A Simulation Study on the Manufacturing of Electronic Chassis

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Abstract

Simulation is a crucial problem-solving strategy for many real world problems. It represents a powerful ‘what if’ tool for analyzing and evaluating i) the behavior of a new or existing system, and ii) the performance of modifications or changes made to the system. Organizations can certainly benefit from its application for enhanced decision support, efficiency and productivity. However, conducting a proper simulation is both an art and a science. It is not an easy task, and many organizations still do not have a clear idea of how to proceed with it. This paper presents the results of a case study conducted in a manufacturing company in Malaysia. Specifically, the major aim is to demonstrate how simulation can be conducted and how it can be applied in the company’s manufacturing activities. Hopefully, the information extracted from this study will be beneficial to organizations that are in the throes of adopting simulation.

Keywords: Simulation; Modeling; WITNESS; Electronic Chassis

1.0 Introduction

In the 21st century, growing global competitions and technology advancements have greatly complicated the manufacturing tasks of companies. A great challenge for them is on how to draw a competitive advantage from the way they handle their immense manufacturing tasks. In order to maintain and enhance the competitiveness of a manufacturing company, the performance of manufacturing processes needs to be continuously reviewed in response to the increasingly evolving market conditions. Determining or predicting the process performance of any changed or improved system is a great challenge. To deal with this challenge, a simulation model can be constructed to evaluate the performance of the system. Simulation provides a great way to tackle a range of industrial problems leading to improvements in efficiency, cost and profitability (Heizer and Render, 2006).

This paper presents the results of a case study conducted to demonstrate the process of performing and applying simulation modeling in a manufacturing company. This in turn will help to provide useful guidance and directions on how simulation can be carried out. Generally, this paper is structured in the following manner. Firstly, it provides a brief literature review on the concepts and fundamentals of simulation. The background information of the case study and the methodology employed in performing simulation, are then described. Following this, the applications of simulation in the company are presented. Initially, simulation was run to gauge the operating characteristics and performance of the company's current manufacturing system. Subsequently, it was used to evaluate the effectiveness of a few proposed modifications or changes made to the system. Finally, the paper culminates with a discussion of the results obtained, and conclusions.

2.0 Literature review

Simulation is the imitation of the operation of a real-world process or system over time. Whether done by hand or on a computer, simulation involves the generation of an artificial history of a system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system (Banks, 2000; Banks et al, 2005).

The idea behind simulation is threefold (Heizer and Render, 2006):

(i) To imitate a real world situation mathematically.
(ii) To study its properties and operating characteristics.
(iii) Finally, to draw conclusions and make decisions based on the results of the simulation.

Simulation can be used when a problem consists of variables that are non-linear and very complex. There may be too many variables which cause a problem cannot be solved mathematically. Hence simulation is the only way to analyze and solve it. Furthermore, simulation can be used to analyze and predict the effect of changes to existing systems. Potential changes to an existing system can first be simulated to predict their impact to the system performance without disrupting the real system. This can prevent risk taking as experimenting changes using real systems can be very costly.

In addition, simulation can be used to obtain operating characteristic estimates in a much shorter time period than that required to gather the same operating data from a real system. This feature of simulation is called time compression (Krajewski and Ritzman, 2002). Besides this, simulation can also be used to study systems in the design stage before they are built. It can be used as a design tool to predict the performance of new systems under varying set of circumstances without building the actual systems.

In general, the two major uses of simulation in manufacturing sectors are design and evaluation of a new system and optimization of an existing system (Carson, 2005). Some applications of simulation in manufacturing sectors are to design and evaluate a new manufacturing process and to assist in determining the interaction effectiveness between process components before any machinery is purchased. In addition, it can also be used to optimize an existing process as it gives an overview of how the system currently operates and allows for evaluation of alternative scenarios without the loss of production. Last but not least, simulation can be used as a preparation for production planning and scheduling. Through simulation, the requirements of a particular manufacturing system can be predicted with a set of probabilistic assumptions.

Simulation can certainly be applied to many aspects of manufacturing systems such as job-shop and flow-line manufacturing processes. Normally, every manufacturing system exhibits many same characteristics, although different in detail. Basically, every manufacturing system consists of products and facilities used to produce them such as machines, operators, tools, storage locations etc. Thus, a model can be developed for different manufacturing systems with little modifications.

To sum up, simulation is a powerful analysis tool in assisting decision makers to make wise decisions in a short time. However, it needs to be emphasized that simulation is only a solution evaluator that identifies a problem clearly and evaluates alternative solutions quantitatively, but it is not a solution generator as it does not generate an optimal solution theoretically.

Simulation software can be divided into two categories which are simulation language and simulator. Simulation languages such as ARENA, EXTEND, GPSS/H, MICROSAINT, MODSIM, AUTOMOD, QUEST etc need the knowledge of programming in order to set up the model (Law and McComas, 1998). On the other hand, simulators such as WITNESS, PROMODEL, SIMPROCESS etc allow a person to simulate a system contained in a specific class of system without programming (Allan, 1988; Law and McComas, 1998).

WITNESS is the Lanner Group's simulation software package (Lanner Group, 2000). It is a culmination of more than a decade's development experience with computer-based simulation. This experience has led to the evolution of a visual, interactive and interpretative approach to simulation without the need for compilation. The benefits of the WITNESS approach are as follows:

(i) People can gain commitment by working together as a team in creating and using WITNESS models.
(ii) Models can be built and tested in small incremental stages, which greatly simplifies model-building, provides the ability to identify errors in the logic and makes the model more reliable.
(iii) The model can be changed at any time during its run. Changes are incorporated immediately leading to faster model building.

The applications of WITNESS are evaluating capital projects, running models regularly for testing production schedules, evaluating alternative proposals, improving existing facilities and managing changes. In addition, WITNESS can be applied in a wide range of industries such as automotive, chemical, electronics, aerospace, engineering, food, paper, government, transport, banking and finance.

3.0 Background of the case study

As mentioned earlier, this research is a real-life case study conducted in a manufacturing company. For anonymity purposes, the company's identity will not be disclosed and it will be denoted as Company A in this paper. The company specializes in the fabrication and manufacturing of metal parts for machineries. Among the major products of the company are electronic chassis, baggage scanner and metal detector. In this research, an electronic chassis model named 'EC' has been chosen for the case study. The reason for choosing this product was because its fabrication process was complicated. Moreover, the company had indicated that it was facing productivity problems in fabricating this product.

EC is an electronic chassis that consists of twenty parts where each of them will undergo different processes as shown in Figure 1. In addition, the number of processes that needs to be undergone by each part is different as well. Although each part will be fabricated through different processes, the process flow of each part is almost the same. In the initial stage, all the twenty parts of EC can be divided into three categories. The first category of parts can be cut directly using laser cutting machines without any preceding process. On the other hand, the second category consists of two parts that need to be turret punched first before being sent for laser cutting. In the third category, there are six parts that need to be sheared and then sub-out to contractors for wire cutting. After either the laser cutting or wire cutting process, all the parts will be sent to the deburring process.

