

**TASK AND WORKER ASSIGNMENT IN
THE SHARED-MACHINE U-SHAPED ASSEMBLY LINE**

The seal of Mahidol University is a large, faint circular emblem in the background. It features a central five-tiered umbrella (parasol) with a flame-like base, surrounded by Thai script. The outer ring of the seal contains the text 'มหาวิทยาลัยมหิดล' (Mahidol University) and 'พุทธทศวรรษ' (Buddhist Decade).

PATTARAWAN KHEMYONG

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF
ENGINEERING (INDUSTRIAL ENGINEERING)
FACULTY OF GRADUATE STUDIES
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Thesis
entitled

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THE SHARED-MACHINE U-SHAPED ASSEMBLY LINE**

Pattarawan Khemyong

Miss Pattarawan Khemyong
Candidate

Ronnachai Sirovetnukul

Lect. Ronnachai Sirovetnukul, Ph.D.
Major advisor

Duangpun Kritchanai Singkarin

Assoc. Prof. Duangpun Kritchanai
Singkarin, Ph.D.
Co-advisor

Thanakorn Naenna

Asst. Prof. Thanakorn Naenna, Ph.D.
Co-advisor

B. Mahaisavariya

Prof. Banchong Mahaisavariya,
M.D., Dip. Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

Thanakorn Naenna

Asst. Prof. Thanakorn Naenna, Ph.D.
Program Director
Master of Engineering Program in
Industrial Engineering
Faculty of Engineering,
Mahidol University

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Miss Pattarawan Khemyong
Candidate



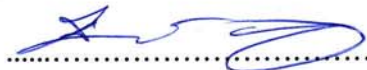
Lect. Ronnachai Sirovetnukul, Ph.D.
Member



Assoc. Prof. Parames Chutima,
Ph.D.
Chair



Assoc. Prof. Duangpun Kritchanhai
Singkarin, Ph. D.
Member



Asst. Prof. Thanakorn Naenna,
Ph. D.
Member



Prof. Banchong Mahaisavariya,
M.D., Dip. Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University



Lect. Worawit Israngkul, M.S.
Dean
Faculty of Engineering
Mahidol University

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Pattarawan Khemyong

TASK AND WORKER ASSIGNMENT IN THE SHARED-MACHINE U-SHAPED ASSEMBLY LINE

PATTARAWAN KHEMYONG 5336115 EGIE/M

M.Eng. (INDUSTRIAL ENGINEERING)

THESIS ADVISORY COMMITTEE: RONNACHAI SIROVETNUKUL, Ph.D.,
DUANGPUN SINGKARIN, Ph.D., THANAKORN NAENNA, Ph.D.

ABSTRACT

This study presents a new approach on a U-shaped assembly line namely, task and worker assignment in the Shared-machine U-shaped line. Because the purpose of this study is to improve the performance of the traditional U-line, decision variables (factors) influencing the performance of assembly line balancing were summarized and identified. A case study of a sample room was done on a garment manufacturing company in Thailand. In order to revolutionize and consider the lean concept of waste reduction and synchronous movement, three objective functions were considered: minimizing the number of workstations (workers), minimizing walking time, and maximizing full work. The results showed that the Shared-machine U-shaped line has the same number of workstations (or workers) as the straight line and traditional U-line, but the walking time is less than the latter while the average utilization of the worker is better satisfied. In addition, the average utilization of the machines is better than other lines. Hence, the proposed model can help improve the task and worker assignment and increase the utilization of machine and worker in a manufacturing company. Finally, a way to apply the assignment to the model under a real situation has been provided.

KEY WORDS: SHARED-MACHINE / U-SHAPED ASSEMBLY LINE / TASK
AND WORKER ASSIGNMENT / IDENTIFIED FACTOR

การมอบหมายงานและพนักงานในสายการประกอบรูปตัวยูที่มีการใช้เครื่องจักรร่วมกัน
TASK AND WORKER ASSIGNMENT IN THE SHARED-MACHINE U-SHAPED
ASSEMBLY LINE

ภัทรวรรณ แคมยงค์ 5336115 EGIE/M

วศ.ม. (วิศวกรรมอุตสาหกรรม)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์: รณชัย ศิริโรเวฐนกุล, Ph.D., ดวงพรรณ ศฤงคารินทร์, Ph.D.,
ธนกรณ์ แน่นหนา, Ph.D.

บทคัดย่อ

การศึกษานี้นำเสนอวิธีการมอบหมายงานบนสายการประกอบรูปตัวยูรูปแบบใหม่ที่มีชื่อว่า การมอบหมายงานและพนักงานในการสายประกอบรูปตัวยูที่มีการใช้เครื่องจักรร่วมกัน เนื่องจากการศึกษานี้มีวัตถุประสงค์ที่จะพัฒนาสายการประกอบรูปตัวยูแบบดั้งเดิมให้ตอบสนองต่อการใช้ประโยชน์จากเครื่องจักรและพนักงานที่มากขึ้น จึงได้ทำการรวบรวม สรุป และระบุตัวแปรตัดสินใจ (ปัจจัย) ที่มีอิทธิพลต่อการจัดสมดุลของสายประกอบ รวมถึงการเก็บข้อมูลจากห้องตัวอย่างของบริษัทผู้ผลิตเสื้อผ้าสำเร็จรูปกรณีศึกษา และเพื่อที่จะทำให้เกิดการเปลี่ยนแปลงในทางที่ดีขึ้นและเป็นไปตามหลักแนวความคิดเกี่ยวกับการลดของเสียและการเคลื่อนย้าย สมการเป้าหมายหลักของการศึกษาจึงพิจารณาจาก 3 ฟังก์ชันวัตถุประสงค์ (1) จำนวนสถานีงานที่น้อยที่สุด (2) เวลาเดินที่น้อยที่สุด และ (3) ภาระงานเต็มทีของสถานีงานสูงที่สุด จากผลการศึกษาแสดงให้เห็นว่า สายการประกอบรูปตัวยูที่มีการใช้เครื่องจักรร่วมกันมีจำนวนสถานีงาน (พนักงาน) เท่ากันกับสายการประกอบแบบเส้นตรงและแบบตัวยูดั้งเดิม แต่จะใช้เวลาน้อยกว่าแบบตัวยูดั้งเดิม ในขณะที่มีภาระงานเต็มทีของสถานีงาน (พนักงาน) อยู่ในระดับที่กำหนด นอกจากนี้สายการประกอบรูปตัวยูรูปแบบใหม่มีการใช้ประโยชน์ของเครื่องจักรโดยเฉลี่ยสูงกว่าสายการประกอบทั้งสองแบบ ดังนั้นรูปแบบสายประกอบและวิธีการที่นำเสนอจึงสามารถช่วยปรับปรุงการมอบหมายงานและพนักงานให้ดีขึ้น รวมถึงเพิ่มการใช้ประโยชน์ของเครื่องจักรและพนักงานได้ และสุดท้ายการศึกษานี้ได้จัดทำแนวทางการดำเนินการสำหรับบริษัทที่สนใจเพื่อนำไปประยุกต์ใช้ในสถานการณ์จริงได้อีกด้วย

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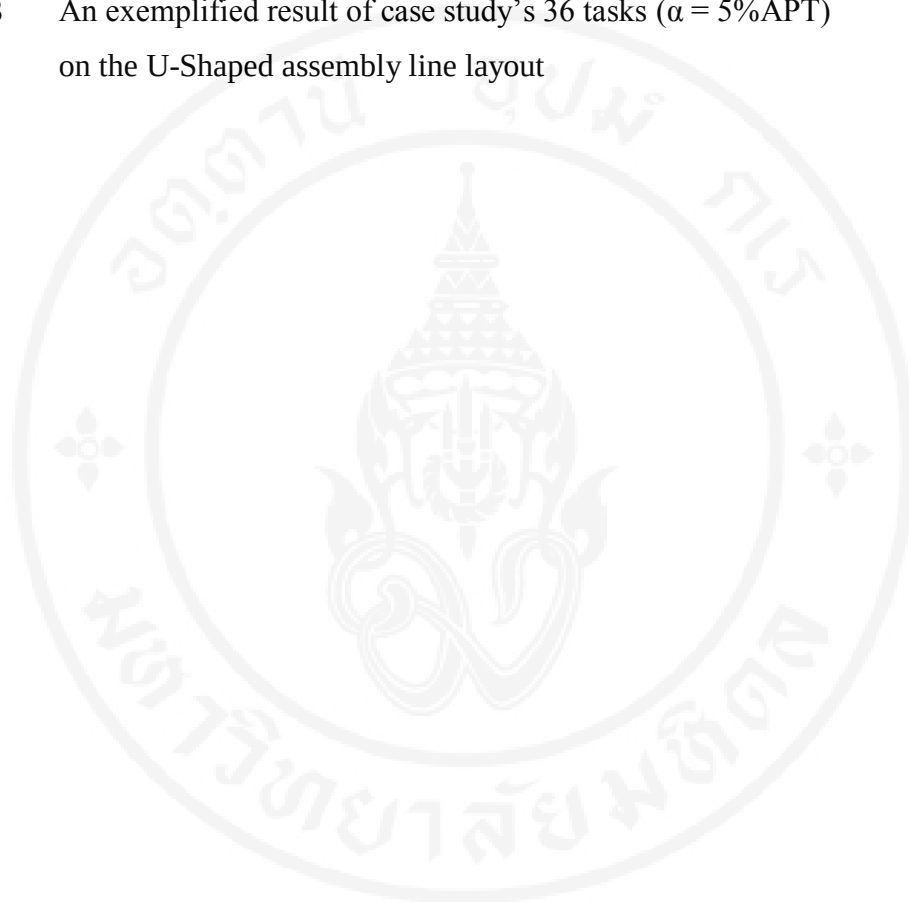
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CHAPTER I

INTRODUCTION

1.1 Background and statement of problems

Almost all apparel manufacturers try their best to finish the assembly work fast by increasing machine or worker utilization but at the same time reducing production cost (Chen *et al.*, 2012). Assembly line balancing is therefore a critical issue to improve the efficiency and to enhance competitiveness (Chen *et al.*, 2012). In general, the production process of garment is separated into four main phases, that is, 1) designing and clothing pattern generation, 2) fabric cutting, 3) sewing, and 4) ironing/packing (Chen *et al.*, 2012). The machines are arranged on a layout by one task for each machine according to production process in the case of the traditional straight line and U-shaped line (Figure 1.1 and 1.2).

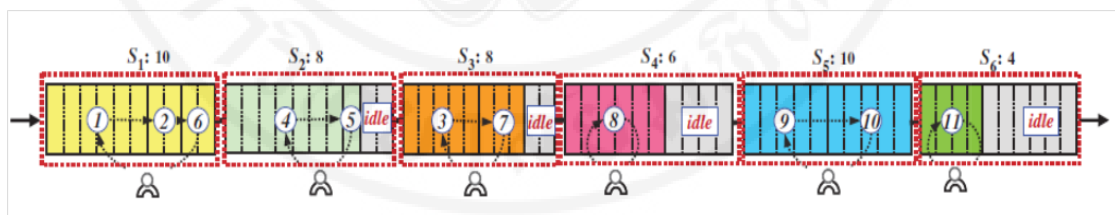


Figure 1.1 An example of a straight assembly line (Hwang and Katayama, 2010)

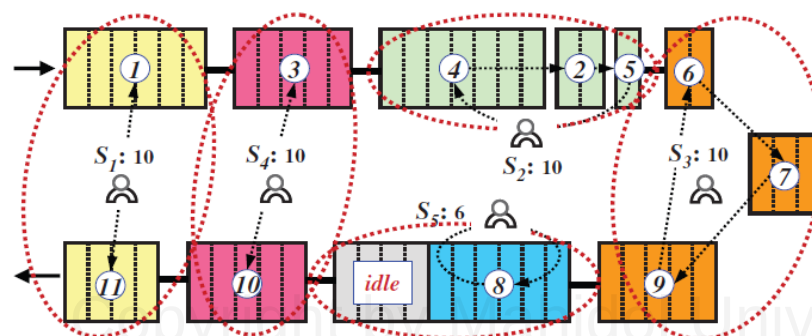


Figure 1.2 An example of a U-shaped assembly line (Hwang and Katayama, 2010)

In the U-shaped lines, operators work inside. One operator supervises both the entrance and the exit of the line (Miltenburg, 2001). Its characteristic that makes it different from a straight line is that the entrance and exit of the U-shaped line are the same position (Kara *et al.*, 2009).

After obtaining the data from the case study, especially in phase 3 and 4, it was observed that the factory divides the type of assembly line by the volume of production order. The main assembly line is run when the volume of production order is medium to high. Similarly, the special assembly line will be run when the volume of production order is low to medium. In addition, it was found that the line, especially the special line, has too many workers and machines. There are many types of the machines in the assembly line such as a sewing machine, a press machine, and an ironing machine. Moreover, any machine of those types can perform many tasks in a cycle by suitable assignment and layout. It deals with reducing the number of machines in assembly line. In other words, the utilization of those machines can be improved. Similarly, the worker utilization will be increased since workers are multiple skills to perform many operations in a cycle.

Most of the previous studies related to the assembly lines, especially in the U-shaped line, concentrate on assembly line balancing problems, which deal with the allocation of the tasks among workstations; in order that the precedence relations are satisfied and the given objective functions are optimized (Tasan and Tunali, 2008). Similarly, the issue of line balancing with the minimum number of resources has always been a serious problem in industry (Ağpak and Gökçen, 2005). Thus, a case of the Shared-machine U-shaped assembly line should be more concerned (Khemyong and Sirovetnukul, 2013). Likewise, a way to apply the assignment to the model under a real world should be explained.

Hence, the main objective in this study is to determine a way to assign the task and worker to workstation in a case of the Shared-machine U-shaped assembly line. Furthermore, the efficient usage of resources that carry out assembly line operations has been targeted by balancing the line with the minimum number of stations (Ağpak and Gökçen, 2005). Thus, three objective functions in this study i.e. minimized number of workstations (or workers), minimized walking time, and maximized full work are considered.

1.2 Objective of the study

This research aims to determine a way to assign the task to workers or workstations in a case of the shared-machine U-shaped assembly line under the multi-model in the same family and to identify the decision variables (factors) influencing the assembly line performance of the proposed model.

1.3 Scope of the work

This study focuses on three objective functions leading to improve the assembly line performance of the traditional U-line through the Shared-machine U-shaped assembly line, that is,

- 1) Minimized the number of workstations (workers) to save space and to reduce the production cost,
- 2) Minimized walking time to reduce the waste time according to the lean concept of waste reduction, and
- 3) Maximized full work to increase the utilization of workers. In addition, the least-utilized worker will be moved to do other works.

Note: due to this study focuses on the garment manufacturing, which the most of all machines can be moved and are inexpensive, minimized number of machines objective function is not taken into account.

In this study, the proposed model is presented via a case study of a sample room in the garment manufacturer of Thailand. The research focuses on the phase of sewing, ironing, and packing. However, the proposed model is subjected to the given assumptions and the shared machine selection is not taken into account. Moreover, only quantitative decision variables (factors) are identified.

1.4 Expected results

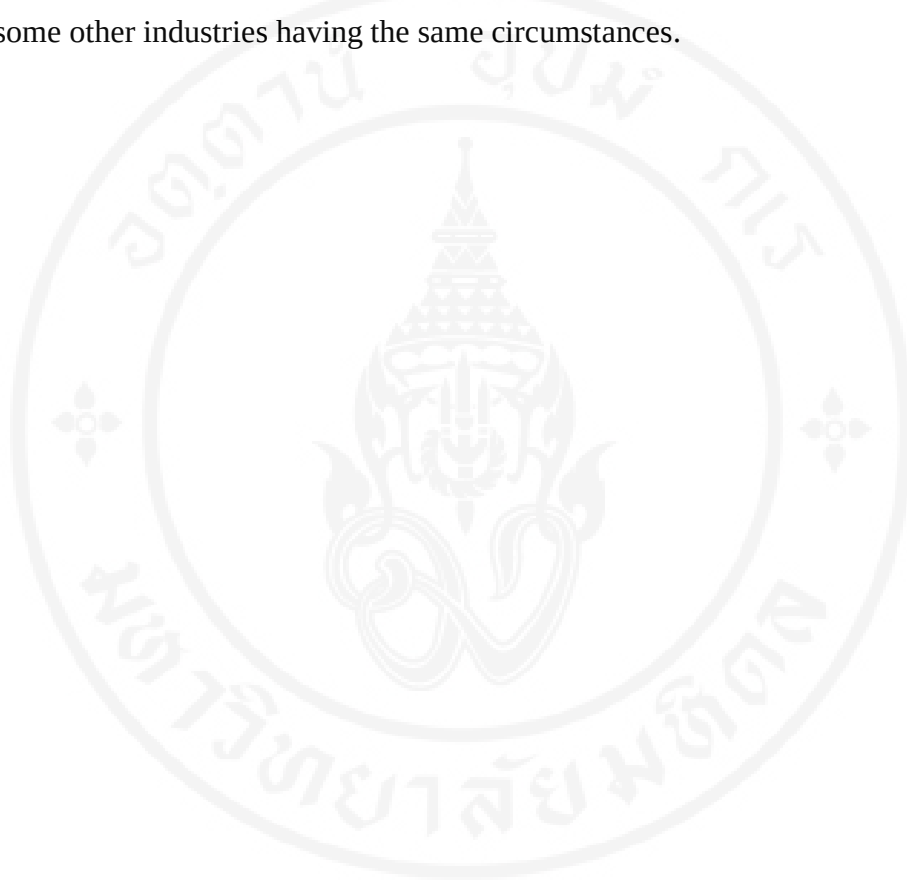
The expected results derive from this proposed research in the following.

