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碩士論文

使用系統模擬提升塑膠薄膜電容器裝配線效率：以 C 公司為例

研　究　生：謝育庭

指導教授：黃欽印 教授

Dr. Huynh Trung Luong

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Improving the Efficiency of a Plastic Film Capacitor Assembly Line by Use of Simulation Software: A Case study of C Company

By
Yu-Ting Hsieh

Advisors：Dr. Chin-Yin Huang
Dr. Huynh Trung Luong

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學生：謝育庭　　　　　　　　　　　　指導教授：　　　　黃欽印 教授

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摘　要

在當今競爭激烈的世界中，裝配線效率和生產力對於以製造為主的企業至關重要。該研究表明了對現有裝配線性能的研究。在該裝配線中，透過工作的過程觀察並記錄工作站的實際週期時間和操作員的表現。 並透過 WITNESS 系統模擬軟體對裝配線的當前佈局進行了分析，以獲取工作站和操作員更詳細準確的數據來分析瓶頸站。然而根據文獻指出，在生產多樣產品的裝配線中，非生產時間應小於 35%。因此，在本案例研究中，根據瓶頸站問題，提出了直線裝配線和 U 型線兩種替代方案。由於裝配線佈局的改變，部分操作人員的工作分配也需要根據替代方案中的佈局設計來重新安排。最後比較當前佈局以及兩種替代方案的系統模擬結果，藉此找出最適合該案例公司的佈局方式。

關鍵字詞：系統模擬、瓶頸站、直線裝配線、U 型線、閒置時間

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Student：Yu-Ting Hsieh

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Department of Industrial Engineering and Enterprise Information
Tunghai University

ABSTRACT

In today's competitive world, assembly line efficiency and productivity are critical in manufacturing companies. This research demonstrates the study about the performance of an existing assembly line. In this assembly line, the actual cycle time of workstations and performance of operators are observed and recorded during the working process. The current layout of assembly line was analysed by WITNESS simulation software in order to analyze bottleneck stations to help obtain more accurate performance data for workstations and operators. According to the Electronic Engineering Research Institute, the non-production time should be less than 35% in the production line of various types of products. Therefore, in this case study, according to the problem of bottleneck station, two kinds of design alternatives are proposed which are straight assembly line and U-shaped line. The task assignments of operators are also considered according to the layout of alternatives. After analysing the data, simulation result from the current layout and the design alternatives are compared to help select the layout with improved efficiency.

Keywords: Simulation Software, Bottleneck Station, Straight Assembly Line, U-Shaped Line, Idle Time

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我想對在撰寫本研究期間幫助過我的所有人表示感謝。我最深切的感謝首先是C 公司允許我使用他們的裝配線真實數據進行這個案例研究，並為我提供了實習的機會，這使我受益匪淺。

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CHAPTER 1 INTRODUCTION

1.1 Background

In recent years, due to the rising awareness of environmental protection and the rise of related industries such as LED and new energy automobile industry, the plastic film capacitor industry has ushered in a golden period of development. Among them, China's production of plastic film capacitors accounts for about 42% of the global total output value (National Bureau of Statistics of China, 2017), and recently, due to the tight trade relationship between China and the United States, the International Association Institute for Supply Management (ISM, 2018) Research pointed out that it has led to the global supply of electronic components. With the continuous increase in raw materials and labor costs, coupled with the shortage of supply due to short supply, large-scale production models are gradually being challenged. Today, rapid changes in consumer demand determine the mode of production. Changes in demand volatility are inevitable, and how to quickly adapt to the current market development is the key issue.

The method of improving the flexibility of workstation personnel by training personnel to be multi-tasking and arranging the number of personnel in the workstation according to the number of orders is called Shojinka [1]. This is a commonly used technique in Toyota Production Systems(TPS), and Shojinka needs to be conditional, for example: U-line design, multi-functional work, etc. There is a need to match the design of the production line to minimize the number of people required between stations. The idle time is not the production time, and the long idle time between stations also leads to high production costs [27].

For the production line design of the enterprise, the linear assembly line is still the most commonly used design. In earlier literature [2], it was found that the advantages of Shojinka can also be achieved by combining multiple linear assembly lines at the same time, that is, to increase the flexibility of the personnel, and to minimize the total idle time of the production line and the number of workstations required [2].

Nowadays, simulation models have been used to evaluate various aspects of manufacturing systems. There are many purposes for using system simulation in manufacturing, including automated system design, manufacturing process validation, evaluation of manufacturing execution plans, and analysis of layout configurations. Kochhar [25] discussed the progress and gradual use of computer simulations of manufacturing systems since the 1960s. The use of simulation can help to enhance the manufacturing system to achieve productivity and cost reduction.

1.2 Statement of the problems

The production process sequence of the plastic film capacitor producer in this research case is winding, hot pressing, wrapping, spray welding, potting, oven and sorting. There are seven stations in which the winding and sorting are automatic stations, and the rest are manual stations. In general, operators in each station can walk unhindered and perform operations as shown in Figure 1.1. Since the winding is an important workstation that affects the function and performance of the plastic film capacitor, the workstation is designed as a clean room so that the operator cannot easily enter and exit as shown in Figure 1.2.

From real data collected, the production efficiency of the hot press and wrapping are lower than that of other stations. In the face of a large number of orders, it is easy to cause the waiting time of the subsequent stations to be lengthened. The potting machine and the oven machine are placed next to each other. Currently, they are operated by one person and one machine. Therefore, the number of people required is large and the working environment is poor due to the high temperature of the oven.

Compared with the traditional linear assembly line, the U-line design will have more advantages, especially in assembly line balance [3], which makes the production line more efficient and less line imbalance problems. In addition, U-line design is highly correlated with manual assembly, and manual assembly lines are more suitable for continuous modification than automatic assembly lines [4].

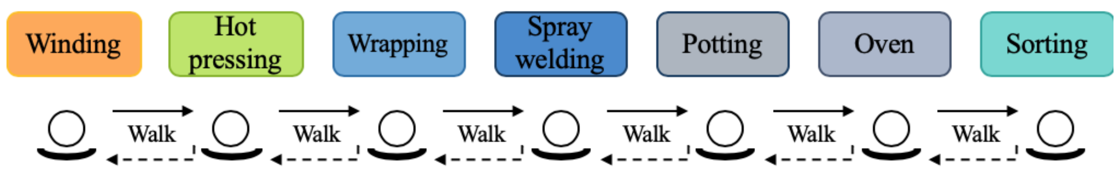

Figure 1. 1 General assembly line design.