Once the parts have been deburred, they will be forwarded to three different processes (countersinking, hair lining and brushing) based on their specifications. Some of the parts will be sent to the countersinking process before proceeding to the hair lining process. On the other hand, some parts can be transported directly to the hair lining process while some will be sent to the brushing process. Following this, those parts that need to be bent will proceed to the bending process before being sent to the subcontractor while the others will be directly sent to the subcontractor for finishing (Alodine and Silver Plating).

All the parts that are completed and returned by the subcontractors will be inspected for quality before proceeding to other processes. After quality inspection, some parts will be directly sent to the stamping of part number, and packing process. On the other hand, some parts will be pressed nut while the others will be silk screened before proceeding to the press nut process. After press nut, the parts will be inspected, stamped with part number, and packed. When all the parts have been completely fabricated and packed, they will be sent to customers.

The fabrication process of the EC product consists of variables that are non-linear and complicated. Besides this, there are too many variables which make it difficult to model the situation mathematically. Therefore, simulation should be used to examine the system and analyze its operating characteristics. In addition, simulation can be used to analyze and predict the effect of changes to the existing system.

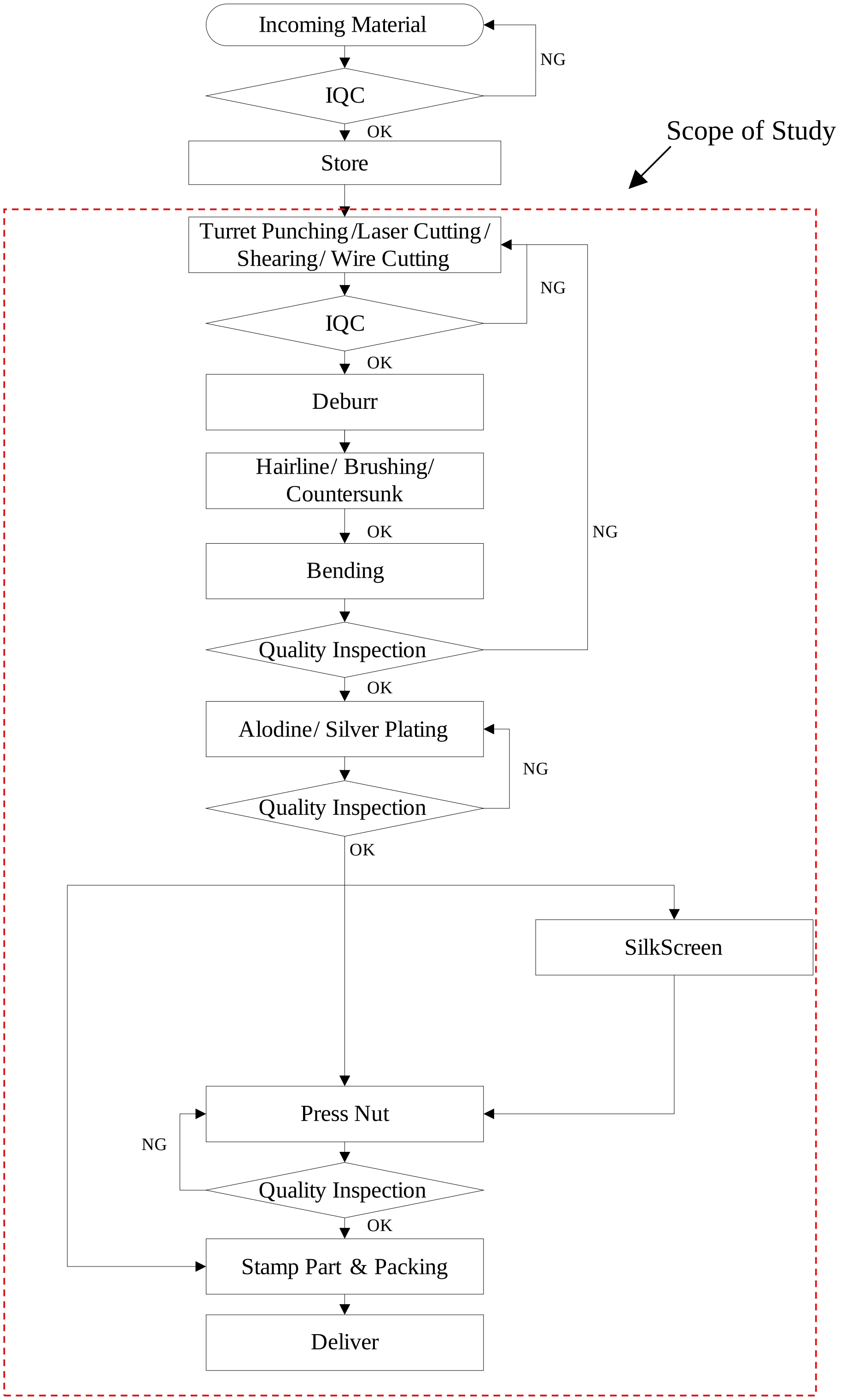


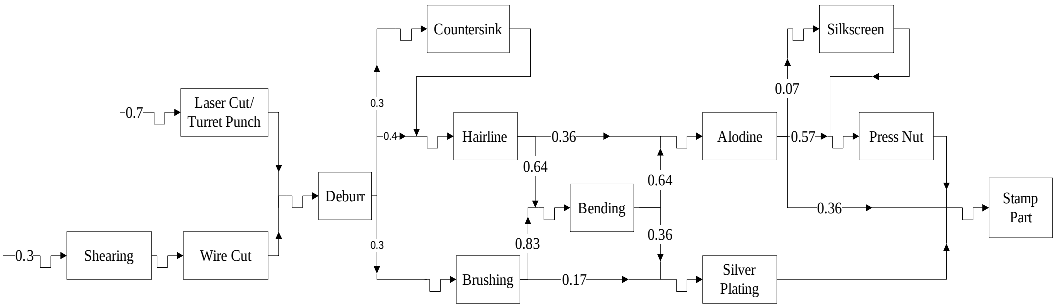
Figure 1: The process flow of EC fabrication

4.0 Methodology

After understanding the whole process, a simulation model can be built to explore and investigate the problem faced in the fabrication of EC. This will subsequently help the company to find out the causes that contribute to the problem. Before building the actual simulation model, a conceptual model needs to be built.

4.1 Construction of conceptual model

A conceptual model is an initial framework prior to constructing a simulation model (Law, 2005). Having a clear conceptual model is necessary to visualize the manufacturing process studied Generally, it shows the machines or processes, buffers, and flow of parts or materials. Figure 2 shows the conceptual model for the current process. As can be seen, there are 13 processes needed to manufacture a complete EC product where each part needs to undergo different processes.



Notes:
The numbers in the model represent the proportion of parts that need to undergo each process .