- 1) The assignment of the task to workers or workstations steps for a case of the Shared-machine U-shaped assembly line under a multi-model production line.

2) The groups of quantitative decision variables (factors) influencing the assembly line performance of the proposed model are identified.

3) The proposed model can help improve the assignment and increase machine and worker utilization of a manufacturing company.

4) The proposed model and assignment would be generalized and utilized to some other industries having the same circumstances.



CHAPTER II

LITERATURE REVIEW

This chapter reviews foundation of background and previous studies in the part of assembly line and research tools to fulfill a gap of task and worker assignment in assembly line problems under a real case study of a sample room in a garment manufacturing. This chapter is divided into seven sections: (1) Garment manufacturing and its current situation, (2) Assembly lines, (3) Line balancing problems, (4) Double assignment, (5) The performance measures and decision variables (factors), (6) Research tools, and (7) Summary of the previous studies.

2.1 Garment manufacturing and its current situation

Garment manufacturing is a traditional industry with global competition (Chen *et al.*, 2012). Almost all apparel manufacturers try their best to finish the assembly work fast by increasing the utilization of machine and worker in order to reduce production cost (Chen *et al.*, 2012). The Just-in-time (JIT) production system has been adopted in today's manufacturing industry to improve the efficiency and to enhance competitiveness. Certainly, a U-shaped line that is also described as a special type of cellular manufacturing in JIT production systems (Milteneburg, 2001) is implemented.

In general, the production process of garment is separated into four main phases, that is, 1) designing and clothing pattern generation, 2) fabric cutting, 3) sewing, and 4) ironing and packing (Chen *et al.*, 2012) that are shown in Figure 2.1. In the case of U-line, the machines are arranged around U-shaped layout by one task (a group of task) for each machine according to the production process. However, after obtaining the data from the case study especially in phase 3 and 4, it was observed that the assembly line, particularly the special line in a sample room, has too many workers

and machines. Multi-skilled worker is able to perform many operations. Similarly, some types of the machines in the line can perform many tasks in a cycle. Hence, the utilization of the machines and workers can be improved by a suitable of assignment and layout.

In the existent literature of assembly line especially line balancing, a case of the Shared-machine U- shaped assembly line including a way to apply the assignment to the model under a real world has not been studied excluding Khemyong and Sirovetnukul (2013) (Section 2.7.1).

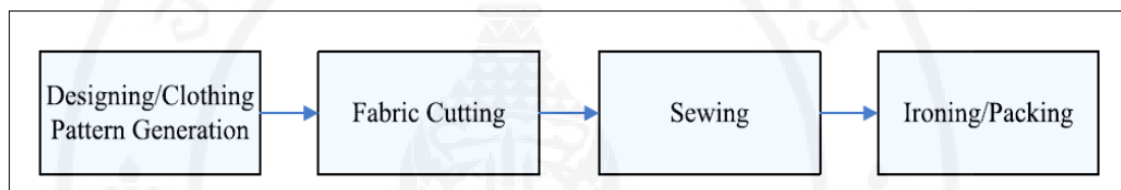


Figure 2.1 Garment manufacturing processes (Chen *et al.*, 2012)

2.2 Assembly lines

Assembly lines consist of successive workstations at which products are processed (Toksari *et al.*, 2008). A workstation is defined as a location along the flow line that the tasks are processed. It consists of human or robotic operators and/or machinery or equipment, and a task is the smallest indivisible work element (Baybars, 1986). Assembly lines can be classified as straight and U-shaped assembly lines by means of the shape of the line (Kara *et al.*, 2009).

2.2.1 Straight line

Straight assembly lines have been an important part of traditional mass production (Kara *et al.*, 2009). The machines in this layout are arranged into a “straight” line. However, U-shaped assembly lines have been increasingly substituted for traditional straight assembly lines in today’s production systems because the role of facility layout in JIT production systems (Kara *et al.*, 2009).

2.2.2 U-shaped assembly line

Because this study focuses on U-shaped assembly line, the background of this layout is described elaborately.

2.2.2.1 U-shaped line layouts

In a U-line layout, the machines are arranged around U-shaped by one task (or a group of task) for each machine according to production process and operators work inside. The U-lines are rebalanced periodically when production requirements change. It requires operators to be multi-skilled (Miltenburg, 2001). In addition, it also requires operators to work standing up and walking according to the layout and the assignment. Miltenburg (2001) divides the U-lines in terms of its complexity to many types as follows.

1) *A simple U-line* (Figure 2.2A and 2.2B) consists of a single U-line and a single product line. This type is a basic U-line that can be used alone or as a building block for another type. In Figure 2.2A, one operator supervises both the entrance and the exit of the line. When a finished product is pulled off the line, a new set of material is input to the line. In other words, no materials enter the line until a finished product leaves. In Figure 2.2B, a case of the U-line that is rebalanced by adding a worker to increase the output rate is presented. Consequently, the line stops quickly whenever there is a problem with a product or a machine.

2) *Multi-lines in a single U* consist of a single U-line and multiple lines. It is appropriate for producing more than two products. Figure 2.3 represents production lines for three products (A B C) organized in a single U-line manned by two workers. This U-line is flexible enough that one worker can run all three lines when reduced output is required, and extra workers can be added when increased output is required.

3) *A double-dependent U-line* consists of two U-lines. It is appropriate for producing two products. Figure 2.4 shows two U-lines manned by three workers. The arrangement is flexible enough that any number of workers can run the lines to accommodate changes in required output.

4) *An embedded U-line* consists of two U-lines, a large U-line encircling a small U-line. It is appropriate for producing two products or more.

However, it may take up a lot of space and require a lot of walking. In addition, a bigger disadvantage is that the same worker is usually not able to operate the entrance and exit operations of a line. Figure 2.5 represents the embedded U-line that all manned by two workers.

5) *Figure-eight-pattern U-lines* consist of multiple U-lines. It is appropriate for producing three products or more. It also has this disadvantage as same as an embedded U-line although it is less severe. The figure-eight-pattern: three U-lines with two workers are shown in Figure 2.6. Worker 1 runs line A and the first half of line B. Worker 2 runs the last half of line B and all of line C. This arrangement is called a figure-eight-pattern because the paths taken by each worker have a figure-eight shape.

6) *Multi-U-line facility* consists of lines and multiple U-lines. It is appropriate for producing more than three products in Figure 2.7.

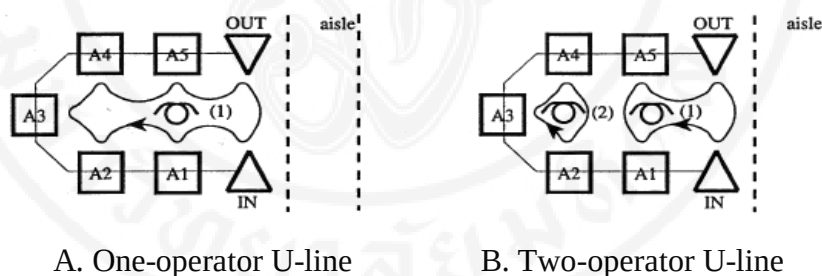


Figure 2.2 Simple U-lines (Miltenburg, 2001)

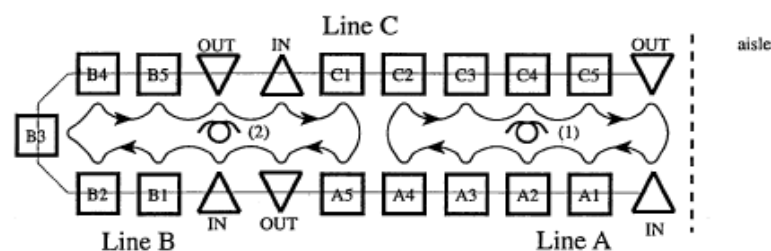


Figure 2.3 Multi-lines in a single U: Three lines in a single U (Miltenburg, 2001)

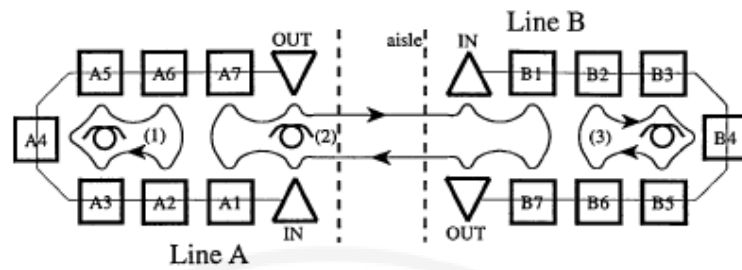


Figure 2.4 Double-dependent U-lines (Miltenburg, 2001)

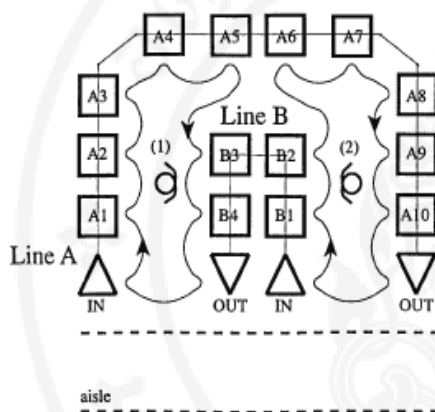


Figure 2.5 Embedded U-lines (Miltenburg, 2001)

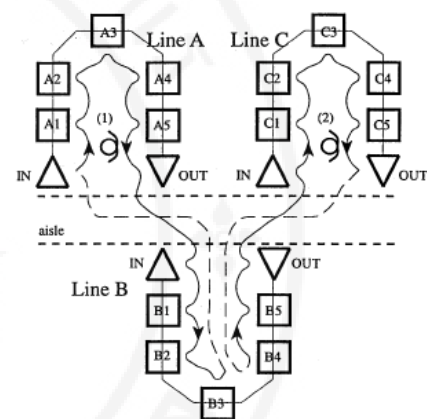


Figure 2.6 Figure-eight-pattern: three U-lines with two operators (Miltenburg, 2001)

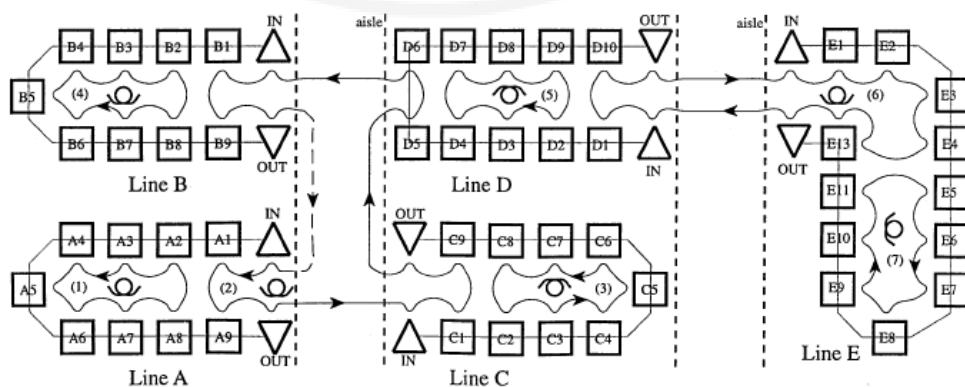


Figure 2.7 Multi-U-line facility (Miltenburg, 2001)

This study is interested in the embedded U-lines and adapts it under a real situation for a case study on a garment manufacturing.

2.2.2.2 Types of stations

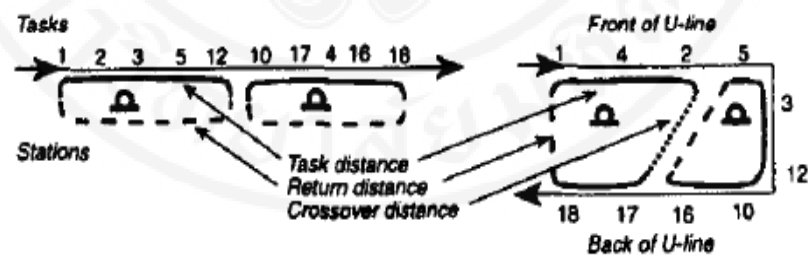
Miltenburg (1998) describes types of stations that are used in U-lines in the following.

1) A *regular station* includes a single group of tasks that is organized in a continuous sequence. There is no crossover distance in this station and the return distance is equal to sum of the task distances (Figure 2.8A). Large regular stations are not desirable on U-lines because it makes communications and problem solving difficult.

2) A *crossover station* includes two groups of tasks located on different sides of a U-line. An operator travels a crossover distance and a return distance to move between these groups of tasks (Figure 2.8B).

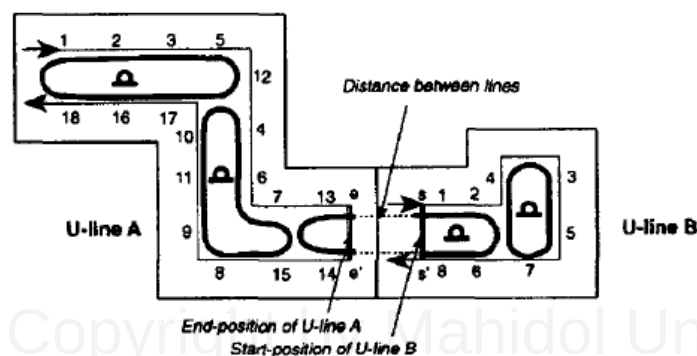
3) A *multiline station* includes tasks from two adjacent U-lines (Figure 2.8C). A return distance depends on the tasks assigned to the station. It will be travel distance between two U-lines or crossover distance.

Because the proposed model in this study is a single U-shaped assembly line, a multiline station is not taken into account.



A. Regular station

B. Crossover station



C. Multiline station

Figure 2.8 Types of station in U-lines (Miltenburg, 1998)

2.2.2.3 The figures of a U-shaped line

Nakade and Nishiwaki (2008) divide the figures in a U-shaped line into two types based on operations of each machine. That is,

1) The first type: there is no automated processing machine. After each worker operates an item at a machine, a worker takes it to the next machine.

2) The second type: the operation of each machine consists of both automated processing and operations by workers. When the automated machine operates the item already, a worker will unload it and operates this item. After that, a worker will load it back to the machine and walks to the next machine.

According to nature of many garments production lines in phase 3 and 4, this study focuses on the first type.

2.2.2.4 Benefits of a U-shaped line

The U-shaped production line is a special type of cellular manufacturing assembly line used in just-in-time (JIT) production systems (Miltenburg, 2001). Many benefits of the U-shaped layout are discussed by Miltenburg and Wijngaard (1994) as follows:

1) Visibility and communications are improved because the close proximity of operators to each other. When quality problems occur, they can be detected quickly and resolved. It is also easier for operators to help each other when problems arise.

2) Operators are multi-skilled to perform most of the operations in the U-line. They rotate through many stations in the U-line according to the assignment. This gives operators the skills that need to respond to problems as well as to changes in the cycle time. Moreover, multi-skilling also disperses the "know-how" through the organization and allows more operators to participate in efforts to improve the process. In addition to being able to perform each operation in the U-line, multi-skilled operators understand the relationships between operations and are better able to make improvements.

3) As a consequence of just-in-time principles, the output from a U-line may need to be adjusted from time to time matching the rate at which the

parts it produces are consumed by subsequent operations. The output rate of a U-line can be adjusted by adding or removing workers (called rebalancing the line).

4) The number of stations required on a U-line is never more than that required on a straight line. This is because there are more possibilities for grouping tasks into stations on a U-line.

After the U-shaped lines are implemented in manufacturing, the great results are reported (Miltenburg, 2001), that is, productivity was improved by an average of 76%. WIP was dropped by 86%. Lead time was reduced by 75%. Defective rates were dropped by 83%.

Therefore, this study is interested in adapting the U-shaped line with a real situation to improve the performance of an assembly line in garment manufacturing.