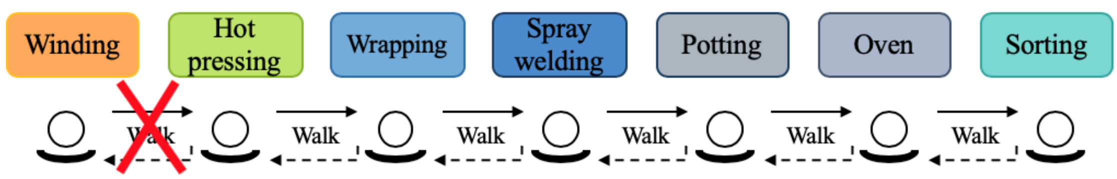

Figure 1. 2 The problem of assembly line in case study

Idle time is also an important part of the consideration of assembly line issues. The idle time is measured as the difference between the cycle time and the workload at each site, where the site workload describes the total operating time of the job it is performing [26]. By reducing idle time, we can also reduce costs as much as possible.

In this case study, the detailed production process and its characteristics are shown in Table 1.1. In Table 1.1, most of the production processes are manual, and only winding and sorting are automated. Figure 1.3 below shows the layout of the manual assembly line for this case. Because this study focuses on the improvement of the manual assembly line, it does not consider the design of the fully automated station.

Table 1.1 Production data in this study

Module Process	Task Characteristics	Process Characteristics
Winding	Automated operations	Clean room
Hot pressing	Manpower operations	Fixed appearance
Wrapping	Manpower operations	Fix production position
Spray welding	Manpower operations	Spray on conductive paint
Potting	Manpower operations	Need secondary potting
Oven	Manpower operations	-
Sorting	Automated operations	Full inspection

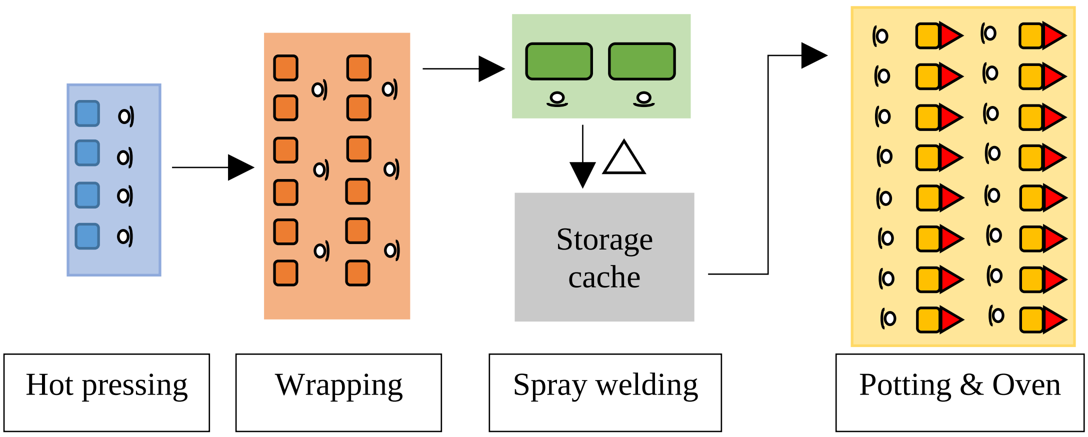

Figure 1. 3 Current layout of manual assembly line

About the problem in potting and baking station, two times potting and baking are need to avoid the problem of overfilling. Figure 1.4 shows the current layout of potting and baking station, however potting station includes more process such as spot welding, casing, pushing and collecting. In the current layout, one operator can perform one potting machine and oven at the same time. Because there are 30 to 40 minutes waiting time for cooling after each baking, an operator can perform two machines simultaneously. However, this may cause idle on the subsequent processes and result in large delayed time on the delivery.

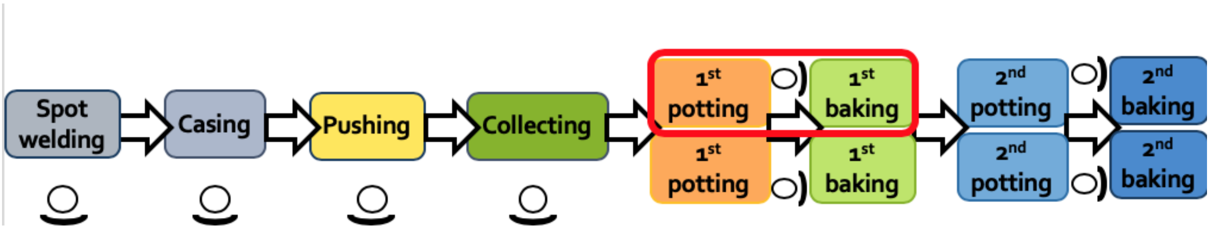

Figure 1.4 Current layout of potting and baking station

When demand is volatile, the method of adjusting the number of personnel in the workstation has been improved by the method of Shojinka. In the Toyota Production System (TPS), Shojinka represents the ability to perform multiple operations through multi-skilled workers, enabling changes in the number of workers as production needs increase or decrease. U-shaped lines are inseparable from Shojinka, U-shaped production lines are mentioned in [5] and [6], while [7] and [8] emphasize the importance of U-shaped lines. But this does not mean that the traditional linear assembly line can not achieve Shojinka, as long as it is suitable, we can still achieve the same goal through the combination of multiple linear assembly lines [2].

1.3 Objectives of the research

To deal with the problem, this study will propose two kinds of alternatives which are U-line and straight assembly line designs, trying to find the most efficient layout design that is suitable for the company in this case study. And the task assignments of operators are also considered according the layout of alternatives. In the subsequent chapters, the performance results of the designs are derived by use of WITNESS simulation software. The design alternatives are compared by idle time, the number of workstations, the cycle time and the number of people required.

1.4 Scope and limitation

This case study will take into account the following conditions and hypotheses：

- The first station of the manufacturing process is designed as a clean room, where the assembly line design cannot be changed at will.
- The layout design of this study does not consider winding and sorting stations.
- The part of the assembly line to be changed is a manual assembly line.
- The U-shaped line and the straight-line assembly line layout design will be built and compared separately.
- The WITNESS simulation software will be used to identify the improvement in term of efficiency. The indicators are idle time and the number of workstations, the required operators and the idle time of the operators.
- The parameters of the model established in this case study are fixed rather than random variables.