Figure 2: Conceptual model of the current EC manufacturing process

4.2 Data collection and analysis

At the same time, the cycle time of each process for each part needs to be determined. Throughout this project, the cycle time of each process for different parts, as well as the set up time required for certain machines, have been collected. A key issue in this activity is to determine how many sets of data need to be collected. The number of data sets (i.e. sample size) required for different cycle time would be different depending on the actual behavior of the individual process and part. Initially, 10 sets of data were collected for each of the cycle time. Based on these data, the corresponding mean, standard deviation and t-value (based on a 95% confidence level) were calculated. Using the equation,

$$n = (ts / k\bar{x})^2 \quad \text{----------} \quad (1) \quad \text{(adapted from Taylor (2007))}$$

where n = sample size or number of replications
t = t-value
s = standard deviation
k = allowable error, 5%
$\bar{x}$ = mean

the required sample size for each of the cycle time was then computed. If the calculated n > 10, this indicates that more data need to be collected. In contrast, if the calculated n $\leq$ 10, this shows that the number of data collected is sufficient.

Once all the data have been collected, their distributions were determined using the Goodness-of-Fit Test (Banks et al, 2005). Since the cycle time variation for each process is relatively small, it could be assumed that the cycle time distribution for each process is uniform. In addition, there are too many processes and parts, where each of them has different cycle time. Thus, it is not practical to analyze the cycle time distribution for all the processes and parts. However, the variation for the set up time of the laser cutting and shearing machines is large, therefore Goodness-of-Fit Test was carried out. The test results indicate that the set up time for both the machines is normally distributed. In short, the cycle time for each part and process has been summarized in Table 1, while Table 2 summarizes the machines’ set up time.

Table 1: Summary of the cycle time for each part and process

Part No.	**Part Name**	**Process**	**Cycle Time**		
			Distribution	**Min Value**	**Max Value**
P1	Plate Nut #6-32	Laser	Uniform	1.45	1.47
		Deburr	Uniform	4.17	4.52
		Hairline	Uniform	0.49	0.50
		Alodine	Uniform	29.00	31.00
		Pressnut	Uniform	2.67	2.87
		Stamp	Uniform	2.97	3.05
P2	Mounting Plate	Shearing	Uniform	1.17	1.23
		Wirecut	Uniform	2.26	2.28
		Deburr	Uniform	4.17	4.52
		Brushing	Uniform	4.10	4.61
		Silver Plating	Uniform	30.00	32.00
		Stamp	Uniform	2.47	2.51
P3	Strap (Output Cap)	Shearing	Uniform	1.42	1.67
		Wirecut	Uniform	1.23	1.25
		Deburr	Uniform	3.52	3.82
		Brushing	Uniform	1.54	1.73
		Bending	Uniform	3.60	3.83
		Silver Plating	Uniform	30.00	32.00
		Stamp	Uniform	2.98	3.05
P4	Strap (Detector Cap)	Shearing	Uniform	1.65	1.75
		Wirecut	Uniform	2.67	2.69
		Deburr	Uniform	2.00	2.17
		Brushing	Uniform	2.05	2.31
		Bending	Uniform	2.53	2.78
		Silver Plating	Uniform	30.00	32.00
		Stamp	Uniform	2.03	2.17
P5	Cover (Voltage Sensor)	Laser	Uniform	0.25	0.27
		Deburr	Uniform	8.30	8.78
		Hairline	Uniform	1.64	1.68
		Bending	Uniform	2.03	2.18
		Alodine	Uniform	29.00	31.00
		Stamp	Uniform	2.68	2.72

Table 1 (Continued)

Part No.	**Part Name**	**Process**	**Cycle Time**		
			Distribution	**Min Value**	**Max Value**
P6	Box (Voltage Sensor)	Laser	Uniform	0.47	0.49
		Deburr	Uniform	4.25	4.58
		Hairline	Uniform	1.64	1.68
		Bending	Uniform	2.13	2.30
		Alodine	Uniform	29.00	31.00
		Pressnut	Uniform	2.52	2.75
		Stamp	Uniform	2.58	2.88
P7	Cover (Adjustment Pot)	Laser	Uniform	0.30	0.37
		Deburr	Uniform	3.52	3.65
		Countersink	Uniform	3.20	3.35
		Hairline	Uniform	0.82	0.84
		Alodine	Uniform	29.00	31.00
		Stamp	Uniform	2.37	2.42
P8	Rear Panel	Laser	Uniform	2.27	2.29
		Deburr	Uniform	4.67	5.10
		Countersink	Uniform	11.18	11.60
		Hairline	Uniform	1.23	1.26
		Bending	Uniform	4.17	4.43
		Alodine	Uniform	29.00	31.00
		Silkscreen	Uniform	2.22	2.32
		Pressnut	Uniform	2.95	3.32
		Stamp	Uniform	2.00	2.35
P9	Strap (Load Cap)	Shearing	Uniform	1.57	1.67
		Wirecut	Uniform	3.23	3.25
		Deburr	Uniform	4.77	5.02
		Brushing	Uniform	0.61	0.69
		Bending	Uniform	4.42	4.65
		Silver Plating	Uniform	30.00	32.00
		Stamp	Uniform	2.13	2.40
P10	Strap (Tune Cap)	Shearing	Uniform	1.60	1.75
		Wirecut	Uniform	3.22	3.24
		Deburr	Uniform	8.68	9.13
		Brushing	Uniform	0.61	0.69
		Bending	Uniform	4.52	4.80
		Silver Plating	Uniform	30.00	32.00
		Stamp	Uniform	2.10	2.13

Table 1 (Continued)

Part No.	**Part Name**	**Process**	**Cycle Time**		
			Distribution	**Min Value**	**Max Value**
P11	Mounting Bracket (Fixed Cap)	Shearing	Uniform	2.18	2.35
		Wirecut	Uniform	1.33	1.35
		Deburr	Uniform	7.03	7.53
		Brushing	Uniform	0.61	0.69
		Bending	Uniform	2.17	2.35
		Silver Plating	Uniform	30.00	32.00
		Stamp	Uniform	3.02	3.32
P12	Front Panel (RFS 3016)	Laser	Uniform	2.47	2.49
		Deburr	Uniform	3.33	3.52
		Hairline	Uniform	0.49	0.50
		Bending	Uniform	0.97	1.05
		Alodine	Uniform	29.00	31.00
		Pressnut	Uniform	3.53	3.87
		Stamp	Uniform	2.22	2.37
P13	Front Panel	Laser & Turret	Uniform	4.87	4.89
		Deburr	Uniform	10.42	10.98
		Hairline	Uniform	1.23	1.26
		Bending	Uniform	2.68	2.95
		Alodine	Uniform	29.00	31.00
		Pressnut	Uniform	4.43	4.72
		Stamp	Uniform	2.45	2.49
P14	Bracket (Interlock)	Laser	Uniform	2.47	2.49
		Deburr	Uniform	6.95	7.32
		Hairline	Uniform	0.49	0.50
		Bending	Uniform	1.67	1.85
		Alodine	Uniform	29.00	31.00
		Pressnut	Uniform	3.20	3.35
		Stamp	Uniform	3.50	3.58
P15	Top Cover	Laser & Turret	Uniform	4.25	4.27
		Deburr	Uniform	7.80	8.03
		Countersink	Uniform	12.93	13.42
		Hairline	Uniform	0.49	0.50
		Alodine	Uniform	29.00	31.00
		Stamp	Uniform	2.58	2.63

Table 1 (Continued)