2.3 Line balancing problems

Assembly lines that consist of a sequence of tasks, each having an operational processing time and a set of precedence relations are widely adopted in manufacturing (Tasan and Tunali, 2008). Most of the previous studies related to the assembly lines focus on assembly line balancing problems, which deal with the allocation of the tasks among workstations; in order that the precedence relations are satisfied and the given objective functions are optimized (Tasan and Tunali, 2008).

2.3.1 Line balancing concepts

Miltenburg and Wijngaard (1994) describe concepts of line balancing in the following.

1) Straight line: a balance is determined by beginning with the first task in the task precedence network and grouping tasks into stations while moving forward through the network. Figure 2.9 presents a typical result of the well-known Jackson problem. Each of the 11 nodes represents a task to be completed. Tasks from a set of assignable tasks that predecessors have already been assigned are selected to form a station.

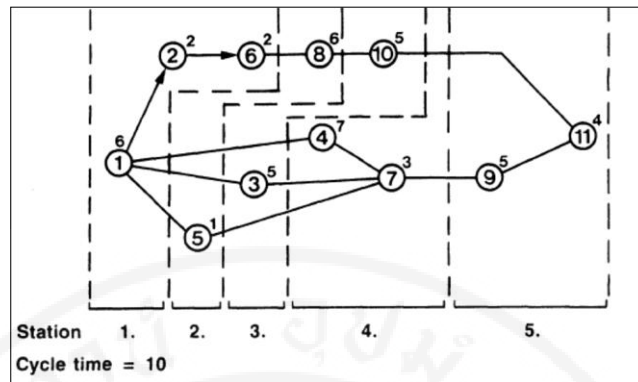


**Figure 2.9 Straight line balancing for Jackson's problem
(Miltenburg and Wijngaard, 1994)**

2) U-shaped line: a balance is determined by beginning with the first task in the task precedence network and grouping tasks into stations while moving forward through the network. In addition, a balance can also be obtained by beginning with the last task and moving backward through the network. An example of the simple U-line balancing problem determines a balance is presented in Figure 2.10.

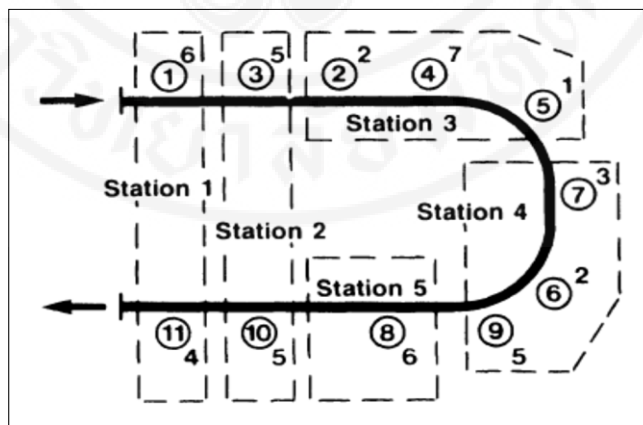


**Figure 2.10 U-shaped line balancing for Jackson's problem
(Miltenburg and Wijngaard, 1994)**

Tasks are grouped into stations, but stations can include tasks located on different parts of the production line. The set of assignable tasks is the union of the set of tasks that predecessors have already been assigned and the set of tasks that successors have already been assigned.

2.3.2 Classification schemes for Assembly Line Balancing Problems (ALBPs)

From a literature review of Tasan and Tunali (2008), the existent classification schemes for ALBPs are divided by the objective functions and problem structures that show in Figure 2.11.

Based on the objective functions, ALBPs is classified into seven types in the following.

1) Type-1 (ALBP-1) of this problem consists of assigning tasks to workstations that tries to minimize the number of workstations for a given cycle time. It can result in lower labor costs and reduced space requirements (Chen *et al.*, 2009). Type-1 is used when a new assembly line has to be implemented and installed (Hwang *et al.*, 2008; Zacharia and Nearchou, 2012). The proposed model in this study is based on this type.

2) Type-2 (ALBP-2) tries to minimize the cycle time for a given number of workstations. It deals with the maximization of the production rate of an assembly line (Chen *et al.*, 2009). Type-2 is used in an existing assembly line when changes in the production process and manufacturing requirements occur (Hwang *et al.*, 2008; Zacharia and Nearchou, 2012). It has a dual relationship with Type-1.

3) Type-E (ALBP-E) is the most general problem version that tries to maximize the line efficiency by simultaneously minimizing the cycle time and a number of workstations.

4) Type-3 (ALBP-3) is to maximize workload smoothness. The issue of workload smoothing in assembly lines allocates tasks among a given number of workstations, so that the workload is distributed as equally as possible (Chen *et al.*, 2009).

5) Type-4 (ALBP-4) is to maximize work relatedness. Work relatedness related tasks are defined as two tasks that are directly connected in a precedence diagram. Allotting such related tasks to the same station is certainly preferable to splitting them into several stations (Lee *et al.*, 2001).

6) Type-5 (ALBP-5) is the combination of Type-3 and Type-4.

Based on the problem structures, ALBPs can be classified into two groups as follows:

1) *The first group* divides ALBP into three models by types of the production lines (Becker and Scholl, 2006; Scholl, 1999) shown in Figure 2.12, that is,

1.1) Single-model assembly line balancing problem (SMALBP) involves only one product produced in line,

1.2) Multi-model assembly line balancing problem (MuMALBP) involves more than one product produced in batches. This study focuses on this type according to the production line of case study, and

1.3) Mixed-model assembly line balancing problem (MMALBP) refers to assembly lines, which are capable of producing a variety of similar product models simultaneously and continuously (not in batches),

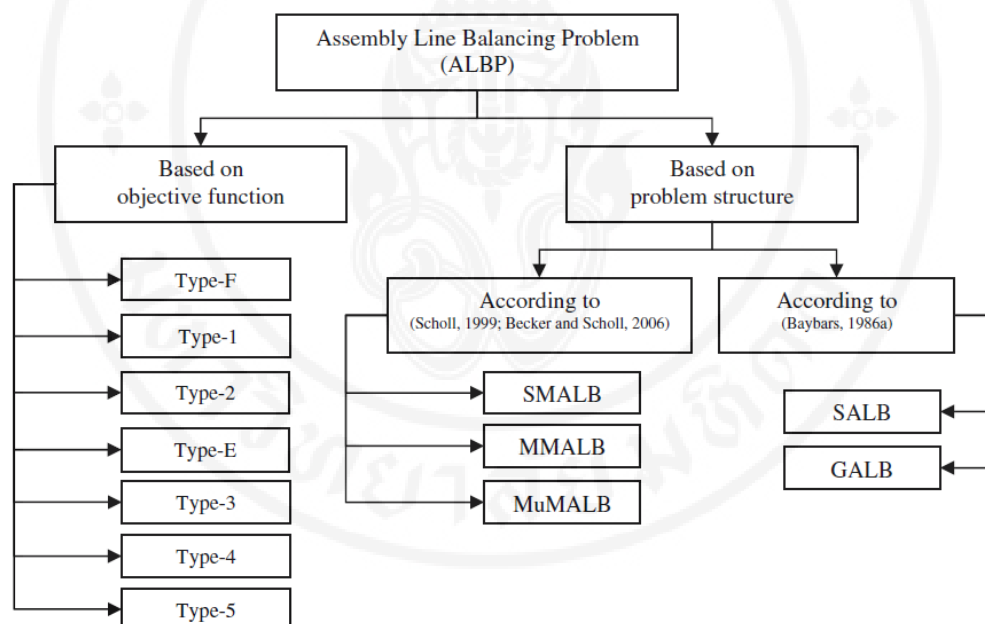


**Figure 2.11 Classification of assembly line balancing problems
(Tasan and Tunali, 2008)**

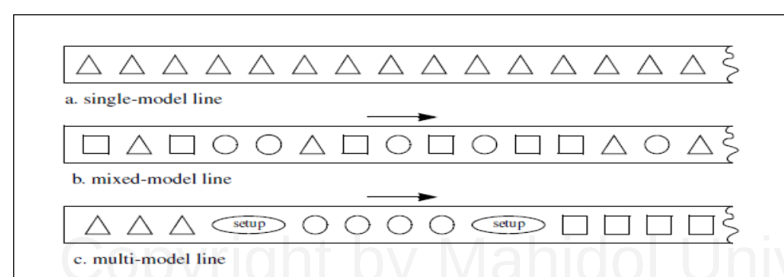


**Figure 2.12 Assembly lines for single and multiple products
(Becker and Scholl, 2006)**

2) *The second group* divides ALBP by two groups (Baybars, 1986; Boysen *et al.*, 2007) based on a set of assumptions by Boysen (2007), that is,

2.1) Simple assembly line balancing problem (SALBP) usually has a set of limiting assumptions:

- (S-1) Mass production of a single product,
- (S-2) All tasks are processed in a predetermined mode (no processing alternatives exist),
- (S-3) Paced line with a fixed common cycle time according to a desired output quantity,
- (S-4) The line is considered to be serial with no feeder lines or parallel elements,
- (S-5) The processing sequence of tasks is subject to precedence restrictions,
- (S-6) Deterministic (and integral) task times,
- (S-7) No assignment restrictions of tasks besides precedence constraints,
- (S-8) A task cannot be split among two or more stations, and
- (S-9) All stations are equally equipped with respect to machines and workers.

2.2) General assembly line balancing problem (GALBP) includes all of the problems that are not SALBP. It has been relaxed or somehow modified those assumptions by various models. For example, balancing of mixed model, parallel, U-shaped and two-sided lines with stochastic dependent processing times. Hence, more realistic ALBPs can be formulated and be solved.

2.4 Double assignment

Miralles *et al.* (2008) describe a double assignment that is a simultaneous assignment of 1) tasks to stations, and 2) available workers to stations. In manufacturing, the consideration of these topics is an extremely complex and difficult matter for a less experienced manager.

In this study, a double assignment is presented and named as task and worker assignment to explain its description obviously.

2.5 The performance measure and decision variables (factors)

A performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of an action (Neely *et al.*, 2005). Ramesh and Kodali (2012) define a performance metric as a verifiable variable that is expressed in either quantitative or qualitative terms.

Since the purpose of this study is to identify the decision variables (factors) influencing the assembly line performance of the proposed model, the possible factors that to affect the performance of assembly lines in previous studies are reviewed. Table 2.1 and 2.2 presents the KPIs and decision variables (factors) for a straight line and a U-shaped line respectively. In addition, some details of these factors are described in Table 2.3.

In this study, qualitative decision variables (factors) are used for designing the model concept, while quantitative decision variables (factors) are used for model balancing.

2.6 Research tools

In this section, the research tools were described to support the research methodology in this study.

2.6.1 On-sited observation and case study

On-site or direct observation is an important tool that can be both formal and casual data collections in any processes. Hence, it may be useful to provide additional information about the topic. The significant advantage of this method is that the real time situation is studied. Thus the information is up-to-date (Garnes and Vikhagen, 2011; Yin, 2009).

Table 2.1 Reviews of the KPIs and decision variables (factors) for a straight line

References	KPIs	Decision variables (Factors)	
		Quantitative	Qualitative
Blum <i>et al.</i> , 2008	Minimizing number of workstations	Available space of a workstation	A Priority Heuristic task assignment
Toksari <i>et al.</i> , 2008	Minimizing of the number of workstations	Processing time with learning effect	
Chen <i>et al.</i> , 2009	Maximizing the workload smoothing	Problem sizes (number of tasks)	Solution methodology
Ayazi <i>et al.</i> , 2011	- Minimizing number of workstations - Minimizing the cycle time - Minimizing workload deviation	Uncertain processing times by deterioration rate of task	
Chen <i>et al.</i> , 2012	- Maximizing the workload smoothing - Reducing cycle time - Increasing operator utilization	- Problem sizes (number of tasks) - Operator skill level - Number of operators	

Table 2.2 Reviews of the KPIs and decision variables (factors) for a U-Shaped line

References	KPIs	Decision variables (Factors)	
		Quantitative	Qualitative
Miltenburg and Wijngaard, 1994	• Optimal number of work stations	• Number of tasks	• The task priority rules
Miltenburg, 2000	• Increasing the line effectiveness • Reducing the effect of breakdowns • Optimal number of work stations	• Cycle time • Failure rate and repair rate • Buffer size	• Buffer location
Chun Hung <i>et al.</i> , 2000	• Positive effect on quality, that is, quality planning, quality control, and quality improvement		• Layout
Aase <i>et al.</i> , 2004	• Improving labor productivity	• Number of tasks • Cycle time • Network density	

Table 2.2 Reviews of the KPIs and decision variables (factors) for a U-Shaped line (cont.)

References	KPIs	Decision variables (Factors)	
		Quantitative	Qualitative
Shewchuk, 2008	- Reducing the quantity of workers on the line - Increasing full work level (average % utilization, all but least-utilized worker)	- Number of machines - Takt time - Walking time	- Worker assignment based on walking path rules - Position of machines
Sirovetnukul, & Chutima, 2010;	- Minimizing the number of workers - Reducing the variation of workloads - Minimizing the walking time	Walking time	

Table 2.2 Reviews of the KPIs and decision variables (factors) for a U-Shaped line (cont.)

References	KPIs	Decision variables (Factors)	
		Quantitative	Qualitative
Rabbani <i>et al.</i> , 2012	- Reducing the variation of workloads - Reducing the number of workstations - Reducing the number of crossover workstations - Increasing the line efficiency	- Operator travel time when an operator moves in crossover workstation - the number of crossover workstations	
Avikal <i>et al.</i> , 2013	- Improving labor productivity - Reducing number of workstations		Task assignment techniques

Table 2.2 Reviews of the KPIs and decision variables (factors) for a U-Shaped line (cont.)

References	KPIs	Decision variables (Factors)	
		Quantitative	Qualitative
Hong <i>et al.</i> , 2013	• Increasing the percentage of actual output over theoretical output (output) • Decreasing average percent blocked (blockage) • Decreasing system WIP • Increasing average percent utilization (utilization)		• Work rules • Inventory flow choices

Table 2.2 Reviews of the KPIs and decision variables (factors) for a U-Shaped line (cont.)

References	KPIs	Decision variables (Factors)	
		Quantitative	Qualitative
Khemyong and Sirovetnukul, 2013	- Reducing the number of workstations - Reducing the walking time - Increasing full work level (average % utilization, all but least-utilized worker) - Increasing machine utilization (reducing the number of machines)	Walking time	- Layout - Task and worker assignment rules

Table 2.2 Reviews of the KPIs and decision variables (factors) for a U-Shaped line (cont.)

References	KPIs	Decision variables (Factors)	
		Quantitative	Qualitative
Manavizadeh <i>et al.</i> , 2013	- Reducing the number of workstations (balancing workload and increasing weighted efficiency) - Reducing total operator cost - Reducing the total number of containers traveling in the pull system	- Operator cost - Skill level of operator - Lead time	- Worker assignment policy - Kanban alert system
Zha and Yu, 2014	- Reducing the moving cost of machines - Reducing the labor cost - Reducing the walking time	- Walking time - Moving cost of machines - Labor cost - Cycle time (vary from demand)	Position of machines

Table 2.3 Reviews of decision variables (factors)

Quantitative perspective		
Decision variables/ factors	Details	References
Number of tasks (or machines)	≤ 30 tasks	Miltenburg & Wijngaard, 1994; Miltenburg, 2000; Aase <i>et al.</i>, 2004; Shewchuk, 2008
	Up to 111 tasks	Miltenburg & Wijngaard, 1994
	34 & 174 tasks	Chen <i>et al.</i>, 2009
	34 & 176 tasks	Chen <i>et al.</i>, 2012
Operator cost	Regular wages and overtime wages for permanent and temporary workers	Manavizadeh <i>et al.</i>, 2013
	Labor salary per unit time	Zha & Yu, 2014
Failure rate &	0.001, 0.002	Miltenburg, 2000
Repair rate	0.05, 0.10	
Buffer size	3, 6	Miltenburg, 2000
Network density	≥ 0.50	Aase <i>et al.</i>, 2004
Number of crossover workstations	≥ 1	Rabbani <i>et al.</i>, 2012

Table 2.3 Reviews of decision variables (factors) (cont.)

Decision variables/ factors	Details	References
Cycle time (or takt time)	6-48 (recommend high volume) 30-60 (recommend low volume) - Low cycle time = $2 \times \text{Max}(\text{manual time})$ - Medium cycle time = $\text{low} + 1/3((\text{total manual time} + \text{walking time}) - \text{low})$ - High cycle time = $\text{low} + 2/3((\text{total manual time} + \text{walking time}) - \text{low})$ - Vary from customer demand	- Miltenburg, 2000 - Aase <i>et al.</i>, 2004 - Shewchuk, 2008 - Shewchuk, 2008 - Shewchuk, 2008 - Zha & Yu, 2014; Khemyong & Sirovetnukul, 2013
Operator skill level	- Skill level: 1-3 - Skill level: 1-4	- Chen <i>et al.</i>, 2012 - Manavizadeh <i>et al.</i>, 2013

Table 2.3 Reviews of decision variables (factors) (cont.)