CHAPTER 2 LITERATURE REVIEW

In this chapter, we discuss the literature related to this research in the past. In Section 2.1, we discuss the limitations and advantages of assembly line design and implementation. In Section 2.2, we explored the mathematical methods of how to balance U-shaped lines and straight assembly lines in the past literature.

2.1 Assembly line design

Shojinka is a combination of Japanese words [9]. This method contains several features: U-line, walking routine design, multi-skilled workers, operator mobility barriers, and continuous improvement of the process [1]. The main concept is that when the demand for a product increases or decreases, the corresponding production line can increase the number of personnel or send it to other workstations to help increase the flexibility of the number of workers. Shojinka can be said to be a method of adjusting and rearranging personnel to improve productivity according to demand [5].

U-line design can be said to be a major focus of the advantages of Shojinka, compared to other layout design like bird cages and isolated islands is more advantageous [5]. Visibility and easy communication will make the U-line personnel have an enhanced effect on the work, and the number of personnel will be less than other layout designs [10]. The benefit of the U-shaped line is not only the reduction of the number of personnel. If two or more U-shaped lines are combined through appropriate design, the operator can directly operate multiple production lines at the same time, which can directly eliminate or reduce Station time idle time.

Benzer pointed out that parallel placement of two or more straight assembly lines during production minimizes the number of workstations when the line is balanced[11]. And the workstations in these combined assembly lines will be able to minimize idle time. In the past literature, most of the tasks of linear assembly line assignment and production line balance are discussed. [2] For the first time, how to realize the advantages of Shojinka by combining multiple linear assembly lines is discussed.

For the case of this study, because the winding station is limited by the process technology, the design of the clean room makes it impossible for the operator to walk smoothly, and because the efficiency of the manual assembly line is low, the idle time of the subsequent station is lengthened. This study attempts to overcome and improve line efficiency through U-shaped lines and multiple straight assembly lines.

2.2 Assembly line balance

Hybrid model production is defined as the size, specification, color and even the material is still produced on the same production line [9]. This will lead to the problem of how to determine the order priority of the order. The mixed model assembly line (MMAL) can balance the production of many types of products at the same time, and more factors need to pay attention to the interaction between the assembly line models [12]. With regard to the balance problem of MMAL, for example [13], [14], [15] and [16], these cases have been implemented and succeeded in the industrial field.

On the other hand, the combination of adjacent workstations through parallel assembly lines (PALs) may lead to efficiency on the production line [17], and most methods for solving PALs are suggested using heuristic algorithms [18] or multiple mathematics. Model [19] to solve.

The SULB (simple U-line balancing) problem was originally constructed by [20]. (TL Urban 1998) is a proposed an integer programming formulation for determining the optimal balance. The more complex NP problem of ULB is also proposed to solve the U-line balance after [21], [23]. problem. These documents have mainly tried the target planning model to minimize the cycle time and minimize the number of workstations. Oksuz and Staoglu[24], the U-shaped wire is related to the manual assembly line. Therefore, the human factor needs to be considered. Try to introduce ergonomics into the line balance to make further considerations.

2.3 Simulation system

In recent years, system simulation has been widely used in theoretical and practical model experiments and evaluation. Kochhar [24] discussed the progress and gradual use of simulation of manufacturing systems since the 1960s. Many industrial companies in developing countries use simulations in their manufacturing systems to solve real-world production problems associated with their day-to-day operations [29]. For example, it was applied to reduce the cycle time of car factory through WITNESS software to improve efficiency and find the best layout [30].

The types in the system can be divided into non- continuous and continuous types. The non-continuity is at the point in time of separation, and its state variables produce an instantaneous change. The bank's cashier system, the food service of the meal, or the rice acquisition system described above are all of this type of application, as the changes must wait until one entity (e.g., employee, car , etc.) arrives. Conversely, the continuity system, the state variables change with time. For example, the aircraft flies through the air, the train rushes in the wilderness, etc., and its position and speed change are time-dependent.

In this case study, it is non-continuous to produce in batches, so the parameters in the model are fixed. There are errors or defective products in production, but the quantity is too small to be ignored.

CHAPTER 3 METHODOLOGY

3.1 Overview

The following flow chart represents how the various stages of the study will be conducted.

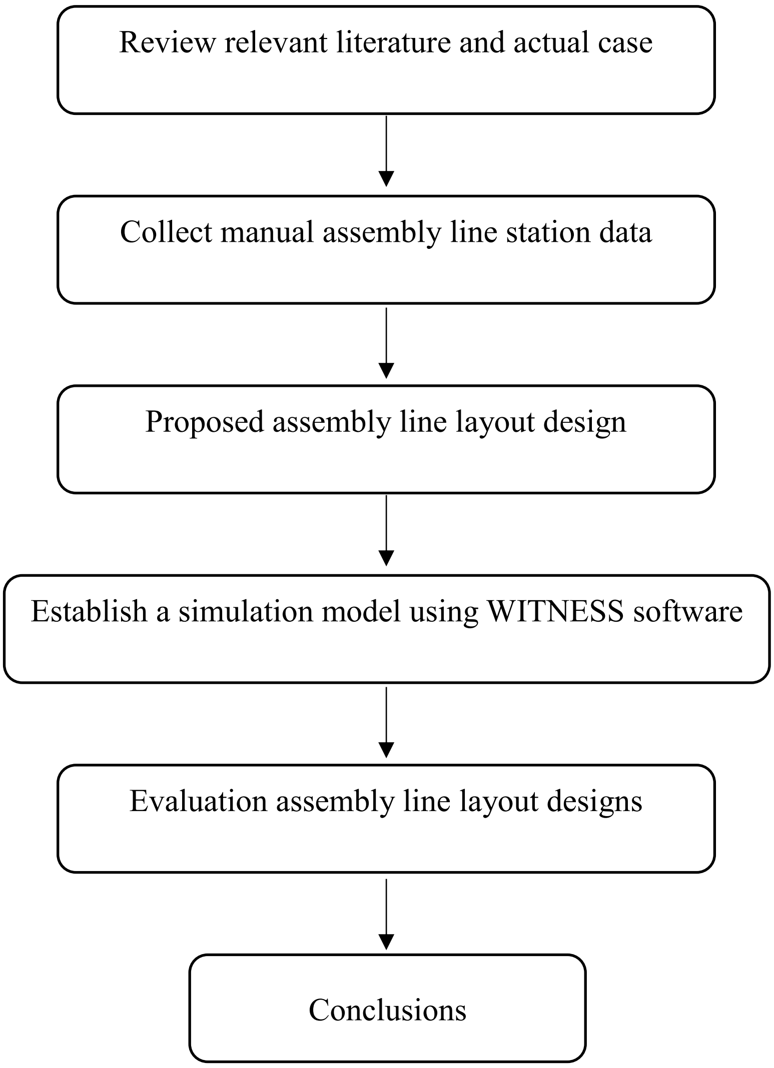

Figure 3. 1 The methodology flowchart

The detailed procedure applied in this research is as follows:

Step 1: Review the assembly line layout design, evaluation assembly line method and the actual case.