Part No.	**Part Name**	**Process**	**Cycle Time**		
			Distribution	**Min Value**	**Max Value**
P16	Side Panel (Load)	Laser	Uniform	3.47	3.49
		Deburr	Uniform	5.82	6.37
		Countersink	Uniform	9.67	10.00
		Hairline	Uniform	0.49	0.50
		Bending	Uniform	3.58	3.83
		Alodine	Uniform	29.00	31.00
		Pressnut	Uniform	2.53	2.72
		Stamp	Uniform	2.38	2.46
P17	Side Panel (Tune)	Laser	Uniform	2.75	2.77
		Deburr	Uniform	4.88	5.35
		Countersink	Uniform	11.20	11.58
		Hairline	Uniform	0.49	0.50
		Bending	Uniform	4.05	4.47
		Alodine	Uniform	29.00	31.00
		Pressnut	Uniform	3.12	3.38
		Stamp	Uniform	2.18	2.25
P18	Motor Panel (Universal)	Laser	Uniform	4.42	4.44
		Deburr	Uniform	6.93	7.42
		Hairline	Uniform	0.49	0.50
		Bending	Uniform	3.98	4.20
		Alodine	Uniform	29.00	31.00
		Pressnut	Uniform	2.18	2.38
		Stamp	Uniform	2.05	2.15
P19	Baseplate (Bias Match)	Laser	Uniform	1.17	1.19
		Deburr	Uniform	7.45	7.85
		Countersink	Uniform	12.62	12.90
		Hairline	Uniform	0.49	0.50
		Alodine	Uniform	29.00	31.00
		Stamp	Uniform	2.35	2.48
P20	Motor Mount (Universal)	Laser	Uniform	0.48	0.55
		Deburr	Uniform	3.33	3.55
		Hairline	Uniform	0.49	0.50
		Alodine	Uniform	29.00	31.00
		Stamp	Uniform	2.15	2.40

Table 2: Summary of machines' set up time

Description	**Parameter**		
	Distribution	**Mean**	**Standard Deviation**
Laser Cutting Machine Set Up	Normal	10.98	1.40
Shearing Machine Set Up	Normal	9.66	1.17

4.3 Development of simulation model

Upon completing the data collection and analysis phase, the next step was to build the simulation model. The simulation software – WITNESS was used for this purpose due to its benefits and advantages highlighted earlier. Specifically, the simulation model consists of parts, machines/processes, buffers and attributes. There are 20 parts, in which each part would undergo different processes. In addition, the cycle time for each process is different for different parts. Therefore, attributes would be used to distinguish the cycle time and the process that each part needs to undergo. Firstly, the parts would be pulled by the machine (laser cutting or shearing) to be processed. Then, they would be pushed to other processes based on the attributes that have been set in each part. A list of elements or components (and the abbreviations used) built into the simulation model is provided below.

PART

P1 : Plate Nut #6-32
P2 : Mounting Plate
P3 : Strap (Output Cap)
P4 : Strap (Detector Cap)
P5 : Cover (Voltage Sensor)
P6 : Box (Voltage Sensor)
P7 : Cover (Adjustment Pot)
P8 : Rear Panel
P9 : Strap (Load Cap)
P10 : Strap (Tune Cap)
P11 : Mounting Bracket (Fixed Cap)
P12 : Front Panel (RFS 3016)
P13 : Front Panel
P14 : Bracket (Interlock)
P15 : Top Cover
P16 : Side Panel (Load)
P17 : Side Panel (Tune)
P18 : Motor Panel (Universal)
P19 : Baseplate (Bias Match)
P20 : Motor Mount (Universal)
PRODUCT : Assembled ES Product

OPERATION/MACHINE
LASER : Laser Cutting /Turret Punching Machine
SHEAR : Shearing Machine
WIRECUT : Wire Cutting (Sub-Out)
DEBURR : Deburring Process
CSK : Countersinking Process
HAIRLINE : Hair Lining Machine
BRUSH : Brushing Process
BEND : Bending Process
ALODINE : Alodine Plating Process (Sub-Out)
SILVER : Silver Plating Process (Sub-Out)
SILKSCREEN : Silk Screen Process
PRESSNUT : Press Nut Process
STAMP : Stamp Part Number (including inspection)
ASSY : Assemble all parts into a product
DLA : Dummy Machine to Accumulate 20 Parts after Laser Cutting
DSH : Dummy Machine to Accumulate 20 Parts after Shearing
DWI : Dummy Machine to Accumulate 20 Parts after Wire Cutting
DDE : Dummy Machine to Accumulate 20 Parts after Deburring
DCSK : Dummy Machine to Accumulate 20 Parts after Countersinking
DHL : Dummy Machine to Accumulate 20 Parts after Hair Lining
DBR : Dummy Machine to Accumulate 20 Parts after Brushing
DBE : Dummy Machine to Accumulate 20 Parts after Bending
DAL : Dummy Machine to Accumulate 20 Parts after Alodine Plating
DSL : Dummy Machine to Accumulate 20 Parts after Silver Plating
DSS : Dummy Machine to Accumulate 20 Parts after Silk Screen
DPN : Dummy Machine to Accumulate 20 Parts after Press Nut
DST : Dummy Machine to Accumulate 20 Parts after Stamp Part Number

BUFFER
BLA : Buffer before Laser Cutting
BSH : Buffer before Shearing
BWI : Buffer before Wire Cutting
BDE : Buffer before Deburring
BCSK : Buffer before Countersinking
BHL : Buffer before Hair Lining
BBR : Buffer before Brushing
BBE : Buffer before Bending
BAL : Buffer before Alodine Plating
BSL : Buffer before Silver Plating
BSS : Buffer before Silk Screen
BPN : Buffer before Press Nut
BST : Buffer before Stamp Part Number

LABOR
WLA : Worker that sets up and operates Laser Cutting/ Turret Punching Machine
WSH : Worker that sets up and operates Shearing Machine

SHIFT
MONTHU (Sub-Shift) : Operations hour from Monday to Thursday
FRI (Sub-Shift) : Operations hour on Friday
Week : Operations hour for one week

ATTRIBUTE
P : Part Number
LACT : Laser Cutting/Turret Punching Cycle Time
SHCT : Shearing Cycle Time
WICT : Wire Cutting Cycle Time
DECT : Deburring Cycle Time
CSKCT: Countersinking Cycle Time
HLCT : Hair Lining Cycle Time
BRCT : Brushing Cycle Time
BECT : Bending Cycle Time
ALCT : Alodine Plating Cycle Time
SLCT : Silver Plating Cycle Time
SSCT : Silk Screen Cycle Time
PNCT : Press Nut Cycle Time
STCT : Stamp Part Number Cycle Time

In order to achieve a reasonable blend of details, the following assumptions have been made:

(i) The manufacturing system operates 8 hours per day and 5 days per week.
(ii) The operating time is as follows:
Monday to Thursday: 0745-1015 (Work)
1015-1030 (Break)
1030-1230 (Work)
1230-1315 (Lunch)
1315-1515 (Work)
1515-1530 (Break)
1530-1700 (Work)
Friday: 0745-1015 (Work)
1015-1030 (Break)
1030-1245 (Work)
1245-1415 (Lunch)
1415-1730 (Work)
(iii) Each machine can process only one part at a time.
(iv) Once an operation is started, it is not interrupted.
(v) There is no reject or rework.
(vi) Machine breakdown time is negligible.