Decision variables/ factors	Details	References
Walking time	1 second for adjacent machines (same row) and 2 seconds for opposite machines - An extra time added to the workload of crossover workstations is 0.1, 0.5 and 10 5% APT time for each unit distance; 1 unit distance for adjacent machines (same row), and each of the walking distance between a pair of tasks is directly proportional to Euclidean distance between locations - According to the shape of the walking path	- Shewchuk, 2008 - Rabbani <i>et al.</i>, 2012 - Sirovetnukul, & Chutima, 2010; Khemyong & Sirovetnukul, 2013 - Zha & Yu, 2014
Number of operators	No limit	Chen <i>et al.</i>, 2012

Table 2.3 Reviews of decision variables (factors) (cont.)

Decision variables/ factors	Details	References
Lead time	Waiting time, processing time (including learning effect, deterioration rate of task), conveyance time and kanban collecting time	- Toksari <i>et al.</i>, 2008 - Ayazi <i>et al.</i>, 2011 - Manavizadeh <i>et al.</i>, 2013
Moving cost of machine	Machine can be moved with certain moving cost	Zha & Yu, 2014
Available space of a workstation (or available space of a production line)	Space limit for each workstation	Blum <i>et al.</i>, 2008
Qualitative perspective		
Decision variables/ factors	Details	References
Buffer location	Be placed between stations	Miltenburg, 2000
Position of machines	- Fixed - Fixed or movable	- Shewchuk, 2008 - Zha and Yu, 2014
Solution methodology	A grouping genetic algorithm to design a balanced assembly line	Chen <i>et al.</i>, 2009

Table 2.3 Reviews of decision variables (factors) (cont.)

Decision variables/ factors	Details	References
Worker assignment	- Walking path rules - Assignment of permanent and temporary workers in each period - A worker will be able to walk and return between the machines within a workstation during a cycle	- Shewchuk, 2008 - Manavizadeh <i>et al.</i>, 2013 - Khemyong & Sirovetnukul, 2013
Layout	- U-shaped line - Shared-machine embeds at the center of U-line	- Chun Hung <i>et al.</i>, 2000 - Khemyong & Sirovetnukul, 2013
Kanban alert system	Based on the Just-In-Time approach	Manavizadeh <i>et al.</i>, 2013
Solution methodology	A grouping genetic algorithm to design a balanced assembly line	Chen <i>et al.</i>, 2009
Work rules	A first-come-first-serve rule and a crossover-and-return rule	Hong <i>et al.</i>, 2013

Table 2.3 Reviews of decision variables (factors) (cont.)

Decision variables/ factors	Details	References
• Inventory flow choices	• Direct flow and buffered flow	• Hong <i>et al.</i>, 2013
• Task assignment techniques	• The maximum ranked positional weight heuristic • Task priority heuristic rule • The tasks are assigned to the same machine first as fully as possible but at a different time • Find the set of tasks on critical path by the critical path method. Assign eligible tasks in the set of tasks on critical path to workstation. Tasks in the set tasks not on critical path are assigned only necessarily	• Miltenburg and Wijngaard, 1994 • Blum <i>et al.</i>, 2008 • Khemyong & Sirovetnukul, 2013 • Avikal <i>et al.</i>, 2013

De Massis and Kotlar (2014) summarize the advantage of a case study research that is particularly appropriate to answer how and why questions or to describe a phenomenon and the real-life context in which it occurred. In addition, the approach openly contrasts, but hopefully complements, statistical empirical research approaches that are primarily used for confirmatory objectives when researchers already know how a phenomenon happens and have a robust idea of why it happens (i.e., hypothetical deduction is possible) and can quantitatively measure all the variables of interest. Data in the case study method are collected by multiple means that may consist of potential qualitative data sources including ethnographical and anthropological data collection techniques, documentation, and historical records, as well as quantitative data sources.

In this study, on-sited observation had been used to collect the observation data for better understand the nature of the garment manufacturer in Thailand. In addition, the quantitative data such as cycle time and task time, and the qualitative data such as precedence relations and types of machine for testing the proposed model are collected from a case study of garment manufacturing.

2.6.2 The in-depth interview

The In-depth interview is a qualitative research technique that concerns conducting intensive individual interviews with a small number of respondents to explore their perspectives on a particular idea, program, or situation (Boyce and Neale, 2006). In-depth interviewing is useful when a researcher want the detailed information about a person's thoughts and behaviors or want to explore new issues in depth (Boyce and Neale, 2006).

Due to this study requires to identify the decision variables (factors) (section 2.5) influencing the assembly line performance of the proposed model by considering manufacturing perspective, the in-depth interview technique is applied. The process for conducting in-depth interviews is as follows (Boyce and Neale, 2006).

1) Plan:

- 1.1) Identify stakeholders who will be concerned.
- 1.2) Identify what information is needed and from whom.
- 1.3) List the experts to be interviewed.

1.4) Ensure research will follow international and national ethical research standards.

2) Develop instruments:

2.1) Develop an interview protocol and the rules that guide the administration and implementation of the interviews. Put simply, these are the instructions that are followed for each interview, to ensure consistency between interviews, and thus increase the reliability of the findings.

2.2) Develop an interview guide that lists the questions or issues to be explored during the interview and includes an informed consent form. The questions should be open-ended rather than closed-ended.

2.3) Translate guides into local languages and test the translation (if required).

3) Train data collectors (if required):

3.1) Identify and train interviewers. Use interviewers that speak the local language.

4) Collect data:

4.1) Set up interviews with the experts (to explain the purpose of the interview, why the expert has been chosen, and the expected duration of the interview).

4.2) Seek informed consent of the interviewee (written or documented oral). Re-explain the purpose of the interview, why the expert has been chosen, expected duration of the interview, whether and how the information will be kept confidential, and the use of a note taker and/or tape recorder.

4.3) Conduct the interview, if an interviewee has consented,

4.4) Summarize key data immediately following the interview.

4.5) Verify information given in interviews as necessary.

5) Analyze data:

5.1) Transcribe and/or review data.

5.2) Analyze all interview data.

6) Disseminate findings:

6.1) Write report.

6.2) Solicit feedback from interviewees and stakeholders.

6.3) Revise.

6.4) Disseminate to interviewees, stakeholders, and the community as appropriate.

2.7 Summary of the previous studies

This section is divided into two parts. The first part (Section 2.7.1) related to the summary of the papers in the part of a U-shaped line balancing to fulfill a gap of task and worker assignment in assembly line problems. The second part (Section 2.7.2) concerns the decision variables (factors) influencing the performance of the assembly line balancing (Section 2.5) that will be used for improving the traditional line concept.

2.7.1 Summary of the papers conducted on U-Shaped assembly line balancing type-1

Table 2.4 presents the summary of the previous studies in the area of assembly line conducted on U-shaped assembly line balancing type-1. The details of problem descriptions, objective functions and the walking time are shown in the second, third and fourth column respectively. The fifth column shows a sharing machine case.

From Table 2.4, the simple U-line usually applied into a real-world is interested from many researchers (Miltenburg, 2001) while the issues of the walking time and a case of the Shared-machine U-shaped assembly line that should be concentrated are found in a few papers.

Table 2.4 Summary of the papers conducted on U-Shaped assembly line balancing type-1

References	Problem Description	Objectives	Walking time (Travel time)	Machine Sharing
Miltenburg and Wijngaard (1994)	U-line, Single model	minimize number of workstations	No	No
Urban (1998)	U-line, Single model	minimize number of workstations	No	No
Miltenburg (1998)	U-line facility, several individual U-line	minimize number of workstations and idle time in a single station	No	No
Sparling and Miltenburg (1998)	U-line, Mixed model	minimize number of workstations	Yes* ¹	No
Scholl and Klein (1999)	U-line, Single model	case 1: minimize number of workstations case 2: minimize cycle time case 3: maximize line efficiency	No	No
Erel <i>et al.</i> (2001)	U-line, Single model	minimize number of workstations	No	No
Miltenburg (2001)	U-line, Single model	minimize number of workstations	Yes* ²	No
Gökçen <i>et al.</i> (2005)	U-line, Single model	minimize number of workstations	No	No

Table 2.4 Summary of the papers conducted on U-Shaped assembly line balancing type-1 (cont.)

References	Problem Description	Objectives	Walking time (Travel time)	Machine Sharing
Baykasoglu (2006)	U-line, Single model	minimize number of workstations and maximize smoothness index	No	No
Hwang <i>et al.</i> (2008)	U-line, Single model	minimize number of workstations (maximize line efficiency) and minimize variation of workload	No	No
Shewchuk (2008)	Lean U-shaped, Single model (Worker allocation problems)	minimize quantity of workers and maximize full work	Yes	No
Sabuncuoglu <i>et al.</i> (2009)	U-line, Single model	minimize number of workstations	No	No
Kara <i>et al.</i> (2009)	U-line, Single model	minimize number of workstations and cycle time	No	No
Kara and Tekin (2009)	U-line, Mixed model	minimize number of workstations (given model sequence)	Yes* ³	No

Table 2.4 Summary of the papers conducted on U-Shaped assembly line balancing type-1 (cont.)

References	Problem Description	Objectives	Walking time (Travel time)	Machine Sharing
Sirovetnukul and Chutima (2009)	U-line, Single and mixed model (Worker allocation problems)	minimize number of workers, deviation of operation times of workers, and walking time	Yes	No
Hwang and Katayama (2010)	Straight and U-shaped line, Mixed model	minimize number of workstations (maximize line efficiency), minimize variation of workload and minimize the maximum distance between average and actual pace of workload	No	No
Sirovetnukul and Chutima (2010)	U-line, Single and mixed model (Worker allocation problems)	minimize number of workers, deviation of operation times of workers, and walking time	Yes	No

Table 2.4 Summary of the papers conducted on U-Shaped assembly line balancing type-1 (cont.)

References	Problem Description	Objectives	Walking time (Travel time)	Machine Sharing
Ağpak <i>et al.</i> (2012)	Two-side U-type, Single model	minimize number of individual stations and number of positions	No	No
Rabbani <i>et al.</i> (2012)	U-line, Mixed model	minimize number of workstations while the minimization of crossover workstations (maximize line efficiency) and minimize variation of workload	Yes* ³	No
Khemyong and Sirovetnukul (2013)	Shared- machine U-Shaped line, mixed model	minimize number of workstations (or workers), walking time and maximize full work	Yes	Yes

*¹ weighted average travel distance are used for each task

*² walking distance is set at one unit for each task and alpha is set at 0.2 time for each unit of distance

*³ to consider only some amount of extra time that allocated to crossover stations

Table 2.5 Summary of qualitative decision variables (factors) and KPIs (cont.)

Qualitative factors	KPIs													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Inventory flow choices					1							1	1	1
Solution methodology											1			

KPIs: [1] Number of workstations or worker [2] Line effectiveness [3] Effect of breakdowns [4] Labor productivity [5] Full work level or worker utilization [6] Total operator cost [7] Total number of containers traveling in the pull system [8] Walking time [9] Number of machines (machine utilization) [10] Moving cost of machines [11] Variation of workloads [12] Output [13] Blockage [14] WIP.

CHAPTER III

RESEARCH METHODOLOGY

The main objective in this study is to determine a way to assign the task and worker to workstation in a case of the Shared-machine U-shaped assembly line and to identify decision variables (factors) influencing the assembly line performance of the proposed model. To achieve this objective, the research methodology is presented.

3.1 Steps of research methodology

The overall research methodology flowchart is shown in Figure 3.1. It begins with observation and literature review and then it is finished with discussion and conclusion. The inputs and outputs of each step are determined in this flowchart.

3.1.1 Observation and literature review

First, a research question starts with desired area observation. In case of this research work, a necessary data of production line is collected from a garment manufacturer in Thailand. Then, the existing workflow can be explored.

After obtaining and interviewing, the characteristic of garment manufacturing are summarized and presented in Table 3.1.

From Table 3.1, a case study of the garment manufacturer divides the production into three types by production orders i.e. sample production, general production, and special production. The general production is the main production line. For a general production, the layout of production line is a W-line, the line consists of 4 straight lines as |||, but the other characteristics are similar to the double U-line. The production system of W-line is one-piece flow, but each workstation has a few buffers or WIP (less than 7 pieces). Multi-skilled workers are required as 1 to 4 level of skill. *Note:* the level can be divided into 4 levels, basic to expert, by ability to

operate machines and quality of finished work. Worker level 1 to 3 will be trained by leadership before working.

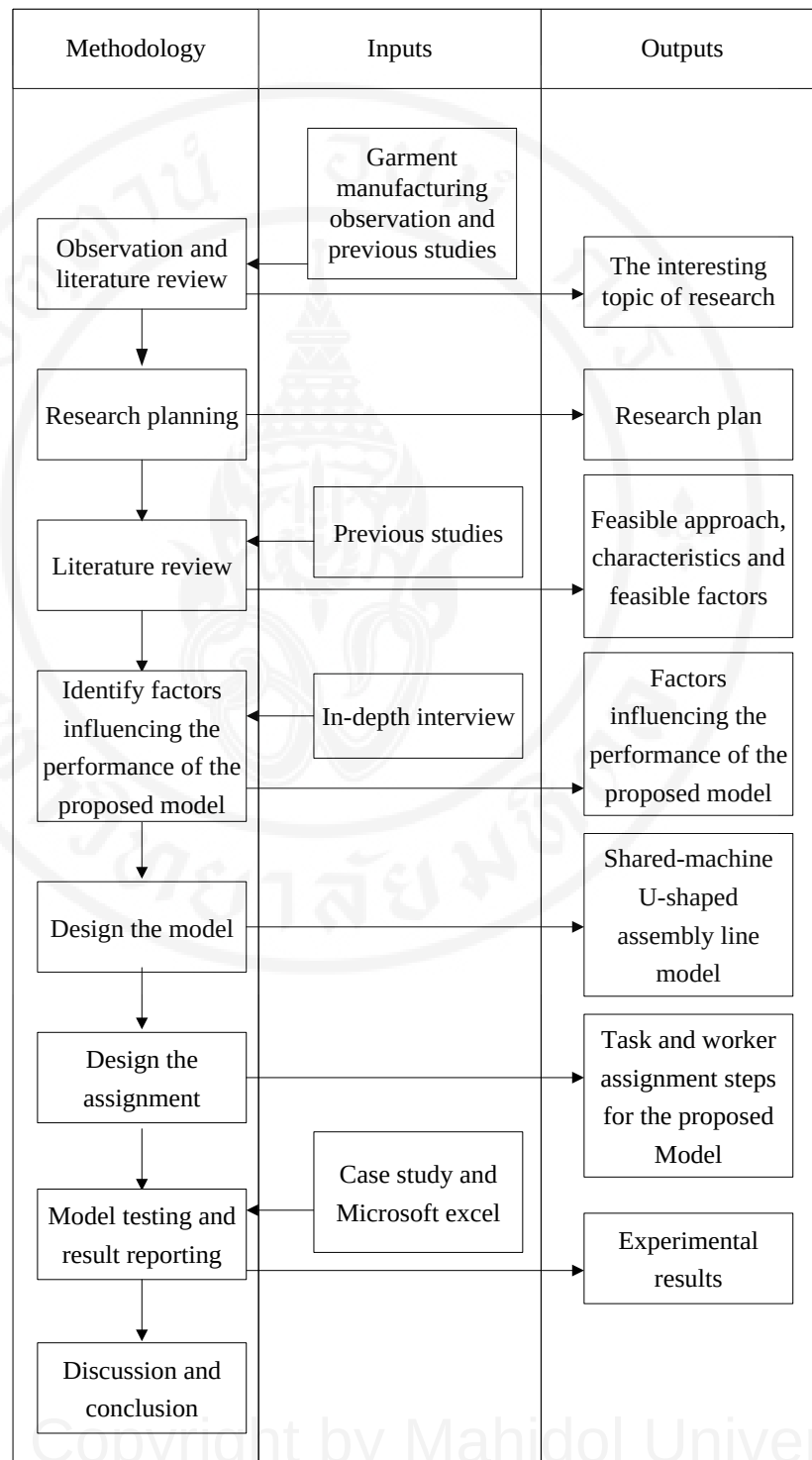


Figure 3.1 The overall research methodology flowchart

Table 3.1 The characteristics of garment manufacturer case studies

Characteristics	Types of production		
	General	Special	Sample
Quantity per order	> 1,000 pieces	100 – 1,000 pieces	< 20 pieces
Layout	W-line	U- line	Not specify
Production system	One piece flow	Batch flow/Bundles	Not specify
Buffer size or WIP (pieces per station)	< 7	Bundle	-
Skill levels of worker (1-4 levels)	1-4	3-4	4
Training/learning curve focus	Yes/Yes	Yes/Yes	Yes/Yes
Machine type / Moveable	No automated/Yes	No automated/Yes	No automated/Yes
Machine sharing	Sometimes	Sometimes	Sometimes
Production practice	Lean concepts	Not specify	Not specify

In addition, some machines are sometimes shared in a same worker (workstation). Moreover, lean concepts are applied in this line. However, in practice, this line usually contains no crossover workstation and in fact, the line is used as a straight line. When the production order is more than 1,000 pieces, the general production is run. For a special production, the line is a U- line with bundles flow and multi-skilled workers are required as 3 to 4 level of skill. When the production order is around 100 to 1,000 pieces, the special production is run. In practice, the special line is usually run in a sample room and the number of workers of this line is approximately 10 workers; similarly, the number of machines is around 1/3 of the general production in a same product. Thus, some machines are sometimes shared in a same worker (workstation). However, in fact, this line is also used as a straight line. For a sample production, it does not specify a layout and production flow. Multi-skilled workers are required as 3 to 4 level of skill. In practice, either one worker or more than one worker produces one product. Thus, sometimes the machine is also shared with a same worker. In addition, this line also runs in a sample room when the production order is

less than 20 pieces. All machines in the factory especially in phase 3 and 4 have no automated and can be moved. The learning curve of worker that helps to improve the productivity of line is focused and tried to motivate workers with extra wages.