Step 2: Collect and record the time required for high, medium and low demand on the manual assembly line workstation.

Step 3: Two assembly line layout schemes are proposed, which are U-shaped line and linear assembly line.

Step 4: Establish a simulation model using WITNESS. The indicators that determine the improvement in efficiency are idle time and the number of workstations, the required operators and the idle time of the operators.

Step 5: The data obtained by WITNESS is analyzed and compared for layout design of the. two schemes.

Step 6: Conclusions and recommendations.

3.2 Data gathering procedure

Since this case study company not only produces plastic film capacitors, some workstations on multiple assembly lines are shared. Therefore, if for a certain type of product idle time is too long during production period, it will not only affect the production efficiency of the current order, but also delay the delivery time of the next order.

In this case study, the company produced an order for plastic film capacitors on average one week. Therefore, I focused on the assembly line of plastic film capacitors. A total of four orders were collected for a one-month period and recorded in per lot. The operating status of the machines in the workstation as shown in the table 3.1. In this stage, the stopwatch tool has been used for gathering data in the assembly line.

Table 3. 1 The time spent in each batch on each workstation under different orders (unit: mins)

	Winding	Hot Pressing	Wrapping	Spray Welding	Potting	Oven	Sorting
Order1	27.6	29.7	32.4	24.6	76.8	124.5	29.4
Order2	25.8	30.6	30.9	22.2	75.3	119.6	27.6
Order3	26.4	28.8	29.7	21.3	74.2	121.7	28.8
Order4	24.6	28.5	29.4	21.3	72.1	122.2	27.0
Average	26.1	29.4	30.6	22.8	74.6	122	28.2

According to the collection of real data, the bottleneck in the current layout is the baking station. In addition to the baking station, the potting station also takes more time than other workstations. However, the potting station includes processes such as spot welding, casing, pushing and collecting. Therefore, more detailed information about the machines and operators in the potting and baking stations needs to be collected for further detailed analysis by WITNESS software.

The following tables not only show the performance of the machines in the potting and baking stations, but also the detail of the operator work for the machines. The change of the assembly line layout and the assignment of the operator's tasks will be based on the information in the following tables, and propose two kinds of alternatives.

Table 3. 2 The operation of the machine in spot welding

<table>
<tr><th>No.</th><th>Operation description</th><th>Time (min)</th><th>No.</th><th>Operation description</th><th>Time (min)</th></tr>
<tr><td>1</td><td>Vibrating plate feeding</td><td>1.2</td><td>4</td><td>Send metal wire</td><td>1.1</td></tr>
<tr><td>2</td><td>Loading capacitor into machine</td><td>0.8</td><td>5</td><td>Start welding</td><td>3.8</td></tr>
<tr><td>3</td><td>Fixed capacitor position</td><td>0.6</td><td>6</td><td>Cleaning weld zone</td><td>1.8</td></tr>
<tr><td colspan="2">Total busy time</td><td colspan="2">9.3 mins</td><td>Machine requirement</td><td>1</td></tr>
</table>

Table 3. 3 The detail of the operator work in spot welding

<table>
<tr><th>No.</th><th>Operation description</th><th>Time (min)</th><th>No.</th><th>Operation description</th><th>Time (min)</th></tr>
<tr><td>1</td><td>Loading capacitor into machine</td><td>0.8</td><td>4</td><td>Cleaning weld zone</td><td>1.8</td></tr>
<tr><td>2</td><td>Preparing metal wires</td><td>1.3</td><td>5</td><td>Adjustment machine</td><td>1.2</td></tr>
<tr><td>3</td><td>Start welding</td><td>2.2</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total busy time</td><td>7.3 mins</td><td colspan="2">Number of operators required</td><td>1</td></tr>
</table>

Table 3. 4 The operation of the machine in casing

<table>
<tr><th>No.</th><th>Operation description</th><th>Time (min)</th><th>No.</th><th>Operation description</th><th>Time (min)</th></tr>
<tr><td>1</td><td>Check the appearance of the case</td><td>3.2</td><td>3</td><td>Vibrating plate feeding</td><td>1.2</td></tr>
<tr><td>2</td><td>Loading capacitor into vibrating plate</td><td>0.8</td><td>4</td><td>Put the capacitor into the case</td><td>2.6</td></tr>
<tr><td colspan="2">Total busy time</td><td>7.8 mins</td><td colspan="2">Machine requirement</td><td>1</td></tr>
</table>

Table 3. 5 The detail of the operator work in casing

<table>
<tr><th>No.</th><th>Operation description</th><th>Time (min)</th><th>No.</th><th>Operation description</th><th>Time (min)</th></tr>
<tr><td>1</td><td>Loading capacitor into vibrating plate</td><td>0.8</td><td>3</td><td>Shipping to the next workstation</td><td>2.6</td></tr>
<tr><td>2</td><td>Collecting semi-finished products</td><td>1.2</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total busy time</td><td>4.6 mins</td><td colspan="2">Number of operators required</td><td>1</td></tr>
</table>

Table 3. 6 The operation of the machine in pushing

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Loading capacitor into vibrating plate	0.9	4	Enter the turntable	1.1
2	Vibrating plate feeding	1.2	5	Enter the aluminum strap to fix the position	1.5
3	Make sure the capacitor is in the case	2.4			
Total busy time		7.1 mins	Machine requirement		1

Table 3. 7 The detail of the operator work in pushing

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Loading capacitor into vibrating plate	0.9	3	Shipping to the next workstation	1.8
2	Collecting semi-finished products	1.6			
Total busy time	4.3 mins	Number of operators required			1