By incorporating all the above elements and details, and inputting all the collected data (e.g. cycle time and set up time), a simulation model has been developed and it is shown in Figure 3.

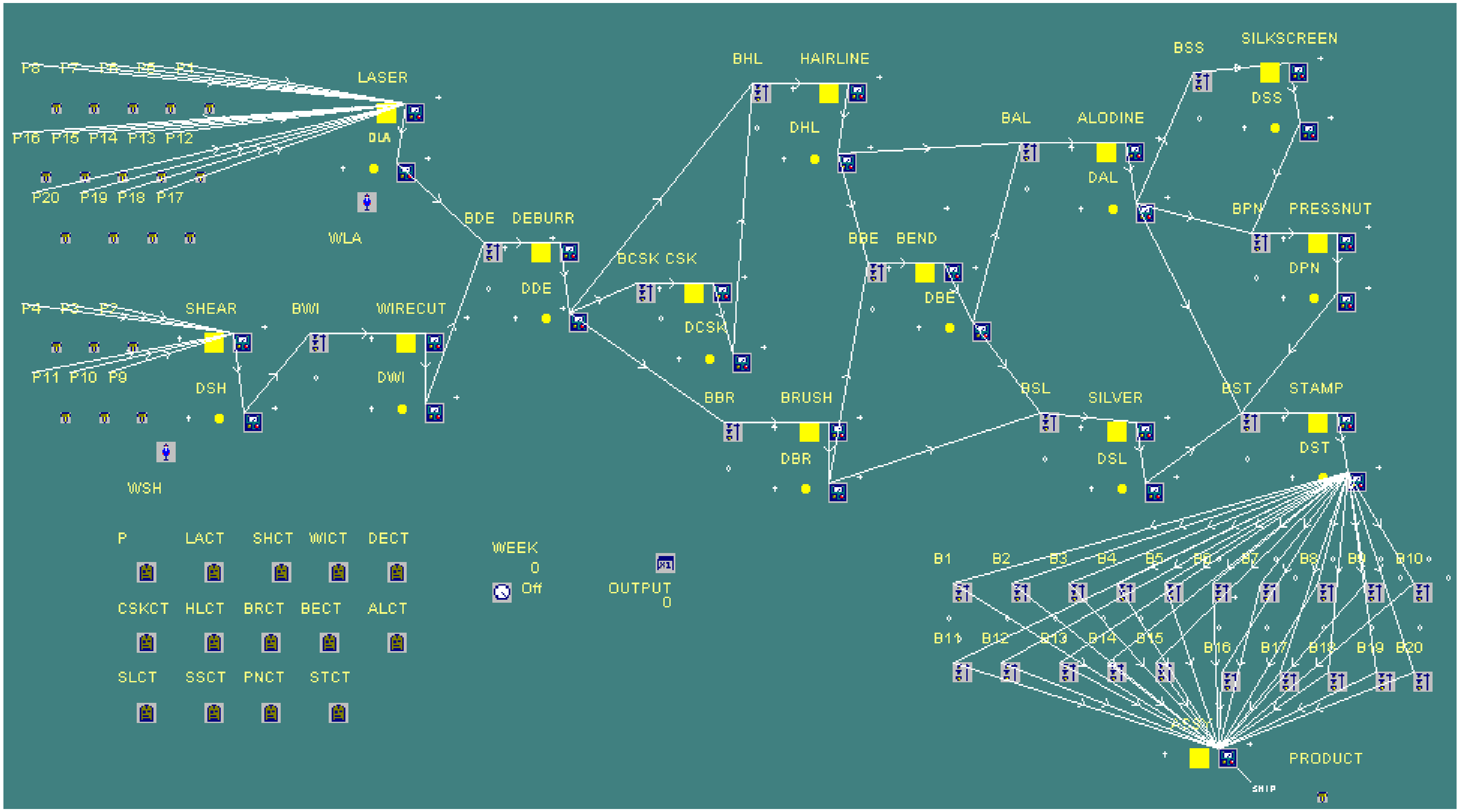


Figure 3: Simulation model for the current system

4.4 Model Verification

Model verification is very important in simulation modeling to ensure that the program of the model performs as intended. In each stage, the model was run with different set of input parameters (Carson, 2005) and the results were checked (e.g. checking whether the outputs were reasonable or not). The steps of verification were repeated stage by stage to ensure that the model was correct. By using this approach, corrective actions can be taken immediately once it has been identified that the model is not performing as expected. In addition, it is easier to identify the problem in the model when verification is done stage-by-stage as compared to verifying the whole model only after its completion.

Throughout the simulation modeling, consultation from experts is needed to ensure that the model resembles the real situation as much as possible (Carson, 2005; Law, 2005). Discussions with the production personnel of the case company have been done to get a better understanding of the real situation in the fabrication of the EC product and to ensure that the model is performing as how the real system operates.

4.5 Model Validation

After building and verifying the simulation model, it has to be run for a certain time period to ensure that it is a true representation of the system (Law and McComas, 1998; Law, 2005). Thus, model validation is needed to test the overall accuracy of the model. In this project, model validation was done by comparing the data generated by simulation with the actual production data (Carson, 2005; Sargent, 2005; Law, 2005). In order to validate the simulation model, the quantities of shipped products from both the simulation model and the actual production were compared. Figure 4 shows the comparison of the outputs generated by the simulation model, with the actual outputs.

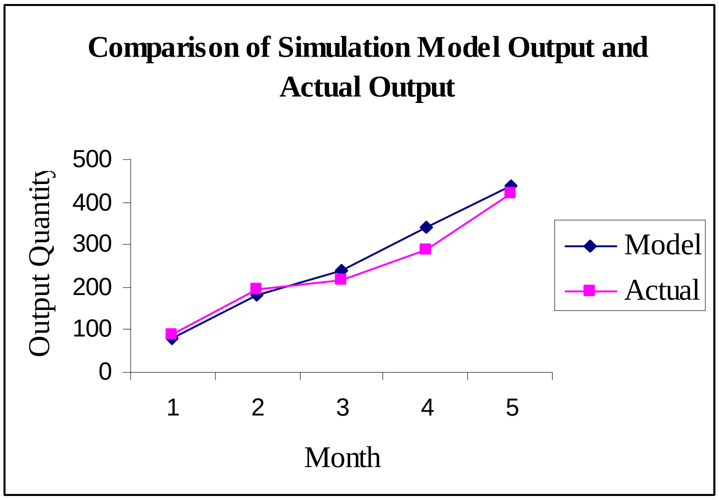


Figure 4: Comparison of simulation model outputs and actual outputs

From Figure 4, it can be seen that the outputs generated by the simulation model are just slightly different from the actual outputs. Thus, it can be concluded that the simulation model is valid as it is able to represent the actual situation.

4.6 Determination of warm up period

Before conducting a full simulation run, the warm up period of the model needs to be determined. Warm up period is the duration needed by the simulation model to transform from transient behavior to steady state (Law and Kelton, 2000). The results generated by the simulation model during the warm up period should be disregarded.