From the collected data, it was observed that many machines in the assembly line particularly in the sample room are not fully used because the line in practice is as a straight line. Hence, the existent assembly line may not respond to the objective of increasing machine utilization since some types of machines can perform many tasks and multi-skilled workers are high levels in order to perform many operations in a cycle.

Moreover, after reviewing literature review (Section 2.1 and 2.7.1; Chapter II), a case of the Shared-machine U- shaped assembly line including a way to apply the assignment to the model with a real world has not been studied excluding Khemyong and Sirovetnukul (2013). Therefore, the research planning is designed.

3.1.2 Research planning

Research plan is constructed to follow-up with research progressiveness by starting from observation and literature review until research discussion.

3.1.3 Literature review

Through an extensive literature review as mentioned in Chapter II, both of the layout and the assignment of task and worker are the most importance qualitative factors that influence the KPIs of assembly line balancing (Section 2.7.2). Hence, this study is interested in the characteristics and benefits of the embedded U-lines and it was adapted under a real situation for a case study of a sample room in a garment manufacturing. In addition, the task and worker assignment is designed to support the model.

The proposed model in this study is based on the U-shaped Assembly Line Balancing Problem of type I (UALBP-I). Finally, the multi model in the same family of the Shared-machine U-shaped assembly line that has no automated machines with walking is presented by considering three objective functions i.e. minimized number of workstations (or workers), minimized walking time, and maximized full work.

3.1.4 Identify factors influencing the assembly line performance of the proposed model

To achieve the purpose of this study, the quantitative decision variables (factors) influencing the assembly line performance of the proposed model are identified in the following steps.

1) After surveying literature review in the part of assembly line balancing (Section 2.5 and 2.7.2; Chapter II), the performance measure and quantitative decision variables (factors) that influence the KPIs of assembly line balancing are summarized and presented in Table 3.2 and 3.3 respectively. From Table 3.2, the KPIs of the proposed model are in a group of productivity measure. Thus, this study focuses on this group only. In Table 3.3, quantitative factors influencing the KPIs of straight line and U-shaped line (the second and third column respectively) are going to identify for the proposed model.

2) This study uses the in-depth interview method to interview the practitioner, whose works are related to the flow of garment assembly line, to identify factors by considering possibility to influence the performance of productivity on assembly line when the proposed model is implemented. Definitions were used to the same understanding of interviewee as shown in the second column of Table 3.4. The extension column describes some details to clarify the meaning of factors and determines some characteristics for the proposed model.

3) After interviewing, the factors influencing the KPIs of the proposed model are presented in Table 3.5 and a Pareto chart is shown in Figure 3.2.

4) Finally, from the results, factors that influence the productivity KPIs of assembly line balancing of the proposed model are in the following.

Top 1: Skill levels of an operator factor are considered as the very high important factor influencing the KPIs of assembly line balancing of the proposed model. In addition, this factor also influences the possibility of model implementation in a real case.

Top 2: Number of tasks or machines factor, cycle time (or takt time) factor, and network density factor are considered as the high important factor influencing the KPIs of assembly line balancing of the proposed model.

Top 3: Failure rate and repair rate factor are considered as the high to medium important factors influencing the KPIs of assembly line balancing of the proposed model.

Top 4: Walking time factor, buffer size factor, and number of cross-workstations factor are considered as the medium important factors influencing the KPIs of assembly line balancing of the proposed model.

Table 3.2 Performance measures and KPIs from the literature review

Performance Measures	KPIs
1. Productivity	1.1 Number of workstations or workers
	1.2 Line effectiveness
	1.3 Effect of breakdowns
	1.4 Labor productivity
	1.5 Full work level or worker utilization
	1.6 Variation of workloads
	1.7 Number of crossover workstations
	1.8 Line efficiency
	1.9 Total number of containers traveling in the pull system
	1.10 Walking time
	1.11 Number of machines
	1.12 Machine utilization
	1.13 Cycle time
2. Cost	2.1 Total operator cost
	2.2 Moving cost of a machines

Table 3.3 Summary of quantitative factors related to productivity KPIs of assembly line balancing from the literature review

Quantitative factors	Straight line	U-shaped line	Shared-machine U-Shaped line
Number of tasks (or machines)	X	X	X
Cycle time (or takt time)		X	X
Failure rate & Repair rate		X	X
Buffer size		X	X
Network density		X	X
Walking time		X	X
Number of crossover workstations		X	X
Operator cost		X	X
Operator skill level	X	X	X
Number of operators	X		X
Lead time	X	X	X
Cost of moving machine		X	X
Available space of a workstation	X		X

Top 5: Lead time factors are considered as the medium to low important factor influencing the KPIs of assembly line balancing of the proposed model.

Top 6: Number of operators' factor is considered as the low to very low important factor influencing the KPIs of assembly line balancing of the proposed model.

Top 7: Cost of moving machine factor is considered as the very low important factor influencing the KPIs of assembly line balancing of the proposed model.

Table 3.4 Definition of quantitative decision variables (factors) and extension

Quantitative factors	Definition	Extension
Number of tasks (or machines)	The amount of task or machine in production line for each product.	≤ 30 tasks (or 30 machines).
Cycle time (or takt time)	Maximum or average time available for each workcycle (Scholl and Becker, 2006).	Vary from customer demands.
Failure rate & repair rate	<u>Failure rate</u> is rate of failure during the station. <u>Repair rate</u> is rate of repairs when station failures.	<u>Failure rate</u> may depend on the probability of failure per unit of work time required completing task assigned to station. <u>Repairs are complete</u> more quickly when the repair rate is high.
Buffer size	The amount of buffer in production line (or fixed WIP) for each connected point.	Small buffer inventories such as 3-6 for each connected point.
Walking time	The amount of travel time for operator walking to work within a workstation during a cycle.	Depend on walking distance.

Table 3.4 Definition of quantitative decision variables (factors) and extension (cont.)

Quantitative factors	Definition	Extension
Number of crossover workstations	The amount of workstation that includes tasks located on different production lines.	≥ 1 workstation(s)
Network density	A characteristic which measures the strength of relation of the assembly network. Network density is defined as the ratio of the total number of precedence relations in the precedence graph (d) and the total number of tasks (N) i.e. $2d/[N(N - 1)]$ (Talbot <i>et al.</i> , 1986).	If the values of network density close to 1 indicate a highly interconnected network, and fewer alternatives available for assigning tasks to a workstation. In other words, if the values of network density close to 0 indicate relatively fewer precedence relationships, and more opportunities for assigning tasks to a workstation.
Operator cost	Regular and overtime wages for worker.	The wage of a temporary worker per unit time is less than the wage of a permanent worker. Types of the worker depend on to skill-levels.
Number of operators	The number of workers is assigned to assembly line.	

Table 3.4 Definition of quantitative decision variables (factors) and extension (cont.)

Quantitative factors	Definition	Extension
Lead time	The amount of time that elapses between when a process starts and when it is complete.	Lead time includes processing time (may depend on skill-levels and efficiency of worker), waiting time, conveyance time and kanban collecting time.
Operator skill level	The working experience of worker related to familiarity with the factory's processing, knowledge of the specialized equipment, ability to recognize good and bad products, speed, and ability to solve problem.	
Cost of moving machines (or changeover cost)	An amount paid or required in payment for moving some stationary machines and/or for changeover process.	Depend on a factory (may be considering by machine types, process and production policy and so on).
Available space of a workstation	The area of production line.	Depend on a factory (may be considering by size and layout of production plant, size of machines and so on).

Table 3.5 Summary results of factors influencing the productivity KPIs of assembly line balancing of the proposed model from the experts

Factors	Impact on “Productivity”			Cumulative percent
	Ranking	Average scores	%	
Operator skill level	1	100	14.5	14.5
Number of tasks (or machines)	2	80	11.6	26.1
Cycle time (or takt time)	2	80	11.6	37.7
Network density	2	80	11.6	49.3
Failure rate & Repair rate	3	70	10.1	59.4
Walking time	4	60	8.7	68.1
Buffer size	4	60	8.7	76.8
Number of crossover workstations	4	60	8.7	85.5
Lead time	5	50	7.2	92.8
Number of operators	6	30	4.3	97.1
Cost of moving machine	7	20	2.9	100.0
Operator cost	8	0	0.0	100.0
Available space of a workstation	8	0	0.0	100.0
Total		690	100.0	

Note: % = (Total average scores /Average scores) x 100, the meaning of score is in the following. Score 100 = very high, 80 = high, 60 = medium, 40 = low, 20 = very low, and 0 = none.

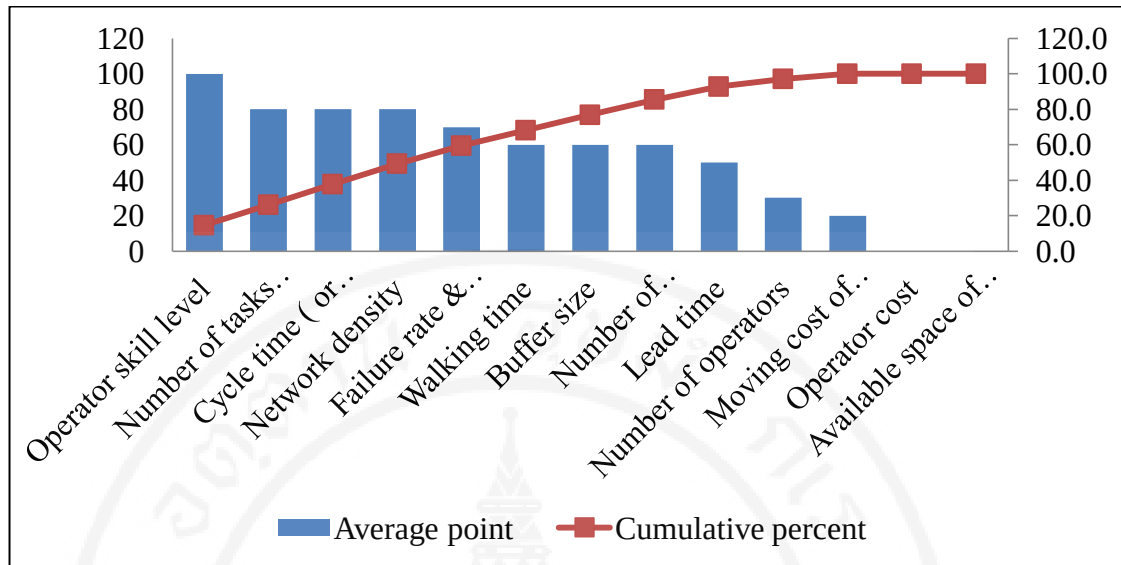


Figure 3.2 A Pareto chart of factors influencing the productivity KPIs of assembly line balancing of the proposed model from the practitioners

Top 8: The following factors including: operator cost factor and available space of a workstation factors are not considered as important factors influencing the KPIs of assembly line balancing of the proposed model.

3.1.5 Design model

According to both of the reviews and the practitioner opinions in previous section, the model of the Shared-machine U-shaped assembly line is designed.

From the reviews (Section 3.1.3), the main differences between the traditional U-line and the Shared-machine U-shaped assembly line (☺) are discussed as follows:

From the layout the embedded U-line has a large U-line encircling a small U-line (Miltenburg, 2001), while the Shared-machine U-shaped assembly line has only one simple U-line and embeds a shared machine in the center. Thus, it will be able to save space and walking.

For the assignment, a machine in the traditional U-line is able to operate only one task, which also pertains to a group of tasks in a cycle. In the Shared-machine U-shaped assembly line, a machine will be able to operate more than one in a cycle but at a different time.

Model configuration illustrates the characteristics of $\cup$ that shows in Figure 3.3.

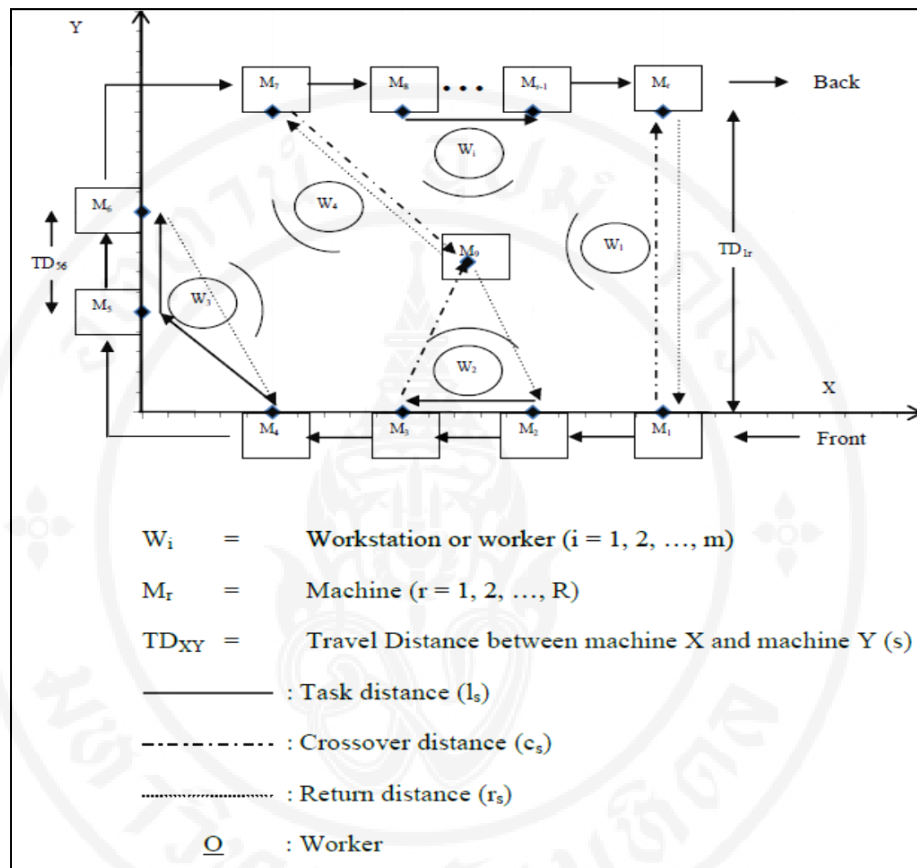


Figure 3.3 Mapping a diagram of the shared-machine of a single U-Shaped assembly line for workstation W_i and machine M_r on grid arrangement when TD_{XY} is travel distance between machine X and machine Y(s)

The Shared-machine U-shaped assembly line can be divided into two types by a shared machine usage in the following.

1) For a fixed worker type, one worker is fixed at a shared machine that is located on the center of line. A worker will be waiting for working only assigned tasks for this machine. The assignment starts from determining the worker, whose work is at a shared machine, and then,

Way 1: to assign a group of task that is free from precedence relation such as a group of preparation task to a (selected) shared machine. In this way, a shared machine is, perhaps, not necessary to locate in a center of the line.

Way 2: to determine a shared machine that is one workstation, where is located at a center of the line, and then to assign the group of task to a shared machine. *Key:* one workstation is equal to one machine.

2) For an unfixed worker type, a worker is not fixed at a shared machine. In other words, a worker can move to any machine. After finished line balancing, two cases will occur.

Case 1: a shared machine is used by any same worker accidentally. In this case, a shared machine is not necessary to locate in a center of the line. It can be moved to a convenient location for the worker.

Case 2: a shared machine is not used by a same worker. It is perfect model for improving the machine utilization.

However, this study focuses on an unfixed worker type of the Shared-machine U-shaped assembly line and presents it via a case study of a sample room in the garment manufacturer of Thailand.