Table 3. 8 The operation of the machine in collecting

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Check product performance	1.8	3	Deliver defective products to the rework area	0.8
2	Capacitor classification according to order	2.6	4	Shipping to potting station	0.6
Total busy time		5.8 mins	Machine requirement		1

Table 3. 9 The detail of the operator work in collecting

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Set up the machine for collecting	1.4	3	Shipping to potting station	0.6
2	Deliver defective products to the rework area	0.8			
Total busy time	2.8 mins	Number of operators required			1

Table 3. 10 The operation of the machine in 1st potting

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Vibrating plate feeding	1.4	4	Hook in aluminum strip	1.2
2	1st potting	1.8	5	Aluminum strips are piled into the tray	1.3
3	Enter the small turntable	1.8	6	Collecting the tray when full	2.1
Total busy time	9.6 mins		Machine requirement	2	

Table 3. 11 The operation of the machine in 1st baking

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Trolley entry	1	4	Trolley out	1
2	Start the oven	0.5	5	Cooling	40
3	1st baking	30	6	Shipping to 2nd potting	1.2
Total busy time	73.7 mins		Machine requirement	2	

Table 3. 12 The detail of the operators in 1st potting and 1st baking

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Set up potting machine	1.2	4	Start oven	0.3
2	Collecting the tray	1.4	5	Collect the trolley	1.4
3	Shipping to oven	0.6	6	Shipping to 2nd potting	0.8
Total busy time	5.7 mins	Number of operators required		2	

Table 3. 13 The operation of the machine in 2nd potting

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Waiting for 1st baking	41.2	5	Aluminum strips are piled into the tray	1.3
2	2nd potting	2.4	6	Collecting the tray when full	2.1
3	Enter the small turntable	1.8	7	Adjustment machine	
4	Hook in aluminum strip	1.2			
Total busy time	50 mins		Machine requirement	2	

Table 3. 14 The operation of the machine in 2nd baking

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Waiting for 2nd potting finish	50	4	2nd baking	30
2	Trolley entry	1	5	Trolley out	1
3	Start the oven	0.5	6	Waiting for cooling	40
Total busy time	122 mins		Machine requirement	2	

Table 3. 15 The detail of the operators in 2nd potting and 2nd baking

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Set up potting machine	2.1	4	Start oven	0.3
2	Collecting the tray	1.5	5	Collect the trolley	1.6
3	Shipping to oven	0.6	6	Shipping to 2nd potting	0.8
Total busy time	6.9 mins	Number of operators required		2	

3.3 Proposed alternatives

The key to reducing the idle time is the proper layout and the task assignment of operators. Therefore, in order to ensure that the proposed alternatives can represent the real situation, the following steps should be taken.

Step 1: Collect the detailed information for machines and operators.

Step 2: Evaluate current layout through WITNESS software in order to identify bottleneck problems.

Step 3: Proposed alternatives which are straight assembly line and U-shaped line based on bottleneck station problems.

Step 4: Reschedule operator assignments based on alternatives.

U-shaped lines are often considered the best way to improve layout in past literature. However, most factories still use the traditional straight assembly line layout, so does the company in this case study. Therefore, two alternatives are proposed in this case study, U-shaped line and straight assembly line. In the end, alternatives will be compared through WITNESS simulation software.

The above data for the machines and operators will be set in the WITNESS simulation software to ensure that the software can realistically present the current layout and derive accurate idle time.

3.4 WITNESS simulation software

WITNESS is a simulation package for the Lanner Group. It is not only one of the simulation software used to analyze the factory layout. The software also provides predictive results, identifies bottlenecks, analyzes problems and develops solutions. It also provides immediate feedback under certain predetermined conditions (Markt et al., 1997).

WITNESS can be used to simulate a complete production run. This allows people to design a facility and preview how the assembly line operates in practice. This is a good way to predict and resolve any problems and inefficiencies that may exist if the production line is built in the current configuration. This software can clearly demonstrate any production bottlenecks, over-idle resources, storage areas that are too small or too large, and any potential problems with the labor associated with part processing.

It is a sophisticated simulation tool used by thousands of organizations around the world to analyze and validate business processes, achieve desired process performance or support continuous process improvement activities. Each element can be in multiple "states" depending on the type of element set in the model. These states can be idle (waiting), busy (processing), blocking, installing, disconnecting, waiting for labor (loop/set/repair), and so on. Complex routing and control logic is implemented through a number of input and output rules and special operations that use functions.

However, in this case study, the assembly line layout change involves the assignment of the operator's tasks. Operators may need to operate multiple machines at the same time, in which case multiple parameter settings need to be considered. This makes it impossible to get the accurate idle time by calculation. Therefore, this case study will use WITNESS simulation software to evaluate alternatives.

Chapter 4 SIMULATION RESULTS

4.1 Evaluate current layout

First of all, current layout is built in WITNESS simulation software as shown in appendix 1 and appendix 2. Model is built into the software based on previously collected real data in order to obtain more accurate data for performance of machines and operators. All workstations and operator data have been carefully set up in the software to avoid errors during the analysis.

The case company's assembly line has 7 stations, of which potting station includes more procedures such as spot welding, casing, pushing, collecting and potting. After running the simulation program, we can collect information about various performance indexes at workstations in the current layout which is shown in Table 4.1. And Figure 4.1 shows the idle time and busy time of a total of 15 operators on the current manual assembly line.

Table 4. 1 Performance of workstations under current layout

	%Idle	%Busy	%Set up	%Broken down
Hot Pressing	9.653	85.65	2.89	1.82
Wrapping	25.05	70.665	1.71	2.57
Spray Welding	16.49	77.09	3.85	2.57
Spot Welding	21.90	68.52	6.25	3.33
Casing	19.56	78.15	1.25	1.04
Pushing	21.67	68.13	7.29	2.92
Collecting	31.88	57.29	7.50	3.33
1st potting	28.98	64.66	4.69	1.67
1st baking	30.96	64.04	3.75	1.25
2nd potting	48.46	46.12	4.17	1.25
2nd baking	60.28	36.60	2.08	1.04

From Table 4.1 we can see that the idle time of the machines for 2nd potting and 2nd baking are significantly higher than the previous workstations. Due to the time for waiting cooling takes so long that led 2nd baking even idle about 60% of the total production time.

