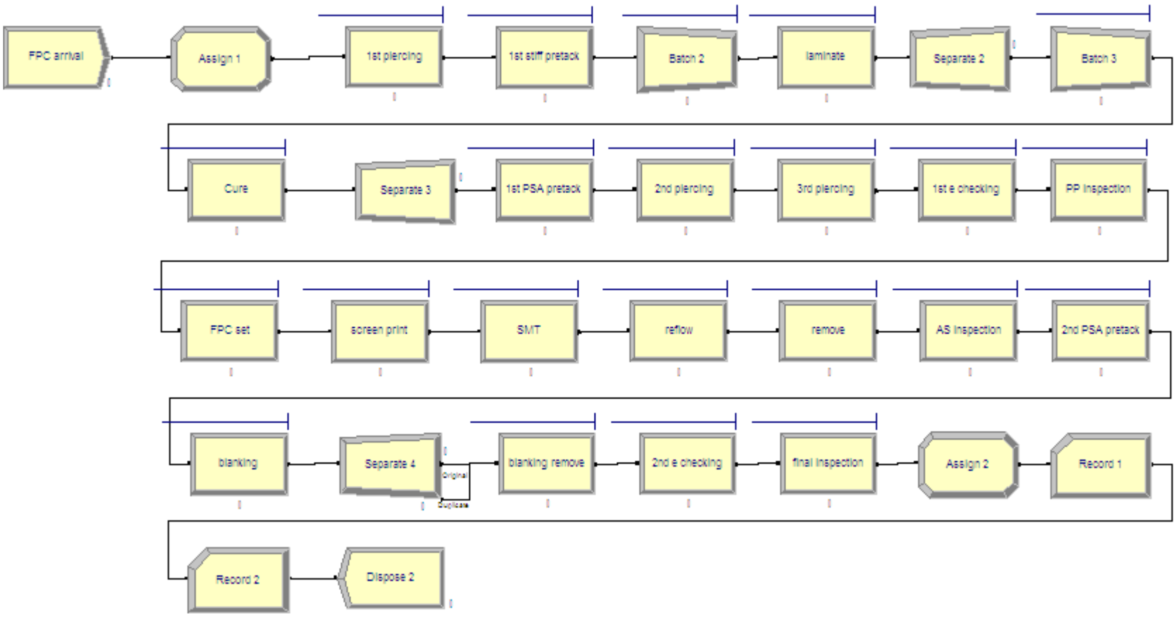

Figure 5: Simulation model of the current push system.

Table 1: Processing time distributions and the number of resources of each process.

No.	Process	Distribution Expression (second)	Operation Resources	
			Number of Machines	Number of Operators
1	1st piercing	TRIA (17.2, 17.5, 18.1, 1)	1	1
2	1st stiffener pretacking	UNIF (37, 46, 2)	2	2
3	Laminate	TRIA (139, 139, 142, 3)	2	-
4	Curing	Constant (19800)	4	
5	1st PSA pretacking	69.1 + 4.38 * BETA (0.934, 1.43, 5)	1	1
6	2nd piercing	UNIF (17, 18.1, 6)	1	1
7	3rd piercing	TRIA (17.1, 17.4, 18.2, 7)	1	1
8	1st electrical checking	UNIF (23, 24.2, 8)	1	1
9	Punching process inspection	TRIA (14.5, 15.9, 16.4, 9)	-	1
10	FPC setting	9 + EXPO (0.36, 10)	-	1
11	Solder Printing	Constant (17.42)	1	-
12	Surface Mounting	Constant (20.31)	1	-
13	Reflow	Constant (28.39)	1	-
14	Removing	TRIA (7.1, 8.04, 8.45, 14)	-	1
15	Assembly inspection	TRIA (14.1, 14.9, 15.8, 15)	-	1
16	2nd PSA pretacking	TRIA (30, 32.3, 39, 16)	2	2
17	Blanking	UNIF (28, 29.1, 17)	1	1
18	Blanking removing	TRIA (3, 3.54, 4.81, 18)	-	3
19	2nd electrical checking	UNIF (5, 5.53, 19)	2	2
20	Final inspection	TRIA (10, 10.2, 12.4, 20)	-	4