From the practitioner opinions (Section 3.1.4), the skill levels of operator factor is the most important factor that influences both of the KPIs of the proposed model and the possibility to implement in a real case. Hence, in practice the firms will be able to apply this model into their assembly line if their skilled workers are able to operate any processes or machines with the same efficiency. Hence, this factor is determined into the assumption of the model. Similarly, the other factors such as cycle time factor, buffer size factor, and walking time factor, which are considered as the important factors, are also determined into the assumptions of the model.

The assumptions of the Shared-machine U-shaped assembly line: the unfixed worker type is as follows:

- 1) Production orders are known and constant,
- 2) Production line can produce several products,
- 3) The volume of each production order is low to medium,
- 4) Flow manufacturing on the Shared-machine U-shaped production line is in synchronous movement with a few bundles of work in process (WIP),
- 5) No automated machines in a Shared-machine U-shaped layout is presented,

6) Based on the types of machine, a machine will be able to operate on more than a group of tasks in a cycle but at a different time. A machine that is located around U-line can operate assigned tasks in the same workstation (worker) only while a shared machine that is located on the center of U-line is able to operate assigned task either same or different workstation (worker). The shared-machine selection is not taken into account.

7) A worker will be able to walk and return between the machines within a workstation during a cycle,

8) All parameters and variables such as task times, walking times, and types of machines are known and constant. In addition, the characteristic of identified decision variables (factors) are satisfied.

9) Trained workers have the same efficiency and multi-functional skilled and they are able to operate any processes or machines,

10) Learning effect has no consideration since it is assumed that worker performance runs into steady state already,

11) Setup times (assumed to be less than 5% compared with task time) are negligible because spared machines are prepared,

3.1.6 Design the assignment steps

According to special characteristics of the proposed model, the Shared-machine U-line task and worker assignment steps are in the following.

Step 1: Determine the cycle time.

Step 2: Assign a task to a workstation according to the U-line constraints (Miltenburg and Wijngaard, 1994). In this research, the side ratio of 1/3 (1:1:1) of U-line is applied (Sirovetnukul and Chutima, 2010).

- a) All tasks are assigned to a workstation.
- b) Each task is assigned only once.
- c) The precedence constraints are satisfied for each task.
- d) The total time in each workstation (the task time + the walking time) does not exceed the given cycle time.
- e) The number of workstations will be minimized.

Note: this step can be skipped if a production line is set up already as a U-line or another line that similar U-line such as W-line layout.

Step 3: Prepare data for the Shared-machine U-line assignment steps.

a) Specify a shared machine that is located on the center of U-line.
b) Determine the locations of the machine on a Shared-machine U-line layout according to the number of machines after the finished line balancing.

c) Calculate the distance from machine to machine. In this study, the walking distance is set at one unit for adjacent machines in the same row. Assume that each of the walking distance between a pair of tasks is directly proportional to Euclidean distance between locations (Sirovetnukul and Chutima, 2010). The example of walking distance for 15-machine problem is shown in Table 3.6. For example, the displacement gives us a walking distance of 2.83 distance units. Calculated as the sum of distance between location 1 and 15 of a fixed shared-machine U-shaped assembly line layout (Figure 3.4) is $\|(0,0), (-2,2)\| = \sqrt{(-2-0)^2 + (2-0)^2} = 2.83$, where $\|\bullet\|$ a Euclidean distance operator. *Note:* Location 1 is assumed to be an origin (0, 0).

d) Transform the distance into the walking time by the coefficient of walking time. Balakrishnan *et al.* (2009) supposed two values of travel time for each problem instance, that is, walking time = the five or ten percentage of Average Processing Times (APT), where APT is the expected value of processing times that is as the total task times divided by total tasks. In this study, the coefficient of walking time (α) is five percentages of APT for a distance unit (Sirovetnukul and Chutima, 2010). However, the walking time is the one of important factors that influences the KPIs of the proposed model according to the practitioner opinions (Section 3.1.4). Hence, this study also determines α is two units of time for a distance unit according to collected data from a real case. The walking distance matrix is as Table 3.6. Thus, the walking time matrix of 5%APT and 2 units of time are shown in Table 3.7 and 3.8 respectively.

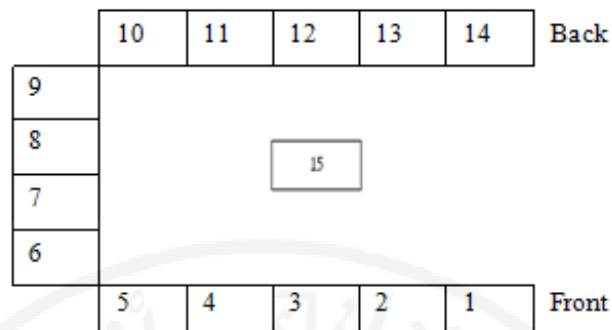


Figure 3.4 The example of a Shared-machine U-shaped assembly line layout of 15-task problem

Step 4: Assign a task and a worker to a workstation according to the Shared-machine U-line constraints (extending from U-line constraints in step 3).

a) Every task is assigned to a workstation and is located on the front, back, or center of the line by considering the precedence relations as follows:

Front: to randomize the set of assignable tasks is the union of the set of tasks that predecessors have already been assigned,

Back: to randomize the set of tasks that successors have already been assigned, and

Center: to randomize the set of a shared-machine tasks.

b) Each task is assigned only once.

c) A machine is assigned to a workstation according to a set of assigned task in the same workstation.

d) Based on the types of machine, the remaining tasks are assigned to the same machine as fully as possible but at a different time.

e) The total time in each workstation (the task time + the walking time) does not exceed the given cycle time.

f) A worker can be assigned to only one workstation. Similarly, each workstation will have only one worker.

g) The number of workstations will be minimized.

Table 3.6 Exemplified displacement distance for a Shared-machine U-shaped assembly line at one unit from one location to another location

From															Walking Distance
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	To
2.83	4.00	4.12	4.47	5.00	5.66	6.10	5.59	5.22	5.02	4.00	3.00	2.00	1.00	0.00	1
2.24	4.12	4.00	4.12	4.47	5.00	5.32	4.72	4.27	4.03	3.00	2.00	1.00	0.00	1.00	2
2.00	4.47	4.12	4.00	4.12	4.47	4.61	3.91	3.35	3.04	2.00	1.00	0.00	1.00	2.00	3
2.24	5.00	4.47	4.12	4.00	4.12	4.03	3.20	2.50	2.06	1.00	0.00	1.00	2.00	3.00	4
2.83	5.66	5.00	4.47	4.12	4.00	3.64	2.69	1.80	1.12	0.00	1.00	2.00	3.00	4.00	5
3.35	6.10	5.32	4.61	4.03	3.64	3.00	2.00	1.00	0.00	1.12	2.06	3.04	4.03	5.02	6
3.04	5.59	4.72	3.91	3.20	2.69	2.00	1.00	0.00	1.00	1.80	2.50	3.35	4.27	5.22	7
3.04	5.22	4.27	3.35	2.50	1.80	1.00	0.00	1.00	2.00	2.69	3.20	3.91	4.72	5.59	8
3.35	5.02	4.03	3.04	2.06	1.12	0.00	1.00	2.00	3.00	3.64	4.03	4.61	5.32	6.10	9
2.83	4.00	3.00	2.00	1.00	0.00	1.12	1.80	2.69	3.64	4.00	4.12	4.47	5.00	5.66	10
2.24	3.00	2.00	1.00	0.00	1.00	2.06	2.50	3.20	4.03	4.12	4.00	4.12	4.47	5.00	11
2.00	2.00	1.00	0.00	1.00	2.00	3.04	3.35	3.91	4.61	4.47	4.12	4.00	4.12	4.47	12
2.24	1.00	0.00	1.00	2.00	3.00	4.03	4.27	4.72	5.32	5.00	4.47	4.12	4.00	4.12	13
2.83	0.00	1.00	2.00	3.00	4.00	5.02	5.22	5.59	6.10	5.66	5.00	4.47	4.12	4.00	14
0.00	2.83	2.24	2.00	2.24	2.83	3.35	3.04	3.04	3.35	2.83	2.24	2.00	2.24	2.83	15

Table 3.7 Exemplified displacement distance for a Shared-machine U-shaped assembly line at 5% APT

From															Walking Time	To														
																1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1		0.00	9.32	18.64	27.96	37.28	46.83	56.88	66.83	76.78	86.73	96.68	106.63	116.58	126.53	136.48
26.36	37.28	38.43	41.68	46.60	52.72	56.88	52.10	48.65	46.83	37.28	27.96	18.64	9.32	0.00		0.00	9.32	18.64	27.96	37.28	46.83	56.88	66.83	76.78	86.73	96.68	106.63	116.58	126.53	136.48
20.84	38.43	37.28	38.43	41.68	46.60	49.54	43.96	39.82	37.57	27.96	18.64	9.32	0.00	9.32		9.32	0.00	9.32	18.64	27.96	37.57	47.02	56.47	65.92	75.37	84.82	94.27	103.72	113.17	122.62
18.64	41.68	38.43	37.28	38.43	41.68	42.96	36.40	31.26	28.35	18.64	9.32	0.00	9.32	18.64		18.64	0.00	9.32	18.64	27.96	37.57	47.02	56.47	65.92	75.37	84.82	94.27	103.72	113.17	122.62
20.84	46.60	41.68	38.43	37.28	38.43	37.57	29.84	23.30	19.21	9.32	0.00	9.32	18.64	27.96		27.96	18.64	9.32	0.00	9.32	18.64	27.96	37.57	47.02	56.47	65.92	75.37	84.82	94.27	103.72
26.36	52.72	46.60	41.68	38.43	37.28	33.93	25.09	16.80	10.42	0.00	9.32	18.64	27.96	37.28		37.28	27.96	18.64	9.32	0.00	9.32	18.64	27.96	37.57	47.02	56.47	65.92	75.37	84.82	94.27
31.26	56.88	49.54	42.96	37.57	33.93	27.96	18.64	9.32	0.00	10.42	19.21	28.35	37.57	46.83		46.83	37.57	28.35	19.21	10.42	0.00	9.32	18.64	27.96	37.57	47.02	56.47	65.92	75.37	84.82
28.35	52.10	43.96	36.40	29.84	25.09	18.64	9.32	0.00	9.32	16.80	23.30	31.26	39.82	48.65		48.65	39.82	31.26	23.30	16.80	9.32	0.00	9.32	18.64	27.96	37.57	47.02	56.47	65.92	75.37
28.35	48.65	39.82	31.26	23.30	16.80	9.32	0.00	9.32	18.64	25.09	29.84	36.40	43.96	52.10		52.10	43.96	36.40	29.84	25.09	16.80	9.32	0.00	9.32	18.64	27.96	37.57	47.02	56.47	65.92
31.26	46.83	37.57	28.35	19.21	10.42	0.00	9.32	18.64	27.96	33.93	37.57	42.96	49.54	56.88		56.88	49.54	42.96	37.57	33.93	27.96	23.30	19.21	10.42	0.00	9.32	18.64	27.96	37.57	47.02
26.36	37.28	27.96	18.64	9.32	0.00	10.42	16.80	25.09	33.93	37.28	38.43	41.68	46.60	52.72		52.72	46.60	41.68	38.43	37.28	33.93	27.96	23.30	19.21	10.42	0.00	9.32	18.64	27.96	37.57
20.84	27.96	18.64	9.32	0.00	9.32	19.21	23.30	29.84	37.57	38.43	37.28	38.43	41.68	46.60		46.60	41.68	38.43	37.28	38.43	37.57	33.93	27.96	23.30	19.21	10.42	0.00	9.32	18.64	27.96
18.64	18.64	9.32	0.00	9.32	18.64	28.35	31.26	36.40	42.96	41.68	38.43	37.28	38.43	41.68		41.68	38.43	37.28	38.43	41.68	42.96	39.82	36.40	33.93	30.92	27.96	24.95	21.94	18.93	15.92
20.84	9.32	0.00	9.32	18.64	27.96	37.57	39.82	43.96	49.54	46.60	41.68	38.43	37.28	38.43		38.43	37.28	38.43	41.68	46.60	49.54	47.02	44.50	41.98	39.46	36.94	34.42	31.90	29.38	26.86
26.36	0.00	9.32	18.64	27.96	37.28	46.83	48.65	52.10	56.88	52.72	46.60	41.68	38.43	37.28		37.28	38.43	41.68	46.60	52.72	56.88	52.10	48.65	45.19	41.73	38.27	34.81	31.35	27.89	24.43
0.00	26.36	20.84	18.64	20.84	26.36	31.26	28.35	28.35	31.26	31.26	26.36	20.84	18.64	26.36		26.36	20.84	18.64	20.84	26.36	31.26	36.16	31.26	26.36	20.84	18.64	20.84	26.36	31.26	36.16

Table 3.8 Exemplified displacement distance for a Shared-machine U-shaped assembly line at 2 units of time

From															Walking Time	To														
																1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1		0.00	2.00	4.00	6.00	8.00	10.05	10.44	11.18	12.21	11.31	10.00	8.94	8.25	8.00	5.66
5.66	8.00	8.25	8.94	10.00	11.31	12.21	11.18	10.44	10.05	8.00	6.00	4.00	2.00	0.00		8.00	2.00	4.00	6.00	8.00	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66	
4.47	8.25	8.00	8.25	8.94	10.00	10.63	9.43	8.54	8.06	6.00	4.00	2.00	0.00			6.00	0.00	2.00	4.00	6.00	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66	
4.00	8.94	8.25	8.00	8.25	8.94	9.22	7.81	6.71	6.08	4.00	2.00	0.00				4.00	0.00	2.00	4.00	6.00	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66	
4.47	10.00	8.94	8.25	8.00	8.25	8.06	6.40	5.00	4.12	2.00	0.00					2.00	0.00	2.00	4.00	6.00	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66	
5.66	11.31	10.00	8.94	8.25	8.00	7.28	5.39	3.61	2.24	0.00						0.00	0.00	2.00	4.00	6.00	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66	
6.71	12.21	10.63	9.22	8.06	7.28	6.00	4.00	2.00	0.00							2.00	0.00	2.00	4.00	6.00	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66	
6.08	11.18	9.43	7.81	6.40	5.39	4.00	2.00	0.00	2.00	4.00	6.00	8.06	10.44			3.61	2.00	4.00	6.00	8.06	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66	
6.08	10.44	8.54	6.71	5.00	3.61	2.00	0.00	2.00	4.00	6.00	8.06	10.44	11.18			5.39	2.00	4.00	6.00	8.06	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66	
6.71	10.05	8.06	6.08	4.12	2.24	0.00	2.00	4.00	6.00	8.06	10.44	11.18	12.21			7.28	4.00	6.00	8.06	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66		
5.66	8.00	6.00	4.00	2.00	0.00	2.24	3.61	5.39	7.28	8.00	8.25	8.94	10.00			8.00	4.00	6.00	8.06	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66		
4.47	6.00	4.00	2.00	0.00	2.00	4.12	5.00	6.40	8.06	8.25	8.94	10.00	11.31			8.25	4.00	6.00	8.06	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66		
4.00	4.00	2.00	0.00	2.00	4.00	6.08	6.71	7.81	8.25	8.94	10.00	11.31	12.21			8.94	4.00	6.00	8.06	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66		
4.47	2.00	0.00	2.00	4.00	6.00	8.06	8.54	9.43	10.63	10.00	8.94	8.25	8.00			10.00	4.00	6.00	8.06	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66		
5.66	0.00	2.00	4.00	6.00	8.00	10.05	10.44	11.18	12.21	10.05	8.94	8.25	8.00			11.31	4.00	6.00	8.06	2.24	2.00	4.00	10.63	11.31	10.00	8.94	8.00	5.66		
0.00	5.66	4.47	4.00	4.47	5.66	6.71	6.08	6.08	6.71	6.71	6.71	6.71	6.71			5.66	4.47	4.00	4.47	5.66	6.71	6.08	6.08	6.71	6.71	6.71	6.71	6.71	6.71	

Step 5: Repeat step 3(b) - 4 until the size of a Shared-machine U-line is stable.

Note: in step 3(b), replaced the location of the unused machine around U-line with the machine that the task is assigned to (if required).

Step 6: Evaluate the objective functions and keep the string that the average of utilization is more than 90%.

Step 7: Repeat step 5 - 6 until the terminating condition is met.

Step 8: Rank the good solutions of three objective functions.

Step 9: Select the candidates according to the good solution in the first rank.

3.1.7 Model testing and result reporting

After the model is constructed, a garment manufacturer will be selected for testing the model. However, only top 1 to top 4 of factor ranking (excluding failure rate and repair rate factors) that are considered as the very high to medium important factors influencing the KPIs of assembly line balancing of the proposed model are applied into model testing because the limit of time in this study. The step of model testing is in the following.