In order to determine the warm up period, the simulation model was run for 1000 minutes and the utilization of the laser cutting machine was recorded every 10 minutes. The time needed for the model to achieve steady state is the warm up period. Figure 5 shows the laser cutting machine utilization for 1000 minutes. It can be seen that the machine utilization is 0% until 465 minutes. This is because the production starts at 7.45am (465 minutes), thus the utilization remains at 0% from 0 minute until 465 minutes. From 465 minutes onward, the utilization starts to increase but it keeps fluctuating and is not stable. From 600 minutes onward, the utilization starts to achieve steady state where the variation has become less. Thus, it can be concluded that the warm up period is 600 minutes.

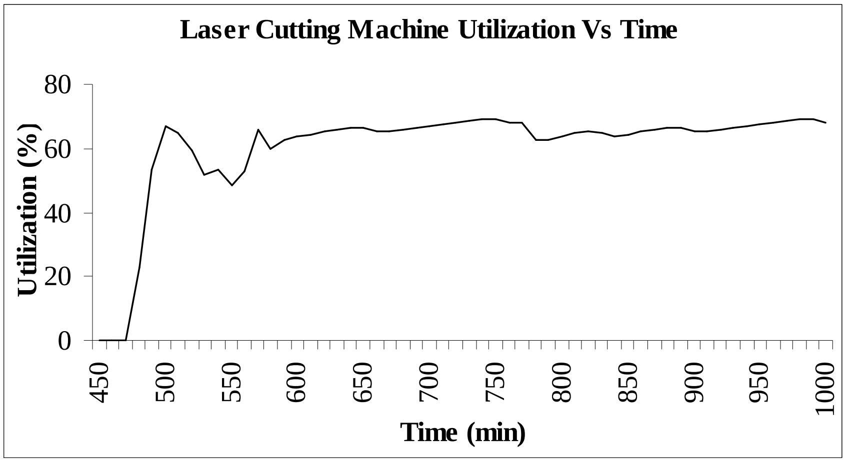


Figure 5: Utilization of the laser cutting machine

4.7 Determination of number of replications

After determining the warm up period, the number of replications for the simulation run needs to be determined as well. It represents the sample size required based on a predefined relative error from the simulation output to estimate the output parameter (Law and Kelton, 2000). In order to determine the number of replications, the simulation model was initially run for 10 replications with a run length of 129600 minutes (3 months) and the outputs generated were recorded. The outputs for the 10 replications are shown in Table 3.

Table 3: Outputs for 10 replications of the current system

Observation	**Output**
1	240
2	280
3	260
4	260
5	260
6	280
7	260
8	240
9	260
10	260
Total	**2600**

Based on the calculation using equation 1 (Taylor, 2007), it is indicated that 6 observations are sufficient for an allowable error of 5% with a 95% confidence level. Thus, no additional replication is needed. Therefore, the simulation model will be run with 6 replicates for all the experiments that would be evaluated.

4.8 Simulation run

Based on the results generated from the simulation run (as shown in Table 4), it can be seen that the current performance of the system is not satisfactory. The total output generated is low where the company is only able to produce 260 units in three months (the target of the company is 320 units). On the other hand, the average WIP is very high and this indicates the occurrence of a bottleneck. Besides this, the utilization of machines and labors is low (merely 36.61%). This shows that the current system for manufacturing the EC product is not effective. Thus, efforts need to be taken to address this problem.

Table 4: Results from the simulation run of the current system

Performance Measure	**Value**
Total Average Output Per Quarter	260
Total Average WIP	1111
Total Average Time Per Part (min)	490.22
Total Average Utilization	36.61%

5.0 Modifications to the system

Based on a thorough analysis of the simulation results as well as the actual production system, it can be seen that there are many parts waiting for the completion of other parts or components before they can be assembled into a complete product. This could indicate that the scheduling method implemented is poor where the sequence in scheduling the parts to be fabricated is inappropriate. On the other hand, the parts are blocked at the deburring department. This indicates that there is a bottleneck at the deburring department. Probably, there are insufficient workers in this particular area. In addition, some of the parts need a long time to be completed. This could be due to the inappropriate process sequence. Thus, the process sequence could be changed. By changing the process sequence, it is anticipated that the cycle time for some activities such as the hair lining and brushing processes, can be shortened.

On the basis of the above discussion, three alternatives have been suggested to improve the existing system. They are:

i) Change the process sequence by putting the hair lining and brushing processes before the laser cutting and shearing activities. This could save a lot of time because there is no need to hair line or brush the separate components one by one (the parts will be hair lined or brushed first before being laser cut or sheared into separate pieces).

ii) Add one or two operators in the deburring department. By doing this, more parts can be deburred at the same time. This could reduce the waiting time of the parts as well as the bottleneck.

iii) Use priority rules (i.e. Shortest Total Processing Time (STPT), Longest Total Processing Time (LTPT), Last Come First Serve (LCFS), Least Operation (LO) and Most Operation (MO)) to schedule the parts for fabrication. These rules are selected based on the request and recommendation from the case company.

Using the methodology discussed earlier, the simulation models for all the proposed alternatives have been built and they are shown in Figures 6, 7 and 8.

6.0 Results and discussion

After running the simulation models for all the proposed alternatives, the results obtained are summarized in Table 5. Based on this table, the results for each alternative can be compared and the best alternative can be selected.

The outcomes indicate that the alternative of adding one operator in the deburring department is the best. This is because it can yield the highest output increment and utilization (machines and labors) improvement. The alternative of adding two operators results in the same total output as adding one operator. This shows that adding more than one worker would not yield a higher increase of output. This could be due to other constraints such as the limited capacities at other workstations that restrict the productivity of EC fabrication. On the other hand, the alternative of adding one operator does not yield the best improvement in terms of Work in Progress (WIP) reduction and time reduction as compared to adding two operators. However, the WIP reduction and time reduction for the former is just slightly different than the latter. Therefore, it is recommended to add only one operator in the deburring department instead of two. This is because adding two operators will incur a higher cost. In addition, it will only result in the same output and a slightly better outcome (in terms of WIP and time), as compared to adding one worker. In contrast, adding one operator is more economic and it is sufficient to improve the output, WIP, time and utilization significantly.

On the other hand, if the company intends to improve the fabrication process without incurring any cost, the company is recommended to change the process sequence where the hair lining and brushing activities are shifted to become the initial processes before the sheet metal is cut into individual pieces. Changing the process sequence can increase the total output by 3.08%, reduce WIP by 38.34%, reduce average time per part by 1.28% and increase utilization by 7.59%. This could be due to the time that has been saved in hair lining and brushing the components. However, the improvement resulted from this alternative is not as much as the improvement gained from adding one operator. Even though adding one operator will increase cost, its improvement yield is much better. On the other hand, changing the process sequence might result in longer traveling distances of parts which will indirectly increase the operation cost. Thus, the company should consider the traveling distance aspect before choosing this option.