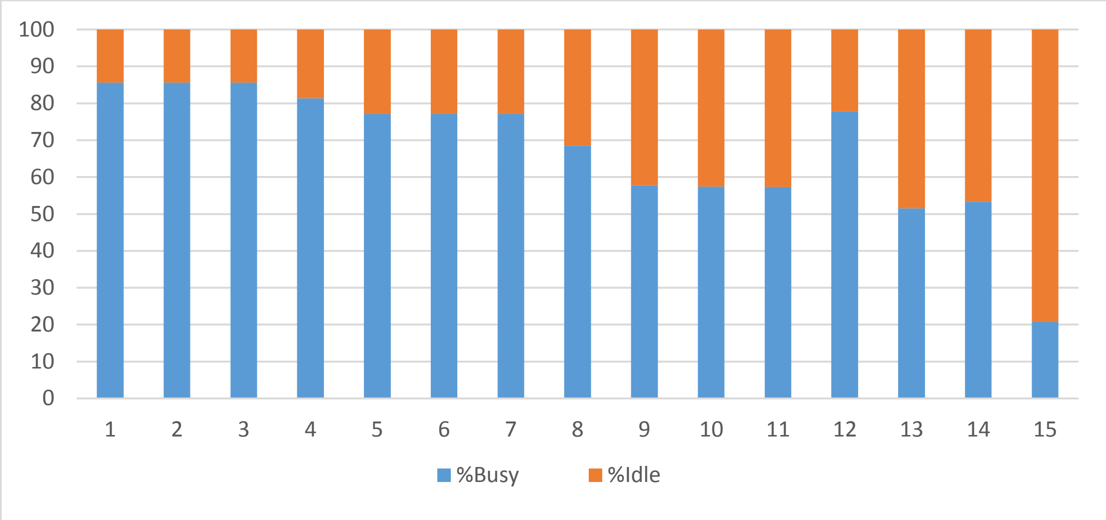

Figure 4. 1 Idle time and busy time of operators under the current layout

After the further analysis of the operator's data through the software found that some workstations were always busy but the operators work in the workstations had a long idle time. Such as the operator09 work in casing station and the operator10 work in pushing station. This is because not every machine requires the operator to make instructions all the time. However, the operator's tasks are not properly assigned in the current layout, which cause the operator to be idle after completing the job in the workstation. On the other hand, waiting for the cooling time after 1st baking also affecting the idle time of the operators in 2nd potting and 2nd baking.

According to the Electronic Engineering Research Institute, the non-production time should be less than 35% in the production line of various types of products. Therefore, this case study will try to improve the bottleneck processes at the potting and baking stations by considering some alternatives for the layout change. And the task assignment of operators also be considered according the layout of alternatives.

4.2 Alternative 1- straight assembly line

The current straight assembly line layout is shown in Figure 4.1, two runs on the potting and baking are needed to avoid the problem of overfilling. Alternative 1's layout is shown in Figure 4.2. The associated WITNESS simulation model is built and shown in Appendix 3, where the straight assembly line of the case company is suggested. The two runs on the baking process have been avoided by rearranging the workstation without affecting the normal process flow. Spot welding, casing and pushing station remain stationary, within which one operator is assigned for each task. After putting the capacitor into the case, the operator performs 1st potting and 2nd potting. Then collection of semi-finished products is carried out after the end of the second potting, followed by baking.

Figure 4.2 The current layout of potting and baking station

Figure 4.3 The layout of potting and baking station in alternative 1

After changing the layout, the operator's task assignment also needs to be considered. In the current layout, a potting and baking machine is operated by an operator at the same time. However, the waiting time for baking and cooling allows the operator to take care of both machines at the same time. As the result that the potting machine only needs to set up the machine and collect the finished product and also considering that potting and baking machines do not require complex and high skilled work. The tasks for operator 10, operator12 and operator13 in Alternative 1 will be rearranged as shown in the following tables.

Table 4. 2 The detail of the operator10 work in 1st potting

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Set up machine1 for potting	1.2	4	Collecting the tray for machine2	1.4
2	Set up machine2 for potting	1.2	5	Shipping to pushing	1.2
3	Collecting the tray for machin1	1.4			
Total busy time	6.4 mins	Number of operators required		1	

Table 4. 3 The detail of the operator12 work in 2nd potting

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Set up machine1 for potting	1.2	4	Collecting the tray for machine2	1.4
2	Set up machine2 for potting	1.2	5	Shipping to baking	0.6
3	Collecting the tray for machine1	1.4			
Total busy time	5.8 mins	Number of operators required			1

Table 4. 4 The detail of the operator13 work in collecting and baking

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Set up the machine for collecting	1.4	4	Deliver defective products to the rework area	0.8
2	Trolley entry into oven	1	5	Collect the trolley	1.4
3	Start oven	0.3			
Total busy time	4.9 mins	Number of operators required			1

In this way, the cooling time that needs to be waited after 1st baking in the current layout can be avoided. It also enables the operator13 who not only having a long idle time but also responsible for the collecting station in the layout of the alternative 1 to perform the work of the collecting and baking station simultaneously.

After running the simulation program, the performance of the workstations in Alternative 1 is shown in Table 4.5. There is a significant reduction in idle time at 1st potting and 2nd potting workstations. This is because the semi-finished product does not need to wait for cooling, and can directly carry out the subsequent process. The number of workstations required has also been reduced from 12 to 10.

Table 4. 5 Performance of workstations under alternative 1

	Spot welding	Casing	Pushing	Collecting	1st potting	2nd potting	1st baking	2nd baking
% idle of Current layout	21.90	19.56	21.67	31.88	28.98	48.46	30.96	60.28
% idle of Alternative 1	18.81	18.53	17.19	25.48	23.31	34.83	30.31	-
Improvement	14%	5%	21%	20%	20%	28%	2%	-

However, because the number of workstations required is reduced, the number of operators required is also reduced from 8 to 6. Through the appropriate task assignment, the operator13 can operate the collecting and baking stations at the same time. The working efficiencies of the operators required after the software running is shown in Table 4.6.

Table 4. 6 Idle time and busy time of operators under the alternative 1

Operators	08	09	10	11	12	13
% Busy	74.56	73.67	77.87	68.46	63.28	71.94
% Idle	25.44	26.33	22.13	31.54	36.72	28.06

4.3 Alternative 2-U shaped line

Alternative 2 is designed with the U-shaped line as shown in Figure 4.3. The associated simulation model is build in Appendix 4. The layout is designed according to the idle time of the operators without affecting the normal process. In Alternative 1, it was found that the change of the workstations can avoid the problem of two runs on the baking; hence the idle time of the 2nd potting and 2nd baking workstations is reduced. However, some operators are still idle for a long time.