1) To interview the practitioner, whose works related to the flow of a garment assembly line, by the in-depth interview method to confirm the consistency of the proposed model about the task and worker assignment under a real garment manufacturing.

2) To balance the assembly line with a collected data from a case study by considering three objective functions as follows:

The objective functions;

Minimize the number of workstations (W)

$$f_1(X) = W = \sum_{i=1}^M S_i \quad (1)$$

Minimize the walking time (WT)

$$f_2(X) = WT = \alpha \sum_{i=1}^M \sum_{j=1}^N (l_{ij} + c_{ij} + r_{ij}) \quad (2)$$

Maximize full work (Ut)

$$f_3(X) = Ut = \frac{\sum_{i=1}^M \sum_{j=1}^N T_{ij} + \alpha \sum_{i=1}^M \sum_{j=1}^N (l_{ij} + c_{ij} + r_{ij}) - u}{C \times (M - 1)} \quad (3)$$

Notation is as follows:

i	=	index on workstations or workers,
j, k	=	index on tasks,
α	=	coefficient of walking time,
u	=	total time of the least utilization of workstation,
M	=	upper bound on the number of workstations,
N	=	the number of tasks of each workstation,
C	=	given cycle time,
T_{ij}	=	task time of task j assigned to workstation i ,
l_{ij}	=	task distance of task j assigned to workstation i ,
c_{ij}	=	crossover distance of task j assigned to workstation i ,
r_{ij}	=	return distance of task j assigned to workstation i .

Data input: from our case study, deterministic combined-model task times that related to precedence constraints and machines are shown in Table 3.9. This study uses the combined-model data, which assumed to be the representative of product families. A Shared-machine U-line layout at the side ratio of 1/3 (1:1:1) that is representative for the workable single U-line (Sirovetnukul and Chutima, 2010). A given cycle time is 1,371 seconds. For 5% APT, the coefficient of walking time (α) is as $0.05 \times (6708.19 / 36) = 9.32$ seconds per meter. In addition, network density is as $(2 \times 37) / (36 \times 35) = 0.0587$.

To balance model: to assign tasks and workers to workstations according to the task and worker assignment of the Shared-machine U-line steps (Section 3.1.6). Calculated the objective functions by Microsoft Excel.

Table 3.9 Deterministic combined-model task time for all models

Task	Predecessor	Single model			Combined model	Machine
		Model 1	Model 2	Model 3	10:6:5	
1	-		25		7.14	M/C1
2	1			45	10.71	M/C2
3	2	564	564	564	564.00	M/C3
4	-	620			295.24	M/C3
5	-		780		222.86	M/C3
6	-			62	14.76	M/C4
7	6			939	223.57	M/C4
8	-	334	334	334	334.00	M/C3
9	-			380	90.48	M/C3
10	9	209	209	209	209.00	M/CS1
11	10	188	188	188	188.00	M/C3
12	-	190	190		144.76	M/C3
13	-			224	53.33	M/C3
14	11,12,13	189	189	189	189.00	M/C3
15	-	158	158	158	158.00	M/C3
16	15			75	17.86	M/C5
17	15	46			21.90	M/C3
18	15		96		27.43	M/C3
19	16,17,18	131	131	131	131.00	M/C3
20	14	257	257	257	257.00	M/C5
21	19,20	160	160	160	160.00	M/C3
22	8,21	224	224	224	224.00	M/C3
23	22	84	84	84	84.00	M/C3
24	23	428	428	428	428.00	M/C5

Table 3.9 Deterministic combined-model task time for all models (cont.)

Task	Predecessor	Single model			Combined model	Machine
		Model 1	Model 2	Model 3	10:6:5	
25	4,5,7,24	92	92	92	92.00	M/C3
26	25	124	124	124	124.00	M/C3
27	3,26	120	120	120	120.00	M/C3
28	27	120	120	120	120.00	M/C3
29	28		53		15.14	M/C5
30	29	637	637	637	637.00	M/C6
31	30	205	205	205	205.00	M/C7
32	31	467	467	467	467.00	F8
33	32	257	257	257	257.00	F8
34	33	213	213	213	213.00	F8
35	34	210	210	210	210.00	M/CS1
36	35	192	192	192	192.00	M/C9
Total task time		6419	6707	7288	6708.19	-

Note: Task 10 and Task 35 are operated on a shared machine (M/CS1); Area F8 is free workspace that is not relevant to any machine.

Equation (1) was used to determine the total number of workstations or workers (W), that is, if workstation i (or worker i) is used, it is 1. If not, it is 0. Hence, the total number of workstations or workers is the summation of the workstation or worker that is used.

For the walking time (WT), assume that the assignment of task to workstation (worker) 1 is [5_ 1_ 12_ 8_ 6_ 4_ 9_ 2_ 13] (Figure 3.4 and Table 3.7). The walking time is $(\alpha) \times (l_{5,1}+l_{1,12}+l_{8,6}+l_{6,4}+l_{9,2}+l_{2,13}+r_{1,5}+r_{6,5}+r_{2,5}) = 9.32 \times (1+1+2+2+3+3+1+2+3) = 167.76$ seconds where the coefficient of walking time (α) is 5% APT. Hence, the walking time of this station is 167.76 seconds. In Equation (2), the total walking time is the summation of the walking time of each workstation i . An exemplified assignment and walking time are shown in Table 3.10.

Table 3.10 Exemplified assignment and walking time

Station (Worker)	Assignment					WT to origin (seconds)
	Task	Machine	Task Time (seconds)	Location	WT (seconds)	
1	5	M/C3	222.86	1	0.00	0.00
	1	M/C1	7.14	2	9.32	9.32
	12	M/C3	144.76	1	9.32	0.00
	8	M/C3	334.00	1	0.00	0.00
	6	M/C4	14.76	3	18.64	18.64
	4	M/C3	295.24	1	18.64	0.00
	9	M/C3	90.48	1	0.00	0.00
	2	M/C2	10.71	4	27.96	27.96
	13	M/C3	53.33	1	27.96	0.00
Total walking time (seconds)					167.76	

Equation (3), maximize full work (U_t) that maximizes the average utilization of all but the least-utilized worker (Shewchuk, 2008). For each worker, utilization is total time (total task time + total walking time) divided by cycle time when the least-utilized worker has total time u . For example, assume that the task time of workstation 1, 2, and 3 are 1,173.29, 1,081.00, and 1,269.76 seconds respectively. The walking time of worker 1, 2, and 3 are 167.76, 183.30, and 98.46 seconds respectively. The cycle time is 1,371 seconds. Thus, the utilization of worker 1 is $(1,173.29 + 167.76) / 1,371 = 0.978$. The utilization of worker 2 and 3, which are computed similarly, are 0.922 and 0.998 respectively. Then, the workstation or worker that has the least-utilization is worker 2. Hence, U_t is $(3,524.05 + 449.52 - 1,264.30) / 1,371 \times 2 = 0.988$. In other words, it is as $(0.978 + 0.998) / 2 = 0.988$.

Result reporting: from in-depth interviewing, the task and worker assignment under a real world are presented. From data analyzed for each model, the comparison analysis is conducted among these groups of the model, i.e. the proposed model, traditional U-line, and traditional straight line by considering:

- a) The objective functions,
- b) The number of machines that are used in model.

3.1.8 Discussion and conclusion

The advantage and disadvantage among three models of the proposed line, traditional U-line, and traditional straight line will be represented along with result reporting. Then, a way to apply the assignment to the Shared-machine U-shaped assembly line under a real world will be guided. Finally, discussion and conclusion are presented.

CHAPTER IV

RESULTS

This chapter reports the consistency of task and worker assignment of the proposed model under a real garment manufacturing by in-depth interviewing and the comparison of traditional model and proposed model by considering three objective functions and the number of machines.

4.1 Result from in-depth interview

This section describes the task and worker assignment under a real situation for approving the model in order to implement.

4.1.1 Task and worker assignment under a real garment manufacturing

In the real world, the practitioner describes the assignment as a simultaneous assignment of (1) tasks including machines to workstations, and (2) available workers to workstations. Hence, a task and worker assignment of the proposed model corresponds with the real assignment of the garment production line.

4.2 A numerical example of a case study

This section presents a numerical example of a case study where the coefficient of walking time (α) is 5%APT. *Note:* a case of $\alpha = 2$ seconds is computed similarly.

4.2.1 Shared-machine U-shaped assembly line

The results of case study's 36-tasks and $\alpha = 5\% \text{APT}$ are illustrated. When the size of a Shared-machine U-line is stable, the number of machines and free workplaces are reduced from 23 to 15, that is, M/C1, M/C2, M/C6, M/C7, F8, M/C9 and M/CS1 = 1; M/C4 and M/C5 = 2; M/C3 = 4. A task and a worker are assigned into a station according to step 4 of the assignment step (Section 3.1.6; Chapter III). An example of task and worker assignment in the Shared-machine U-shaped assembly line is presented in Table 4.1. In addition, the result of case study's 36-tasks can be described in Figure 4.1. For example, the production line has six workstations (workers). Worker 1 operates a group of tasks of {5 12 8 4 9 13}, {1}, {6}, and {2} by M/C 3 No.1, M/C 1 No. 1, M/C4 No.1, and M/C2 No. 1 respectively at location 1, 2, 3, and 4 of front production line with a walking time 167.76 seconds. Worker 2 operates a group of tasks of {36} by M/C9 No.1 at location 14, operates a group of tasks of {35, 10} by M/CS1 that is a shared-machine at location 15 of the center of production line, and operates a group of tasks {34, 33} with a manual work (no machine) at location 13 of back production line. Total walking time of Worker 2 is 139.40 seconds. Worker 3 to worker 6 is also described in a similar manner. Finally, the time chart of operation in each workstation (worker) is shown in Figure 4.2. In the time chart, each worker starts to work at the same time after working in the steady state. A group of tasks is assigned to a same machine but at a different time, there is no waiting time.

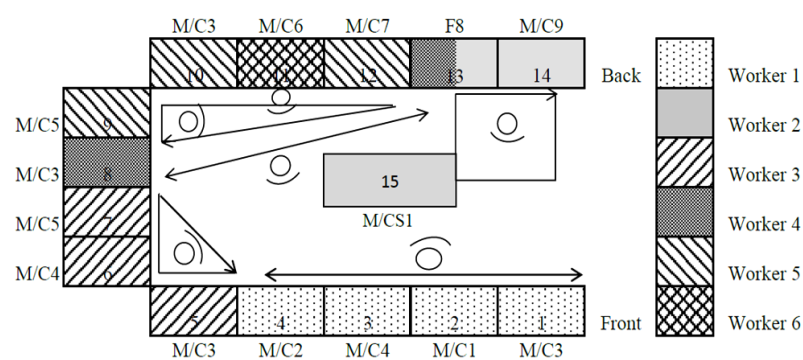


Figure 4.1 An exemplified result of case study's 36 tasks ($\alpha = 5\% \text{APT}$) on the Shared-machine U-Shaped assembly line layout

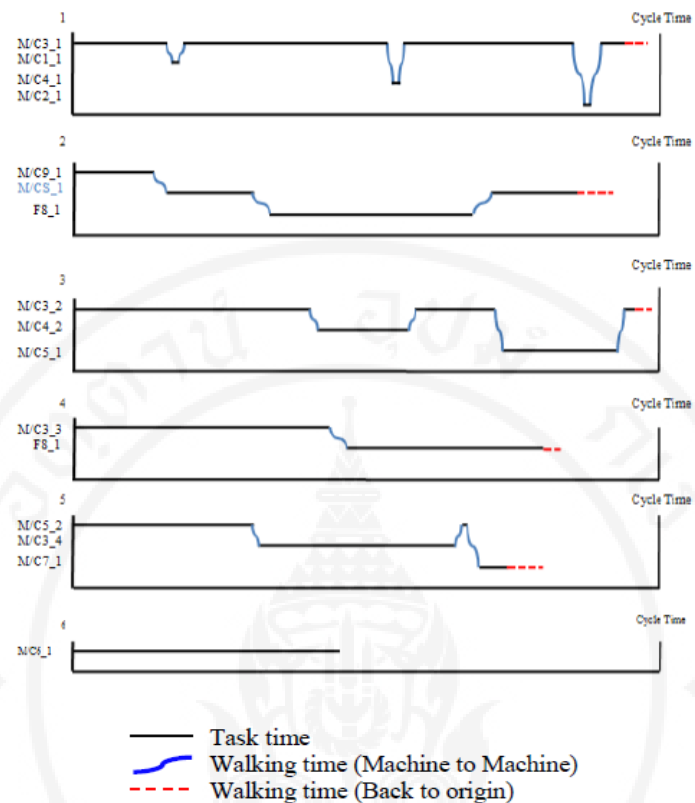


Figure 4.2 Time chart of operation in each worker

4.2.2 Traditional U-shaped assembly line

An example of task and worker assignment in the U-shaped assembly line is presented in Table 4.2. Then Figure 4.3 presents an exemplified result of case study's 36 tasks ($\alpha = 5\%$ APT) on a U-Shaped assembly line layout.

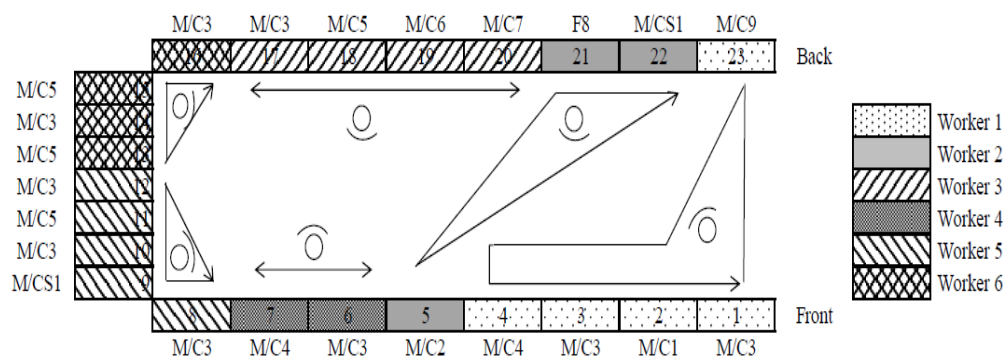


Figure 4.3 An exemplified result of case study's 36 tasks ($\alpha = 5\%$ APT) on the U-Shaped assembly line layout

Table 4.1 An example of task and worker assignment in the Shared-machine U-shaped assembly line

Station (Worker)	Task considered		Assignment					Total time (3) (1)+(2) (seconds)	WT to origin (4) (seconds)	Given cycle time (5) (seconds)	Idle time (5)-(3)-(4) (seconds)	Utilization (3)+(4)/(5)	Utilization without walking time
	Front graph	Back graph	Task	Machine	(2)Task time (seconds)	Location	(1)WT (seconds)						
1	5	36	5	M/C3	222.86	1	0.00	222.86	0.00	1371.00	1148.14		
	1	36	1	M/C1	7.14	2	9.32	16.46	9.32		1122.36		
	12	36	12	M/C3	144.76	1	9.32	154.08	0.00		968.28		
	8	36	8	M/C3	334.00	1	0.00	334.00	0.00		634.28		
	6	36	6	M/C4	14.76	3	18.64	33.40	18.64		582.24		
	4	36	4	M/C3	295.24	1	18.64	313.88	0.00		268.36		
	9	36	9	M/C3	90.48	1	0.00	90.48	0.00		177.88		
	2	36	2	M/C2	10.71	4	27.96	38.67	27.96		111.25		
	13	36	13	M/C3	53.33	1	27.96	81.29	0.00		29.95	0.978	0.856
2	10	36	36	M/C9	192.00	14	0.00	192.00	0.00	1371.00	1179.00		
	10	35	35	M/CS1	210.00	15	26.36	236.36	26.36		916.28		
	10	34	34	F8	213.00	13	20.84	233.84	9.32		673.12		
	10	33	33	F8	257.00	13	0.00	257.00	9.32		406.80		
	10	32	10	M/CS1	209.00	15	20.84	229.84	26.36		150.60	0.890	0.788
3	3	32	3	M/C3	564.00	5	0.00	564.00	0.00	1371.00	807.00		
	7	32	7	M/C4	223.57	6	10.42	233.99	10.42		562.59		
	15	32	15	M/C3	158.00	5	10.42	168.42	0.00		394.17		
	17	32	17	M/C3	21.90	5	0.00	21.90	0.00		372.26		
	16	32	16	M/C5	17.86	7	16.80	34.66	16.80		320.81		
	20	32	20	M/C5	257.00	7	0.00	257.00	16.80		47.01		
	18	32	18	M/C3	27.43	5	16.80	44.23	0.00		2.78	0.998	0.926

Table 4.1 An example of task and worker assignment in the Shared-machine U-shaped assembly line (cont.)