From the simulation run, it can be seen that using different priority rules does not have much impact on the fabrication of EC. All the priority rules used in scheduling the parts for fabrication do not yield any output increment. Although the adoption of the LCFS, LTPT and MO rules can reduce the average time per part, this improvement is not sufficiently significant to increase the average output. This could be due to the bottleneck at the deburring department which delays the parts from proceeding to the next process and limits the effect of changing the parts sequence. In addition, these priority rules do not have much effect on WIP and utilization. Interestingly, the STPT and LO rules could even make the situation worse than the current process. This is because both of them would increase WIP and reduce utilization. Thus, they should not be used in scheduling the parts for fabrication. In short, using priority rules does not yield a significant improvement.

7.0 Conclusions

This paper has presented the results of a case study conducted to illustrate the process of performing simulation modeling, as well as its applications in a manufacturing company. Specifically, the steps involved in the simulation modeling of electronic chassis fabrication (e.g. conceptual model construction, data collection and analysis, simulation model development, model verification and validation, warm up period determination etc) have been described. In addition, its applications as an analyzer and evaluator of the i) performance of the current manufacturing system and ii) effectiveness of a few proposed improvement alternatives or modifications, have been demonstrated. The simulation results indicate that the performance of the current production system is not satisfactory. Among the improvement alternatives proposed to address this problem, the option of adding one operator in the deburring department is shown to be the best. In essence, this case study has provided useful insights and directions on how simulation modeling can be conducted and applied. It is hoped that this study will be beneficial to companies that are either attempting or struggling to perform simulation modeling.

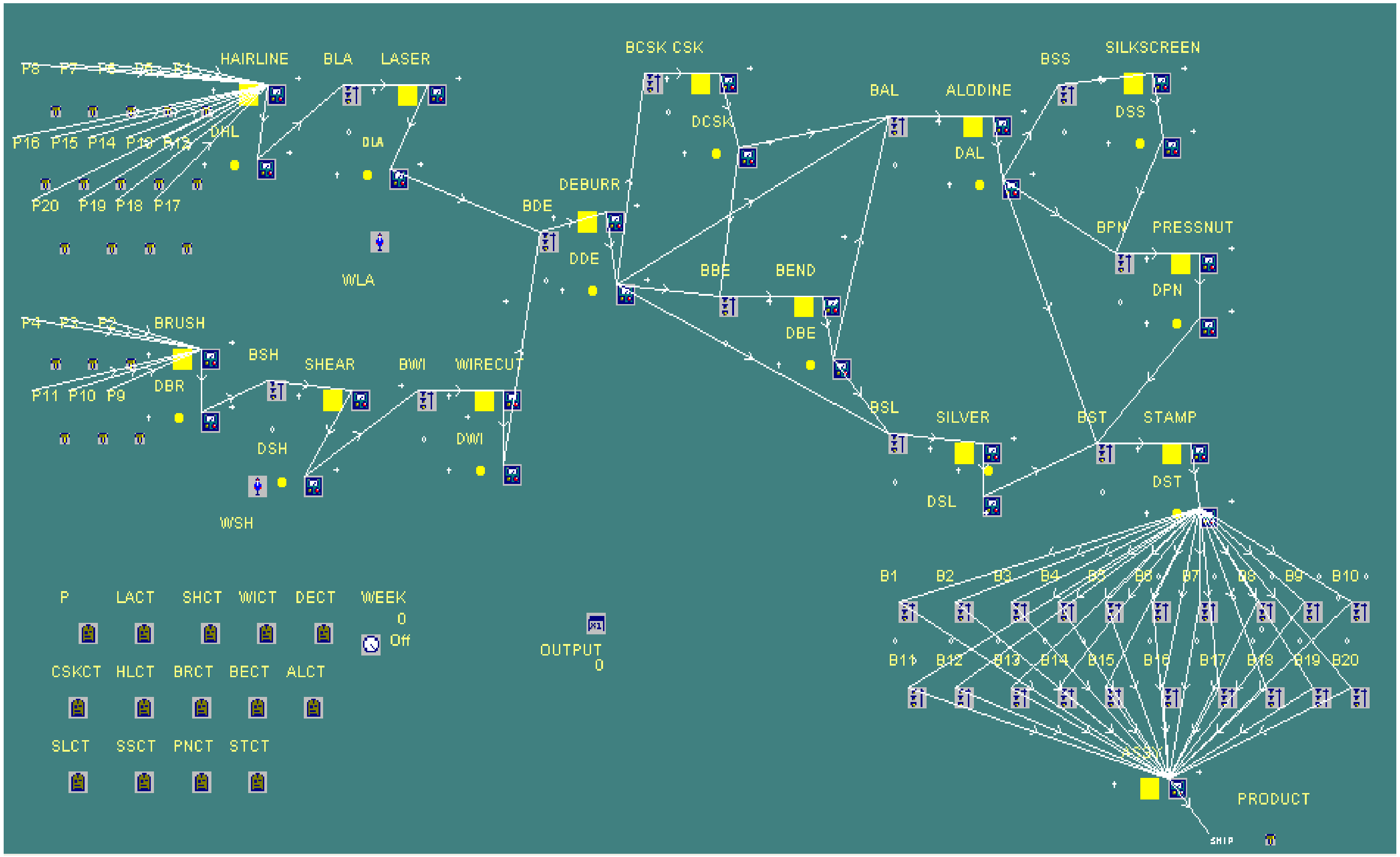


Figure 6: Simulation model for alternative 1 (changing the process sequence)