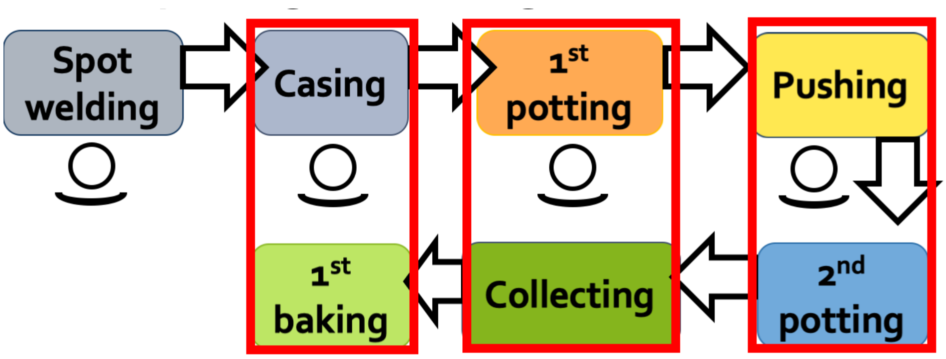

Figure 4.4 The layout of potting and baking station in alternative 2

Therefore, the purpose of alternative 2 is to use the characteristics of the U-shaped line making operators who with long idle time can operate adjacent machines at the same time in order to reduce the idle time of operators. Due to the site constraints of current layout in this case study, U-shaped line design was performed for potting and baking workstations in Alternative 2. Arrange the workstations placement order as in Alternative 1. But the U-shaped line can make the workstations become closer, which gives the operator the opportunity to operate multiple machines at the same time to avoid the problem of operators being idle.

However, about the task assignment of operators in alternative 2, spot welding requires an operator with high skill. Moreover, both the machine and the operator's idle ratio are lower than other workstations. Therefore, the task of assignment for operator08 work in spot welding remains unchanged. The work performed by the operators in the casing, collecting and pushing stations is short and uncomplicated. Through the design of the U-shaped line, the operator can handle the problem of the adjacent machine nearby. Therefore, in alternative 2, the tasks can be reassigned to the operators as shown the detail in the following tables.

Table 4. 7 The detail of the operator09 work in casing and baking

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Loading capacitor into vibrating plate	1.2	4	Collecting semi-finished products	1.5
2	Trolley entry into oven	1	5	Collect the trolley	1.4
3	Start oven	0.3			
Total busy time	5.4 mins	Number of operators required	1		

After operator09 finish loading the capacitor into the vibrating plate then start the oven to perform baking. Consider the waiting time for baking, operator09 can collect semi-finished products in casing station during the waiting time for baking.

Table 4. 8 The detail of the operator10 work in 1st potting and collecting

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Set up the machine for collecting	1.4	4	Collecting the tray for machin1	1.4
2	Set up machin1 for potting	1.2	5	Collecting the tray for machine2	1.4
3	Set up machin2 for potting	1.2	6	Deliver defective products to the rework area	0.8
Total busy time	7.8 mins	Number of operators required	1		

Since the machine in the collecting station will not stop running unless the machine is broken. Operator10 work in collecting station only needs to set up the machine and deliver defective products to the rework area. Therefore, operator10 have enough time to start the machine and collect the semi-finished products in the potting station after set up the machine in collecting station.

Table 4. 9 The detail of the operator11 work in pushing and 2nd potting

No.	Operation description	Time (min)	No.	Operation description	Time (min)
1	Loading capacitor into vibrating plate	0.9	4	Collecting semi-finished products in pushing	1.6
2	Set up machine1 for potting	1.2	5	Collecting the tray for machine1	1.4
3	Set up machine2 for potting	1.2	6	Collecting the tray for machine2	1.4
Total busy time	7.7 mins	Number of operators required		1	

Loading capacitor into vibrating plate and set up machine for potting all takes only a short time. Since the capacitor takes more time in the potting than the pushing. After start potting machine, operator11 can utilize the waiting time for potting to collect semi-finished products in pushing station.

After running the simulation program, the workstations required for potting and baking stations are shown in Table 4.10. As compared with current layout, only one-time baking is required in alternative 2. The layout in alternative 2 also helps to reduce the total number of workstations required from 12 to 10. The idleness between workstations has been significantly reduced especially at 1st potting and 2nd potting station.

Table 4. 10 Performance of workstations under alternative 2

	Spot welding	Casing	Pushing	Collecting	1st potting	2nd potting	1st baking	2nd baking
% idle of Current layout	21.90	19.56	21.67	31.88	28.98	48.46	30.96	60.28
% idle of Alternative 2	19.73	17.42	17.19	22.52	19.78	32.00	27.38	-
Improvement	10%	11%	21%	29%	32%	34%	12%	-

Table 4.11 shows the efficiencies of operators required in Alternative 2. The U-shaped line design allows for a more appropriate allocation of idle operators. Operator09 can operate both casing and baking, operator10 can operate 1st potting and collecting at the same time, operator11 can operate both pushing and 2nd potting. Proper task assignment allows operators to perform multiple

machines simultaneously, reducing staff waste and idle time. The required number of operators are reduced from 8 to 4.

Table 4. 11 Idle time and busy time of operators under the alternative 2

Operators	08	09	10	11
% Busy	79.68	80.62	82.57	78.54
% Idle	20.32	19.38	17.43	21.46

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this case study, the current assembly layout was built in WITNESS simulation software according to the real data in order to further analyzes the bottleneck station. After understanding the bottleneck station problem, we develop improved layouts based on the problem and propose two kinds of alternatives for potting and baking stations. The task assignment of the operators is also considered and varies depending on the alternatives. The target is to determine whether we can improve efficiency in terms of the idle time of the workstation, the number of workstations, the required operators and the idle time of the operators.

Table 5.1 compares the current layout with the two alternatives using four indicators. From the results, we can find that the changes of the layout in alternative 1 which is the traditional straight assembly line can also help provide the flexibility of personnel scheduling, thereby improving the efficiency of the assembly line and reducing the idle time. Compared to the current layout, Alternative 1 can reduce machine idle time by 12%, and the number of workstations required is reduced by two. On the other hand, the average idle time of the operator is also reduced by 16%, and the number of operators required is also reduced by two. This proves that not only U-shaped lines can help achieve the flexibility of staff scheduling, but also through the appropriate layout changes of traditional straight line the above improvement can be achieved.