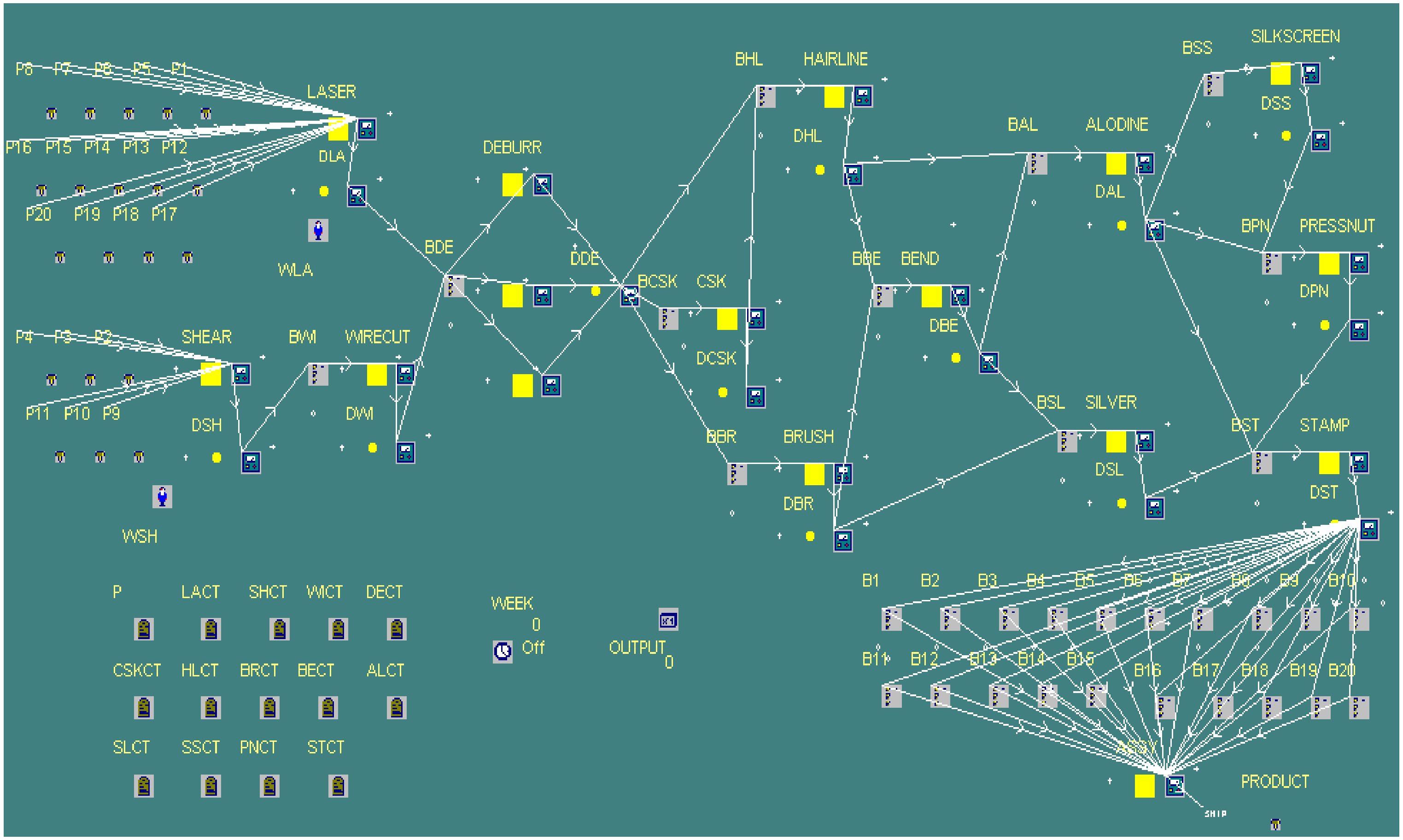


Figure 7: Simulation model for alternative 2 (adding operators in the deburring department)

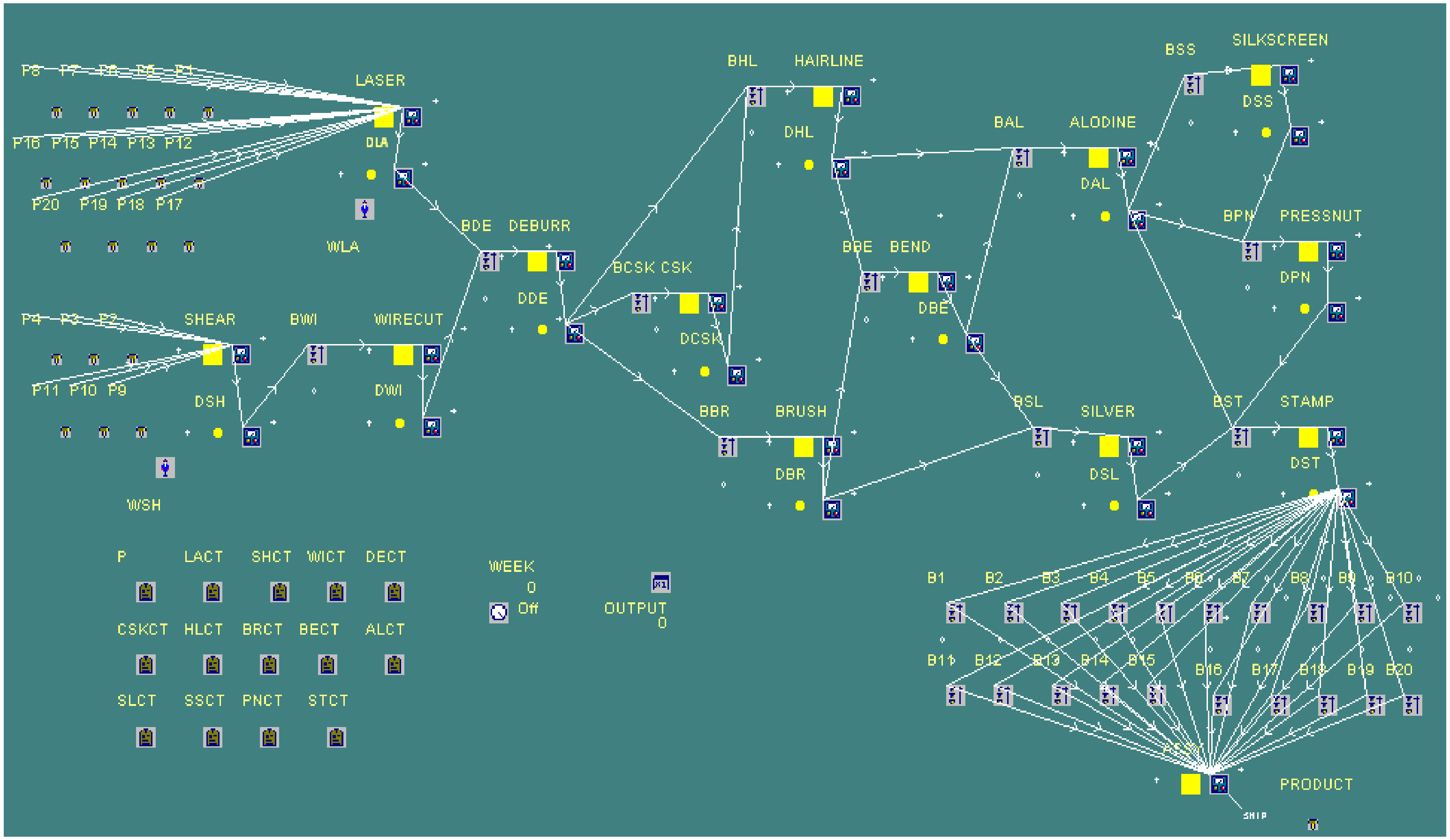


Figure 8: Simulation model for alternative 3 (using priority rules in scheduling the parts for fabrication)

Table 5: Comparison of results for all alternatives

Alternatives	**Total Average Output**	**Total Average Output Increment (%)**	**Total Average WIP**	**Total Average WIP Reduction (%)**	**Total Average Time**	**Total Average Time Reduction (%)**	**Total Average Utilization**	**Total Average Utilization Improvement (%)**
Existing	260	-	1111	-	490.22	-	36.61	-
Alternative 1								
Change Process Sequence	268	3.08	685	38.34	483.96	1.28	39.39	7.59
Alternative 2								
Add 1 Operator	332	27.69	373	66.43	389.89	20.47	40.59	10.87
Add 2 Operators	332	27.69	354	68.14	389.68	20.51	38.02	3.85
Alternative 3								
LCFS	260	0	1055	5.04	489.98	0.05	36.67	0.16
STPT	260	0	1131	-1.80	490.23	0	36.50	-0.30
LTPT	260	0	1049	5.58	490.00	0.05	36.68	0.19
LO	260	0	1140	-2.61	490.23	0	36.49	-0.33
MO	260	0	1040	6.39	489.18	0.21	36.74	0.36

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