In Alternative 2, although the average idle time of the workstation and the number of workstations required are not far from the straight assembly line in alternative 1. However, there has been a significant improvement in the idle time and number of operators. In consideration of the cost and the existing conditions, the redundant operators can be dispatched to other assembly lines to help achieve the reduction in costs and improving efficiency. Due to the limitations of this case study only one assembly line was considered. However, there are common workstations among multiple assembly lines in this case study company. In the future, it would be better if multiple assembly lines of the company can be considered simultaneously by combing straight assembly line and U-shaped line.

Table 5. 1 Comparison of alternatives to current layout

	Average % idle Of workstations	Number of workstations	Average % idle Of operators	Number of operators
Current layout	32.96	12	44.83	8
Alternative 1	24.07	10	28.37	6
Alternative 2	22.29	10	19.65	4

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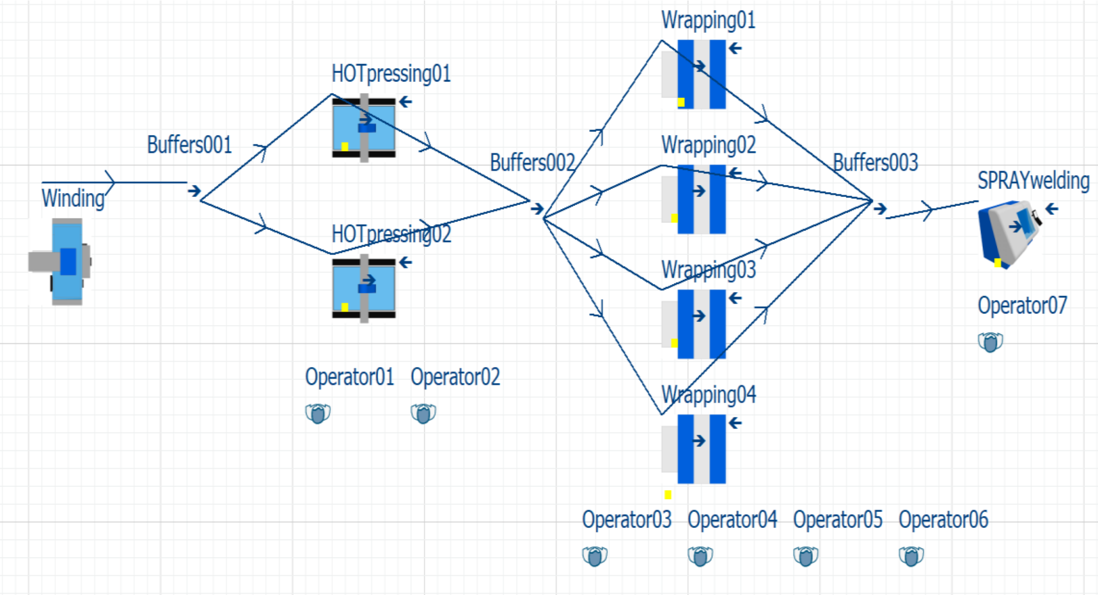
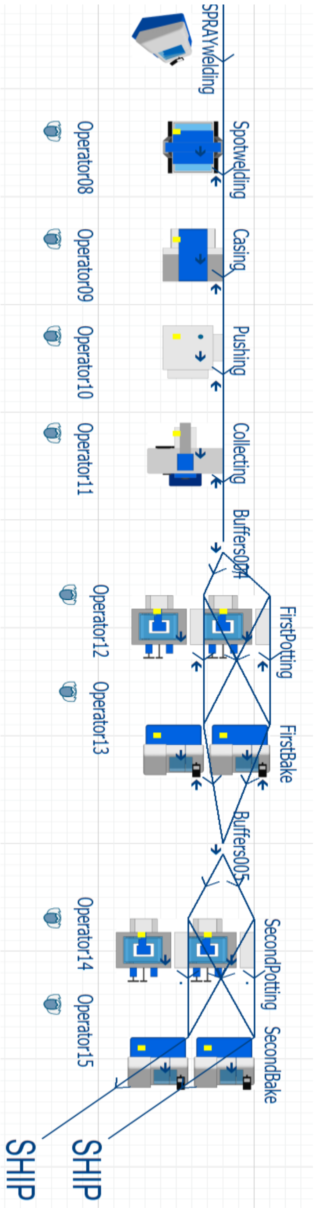
APPENDICES

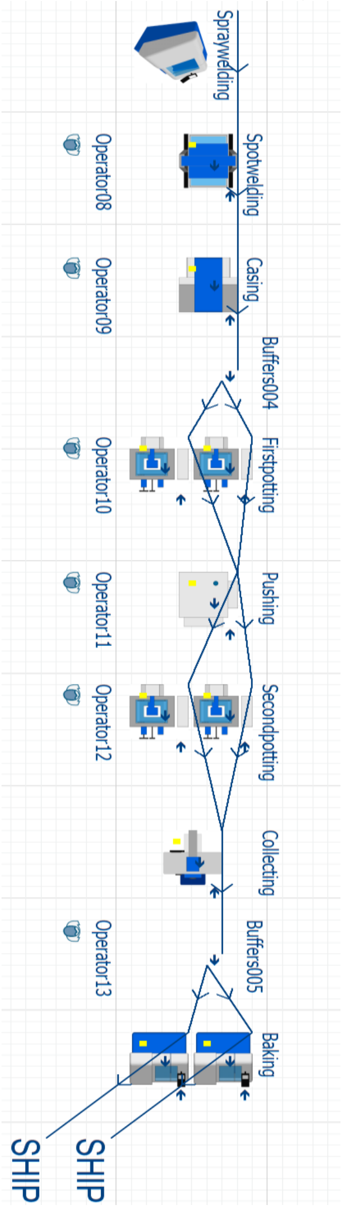
Appendix 1. Current manual assembly line layout constructed in WITNESS software from station 1 to station 4



Appendix 2. Current manual assembly line layout constructed in WITNESS software from station 4 to station 7



Appendix 3. The layout of alternative 1 constructed in WITNESS software



Appendix 4. The layout of alternative 2 constructed in WITNESS software