Station (Worker)	Task considered		Assignment					Total time (3) (1)+(2) (seconds)	WT to origin (4) (seconds)	Given cycle time (5) (seconds)	Idle time (5)-(3)-(4) (seconds)	Utilization (3)+(4)/(5)	Utilization without walking time
	Front graph	Back graph	Task	Machine	(2)Task time (seconds)	Location	(1)WT (seconds)						
4	19	32	19	M/C3	131.00	8	0.00	131.00	0.00	1371.00	1240.00		
	21	32	21	M/C3	160.00	8	0.00	160.00	0.00		1080.00		
	22	32	22	M/C3	224.00	8	0.00	224.00	0.00		856.00		
	23	32	23	M/C3	84.00	8	0.00	84.00	0.00		772.00		
	24	32	32	F8	467.00	13	39.82	506.82	39.82		225.36	0.836	0.778
5	24	31	24	M/C5	428.00	9	0.00	428.00	0.00	1371.00	943.00		
	25	31	25	M/C3	92.00	10	10.42	102.42	10.42		830.16		
	26	31	26	M/C3	124.00	10	0.00	124.00	10.42		695.74		
	27	31	27	M/C3	120.00	10	0.00	120.00	10.42		565.32		
	28	31	28	M/C3	120.00	10	0.00	120.00	10.42		434.90		
	29	31	29	M/C5	15.14	9	10.42	25.56	0.00		409.34		
	30	31	31	M/C7	205.00	12	28.35	233.35	28.35		147.64	0.892	0.805
6	30		30	M/C6	637.00	11	0.00	637.00	0.00	1371.00	734.00	0.465	0.465
Total Walking Time									604.48	Max Full Work		0.919	0.831
Average Utilization of workstation (without walking time)													0.770

Table 4.2 An example of task and worker assignment in the U-shaped assembly line

Station (Worker)	Task considered		Assignment					Total time (3) (1)+(2) (seconds)	WT to origin (4) (seconds)	Given cycle time (5) (seconds)	Idle time (5)-(3)-(4) (seconds)	Utilization (3)+(4)/(5)	Utilization without walking time
	Front graph	Back graph	Task	Machine	(2)Task time (seconds)	Location	(1)WT (seconds)						
1	5	36	5	M/C3	222.86	1	0.00	222.86	0.00	1371.00	1148.14		
	1	36	36	M/C9	192.00	23	65.24	257.24	65.24		825.66		
	1	35	1	M/C1	7.14	2	65.90	73.04	9.32		743.30		
	4	35	4	M/C3	295.24	3	9.32	304.56	18.64		420.10		
	9	35	9	M/C3	90.48	3	0.00	90.48	18.64		310.99		
	6	35	6	M/C4	14.76	4	9.32	24.08	27.96		258.94	0.811	0.600
2	2	35	35	M/CS1	210.00	22	0.00	210.00	0.00	1371.00	1161.00		
	2	34	34	F8	213.00	21	9.32	222.32	9.32		929.36		
	2	33	33	F8	257.00	21	0.00	257.00	9.32		663.04		
	2	32	32	F8	467.00	21	0.00	467.00	9.32		186.72		
	2	31	2	M/C2	10.71	5	67.85	78.56	70.98		37.18	0.973	0.844
3	3	31	31	M/C7	205.00	20	0.00	205.00	0.00	1371.00	1166.00		
	3	30	30	M/C6	637.00	19	9.32	646.32	9.32		510.36		
	3	29	29	M/C5	15.14	18	9.32	24.46	18.64		467.26		
	3	28	28	M/C3	120.00	17	9.32	129.32	27.96		309.98		
	3	27	27	M/C3	120.00	17	0.00	120.00	27.96		162.02		
	3	26	26	M/C3	124.00	17	0.00	124.00	27.96		10.06	0.993	0.891
4	3	25	3	M/C3	564.00	6	0.00	564.00	0.00	1371.00	807.00		
	8	25	8	M/C3	334.00	6	0.00	334.00	0.00		473.00		
	15	25	15	M/C3	158.00	6	0.00	158.00	0.00		315.00		
	7	25	7	M/C4	223.57	7	9.32	232.89	9.32		72.79	0.947	0.933

Table 4.2 An example of task and worker assignment in the U-shaped assembly line (cont.)

Station (Worker)	Task considered		Assignment					Total time (3) (1)+(2) (seconds)	WT to origin (4) (seconds)	Given cycle time (5) (seconds)	Idle time (5)-(3)-(4) (seconds)	Utilization (3)+(4)/(5)	Utilization without walking time
	Front graph	Back graph	Task	Machine	(2)Task time (seconds)	Location	(1)WT (seconds)						
5	10	25	12	M/C3	144.76	8	0.00	144.76	0.00	1371.00	1226.24	0.900	0.716
	12	25	10	M/CS1	209.00	9	10.42	219.42	10.42		996.40		
	13	25	13	M/C3	53.33	10	0.00	53.33	16.80		926.26		
	11	25	16	M/C5	17.86	11	9.32	27.18	25.09		874.00		
	14	25	11	M/C3	188.00	12	9.32	197.32	33.93		642.75		
	17	25	17	M/C3	21.90	12	0.00	21.90	33.93		586.91		
	18	25	14	M/C3	189.00	12	0.00	189.00	33.93		363.98		
	16	25	18	M/C3	27.43	12	0.00	27.43	33.93		302.62		
	19	25	19	M/C3	131.00	12	0.00	131.00	33.93		137.69		
6		25	25	M/C3	92.00	16	0.00	92.00	0.00	1371.00	1279.00	0.992	0.908
		24	24	M/C5	428.00	15	10.42	438.42	10.42		830.16		
		23	23	M/C3	84.00	14	9.32	93.32	16.80		720.04		
		22	22	M/C3	224.00	14	0.00	224.00	16.80		479.24		
		21	21	M/C3	160.00	14	0.00	160.00	16.80		302.44		
		20	20	M/C5	257.00	13	9.32	266.32	25.09		11.03		
Total Walking Time									990.12	Max Full Work		0.961	0.859
Average Utilization of workstation (without walking time)													0.815

4.2.3 Traditional straight assembly line

An example of task and worker assignment in the straight assembly line is presented in Table 4.3.

Table 4.3 An example of task and worker assignment in the straight assembly line

Station (Worker)	Task considered		Assignment					Total time (3) (1)+(2) (seconds)	WT to origin (4) (seconds)	Given cycle time (5) (seconds)	Idle time (5)-(3)-(4) (seconds)	Utilization (3)+(4)/(5)
	Front graph	Back graph	Task	Machine	(2)Task time (seconds)	Location	(1)WT (seconds)					
1	5		5	M/C3	222.86	1		222.86		1371.00	1148.14	0.971
	1		1	M/C1	7.14	2		7.14			1141.00	
	12		12	M/C3	144.76	3		144.76			996.24	
	8		8	M/C3	334.00	3		334.00			662.24	
	6		6	M/C4	14.76	4		14.76			647.48	
	4		4	M/C3	295.24	5		295.24			352.24	
	9		9	M/C3	90.48	5		90.48			261.76	
	2		2	M/C2	10.71	6		10.71			251.05	
	13		13	M/C3	53.33	7		53.33			197.71	
	15		15	M/C3	158.00	7		158.00			39.71	
2	3		3	M/C3	564.00	8		564.00		1371.00	807.00	0.913
	7		7	M/C4	223.57	9		223.57			583.43	
	10		10	M/CS1	209.00	10		209.00			374.43	
	11		11	M/C3	188.00	11		188.00			186.43	
	16		16	M/C5	17.86	12		17.86			168.57	
	17		17	M/C3	21.90	13		21.90			146.67	
	18		18	M/C3	27.43	13		27.43			119.24	

Table 4.3 An example of task and worker assignment in the straight assembly line (cont.)

Station (Worker)	Task considered		Assignment					Total time (3) (1)+(2) (seconds)	WT to origin (4) (seconds)	Given cycle time (5) (seconds)	Idle time (5)-(3)-(4) (seconds)	Utilization (3)+(4)/(5)
	Front graph	Back graph	Task	Machine	(2)Task time (seconds)	Location	(1)WT (seconds)					
3	14		14	M/C3	189.00	14		189.00		1371.00	1182.00	0.762
	19		19	M/C3	131.00	14		131.00			1051.00	
	20		20	M/C5	257.00	15		257.00			794.00	
	21		21	M/C3	160.00	16		160.00			634.00	
	22		22	M/C3	224.00	16		224.00			410.00	
	23		23	M/C3	84.00	16		84.00			326.00	
4	24		24	M/C5	428.00	17		428.00		1371.00	943.00	0.656
	25		25	M/C3	92.00	18		92.00			851.00	
	26		26	M/C3	124.00	18		124.00			727.00	
	27		27	M/C3	120.00	18		120.00			607.00	
	28		28	M/C3	120.00	18		120.00			487.00	
	29		29	M/C5	15.14	19		15.14			471.86	
5	30		30	M/C6	637.00	20		637.00		1371.00	734.00	0.955
	31		31	M/C7	205.00	21		205.00			529.00	
	32		32	F8	467.00	22		467.00			62.00	
6	33		33	F8	257.00	23		257.00		1371.00	1114.00	0.636
	34		34	F8	213.00	23		213.00			901.00	
	35		35	M/CS1	210.00	24		210.00			691.00	
	36		36	M/C9	192.00	25		192.00			499.00	
Total Walking Time									0.00	Max Full Work		0.851

4.3 Data analysis

The summary of results for all models according to the objective functions and the number of machines including free workplaces is shown in Table 4.4. From Table 4.4, the results of the Shared-machine U-shaped assembly line balancing according to three objective functions are as follows. At $\alpha = 5\% \text{APT}$, the number of workstations or workers (W) is 6, the walking time (WT) is 604.48 seconds and the full work (Ut) is 0.919. At $\alpha = 2$ seconds, the number of workstations or workers (W) is 6 as well, the walking time (WT) is 98.540 seconds and the full work (Ut) is 0.900. Moreover, the results of UALBP-I and SALBP-I in the same test-bed problem are presented. The former, W is 6, WT is 990.12 seconds and Ut is 0.961 where $\alpha = 5\% \text{APT}$. While, W is 6, WT is 196.48 seconds and Ut is 0.939 where $\alpha = 2$ seconds. The latter, W is 6, Ut is 0.851, and no walking time. In addition, the number of machines and free workplaces of the proposed line, traditional U-line ($\alpha = 5\% \text{APT}$ and 2 seconds), and straight line are 15, 23, 20, and 25 respectively. For the special case*, this study tries reducing the walking time by moving a shared machine from a center of the line to a convenient location for a worker when the shared machine is used by the same worker (or workstation) and rebalancing. The result of this trial is reported, that is, the walking time is reduced from 604.48 to 525.42 seconds. However, the machine location should be considered before moving a shared machine.

Table 4.4 Summary of results for all models according to the objective functions and the others

Model	Coefficient of walking time	Objective function			Others
		Number of workstations	Walking time	Full work (average utilization)	Number of machines + free workplaces
Shared-machine U-shaped line	5% APT	6	604.48 (525.42)*	0.919	15
	2 seconds	6	98.540	0.900	15

Table 4.4 Summary of results for all models according to the objective functions and the others (cont.)

Model	Coefficient of walking time	Objective function			Others
		Number of workstations	Walking time	Full work (average utilization)	Number of machines + free workplaces
U-line	5% APT	6	990.12	0.961	23
	2 seconds	6	196.48	0.939	20
Straight line	-	6	0	0.851	25

Note: *To move a shared machine from a center of the line to a convenient location for a worker when the same worker (or workstation) uses the shared machine.

CHAPTER V

DISCUSSION AND CONCLUSION

This chapter describes contribution from this research through discussion and conclusion. In addition, the research limitation and recommendations for further research are provided.

5.1 Discussion

5.1.1 The comparison of the KPIs results between the proposed model and the others

From the results (Chapter IV), while the number of workers of those lines is the same, workers in the Shared-machine U-shaped line spend time on walking less than the traditional U-line because its smaller size. The full workload is more than 90%; consequently, the utilization of worker is acceptable. In addition, it provides the opportunity to increase the utilization of least-utilized worker. Finally, the number of machines of the proposed U-line is less than the traditional U-shaped line and straight line. In other words, the average of machine utilization in this line is improved.

5.1.2 The comparison of the walking time results between different coefficients

From section 3.1.6 (Chapter III), the coefficient of walking time (α), which is used to calculate the walking time in this study, is determined by two cases. First, according to the literature review (Balakrishnan et al., 2009; Sirovetnukul and Chutima, 2010), α is assumed to be 5% APT. Second, according to a collected data from a real case, α is assumed to be two seconds. After finished line balancing, the walking time at $\alpha = 5\%$ APT is higher than the walking time at $\alpha = 2$. It is because 5% APT in this study is 9.32 seconds per meter that it is too high for a real situation. Thus,

$\alpha = 5\%$ APT is not suitable for a real case study. In other words, a unit for distance should be considered before using any coefficient.

5.1.3 The comparison between the proposed model and the case study model

In the sample room, the special line produces many products in low to medium volumes. There are many types of machines that can be used more than one in a cycle. In addition, workers are multi-skilled and high levels. Based on an assembly line concept, the U-line that is currently assembly line is suitable for applying in a case study in order to respond a new market trend, that is, shorter product life cycles and increased demands for customization. However, the U-line cannot improve the utilization of workers and machines directly. Hence, the key difference between the advantage of U-line and the Shared-machine U-shaped assembly line, which is supported by the task and worker assignment (Section 3.1.6), is the incremental utilization of the machine and worker.

However, the case study of U-line in practice usually contains no crossover workstation and the assignment of task and worker are usually determined as a straight line. In such a situation, the assembly line has too many workers and machines. In addition, some advantages of the U-line (Miltenburg and Wijngaard, 1994; Rabbani *et al.*, 2012) and the Shared-machine U-shaped line will be completely ignored.

5.2 Conclusion

This study presents task and worker assignment in the Shared-machine U-shaped assembly line via the case study of a sample room in a few garment manufacturers of Thailand. To revolutionize this assembly line by the lean concept of waste reduction and synchronous movement, three objective functions are considered i.e. minimized the number of workstations (workers), minimized walking time, and maximized full work. The purposes of the first and second criteria are to save space and walking while the purpose of the third criteria is to increase the average of

utilization of workers. In addition, the least-utilized worker will be moved to do other works.

As a result, the Shared-machine U-shaped assembly line is suitable for the modern garment industry since the assembly line requires only few workers and machines to respond to a variety of production in low to medium volumes. It helps them to enhance competitiveness, improve task and worker assignment and increase the utilization of machines and workers. Each machine in this line enables to operate more than a group of tasks in a cycle but at different time.

5.2.1 The advantage of the Shared-machine U-shaped assembly line

The advantages of the Shared-machine U-shaped assembly line are summarized as follows:

For designed layout: the layout of Shared-machine U-shaped assembly line is adapted from the embedded U-line. After adapting, the Shared-machine U-shaped assembly line has only one simple U-line and embeds a shared machine in the center. The size of the Shared-machine U-shaped line is smaller than the embedded U-line, which has a large U-line encircling a small U-line (Milteneburg, 2001). Therefore, it will be able to save space and walking. Since a shared machine is located at a center, any multi-skilled worker is able to use it with a hardly different distance. However, the layout can be adjusted to another pattern, in addition to the assumptions of the model, by moving a shared machine from a center to a convenient location for a worker if the machine is used by the same worker or workstation.

For designed assignment: the task and worker assignment is designed for supporting the model. The main difference between the traditional U-line assignment and the Shared-machine U-shaped assembly line assignment is in the following. In the traditional U-line assignment, a machine is able to operate only one assigned task (a group of tasks) in a cycle. In the Shared-machine U-shaped assembly line assignment, a machine will be able to operate more than one in a cycle but at different time. In addition, the shared machine is able to operate assigned task either same or different workstation (worker).

For other circumstances: the proposed model is suitable for the modern garment industry since the assembly line has only some workers and machines to

respond to a variety of production in low to medium volumes. For example, the special line in a sample room. In addition, it helps them to enhance competitiveness, improve task and worker assignment, and increase the utilization of machines and workers. However, the improvement of visibility and communications, multi-skilled workers, simplicity of rebalancing the line and reduction in number of workstations are found in this model.

5.2.2 A way to apply a task and worker assignment to the Shared-machine U-shaped assembly line for a garment manufacturing

A way to apply a task and worker assignment to the Shared-machine U-shaped assembly line for a garment manufacturing can be divided into three steps as follows:

Step 1: Prepare the data input for setup line.

- a) Check the production plan,
- b) Understand about the product type, quantity, materials, process, machines, precedence graph, and standard time,
- c) Determine the cycle time,
- d) Determine the shared machine,
- e) Determine the coefficient of walking time for a unit distance.

Step 2: Setup line.

- a) Prepare the machines and materials,
- b) Determine the size ratio of U-line,
- c) Pre-balance line into U-line to know the approximate number of machines and area (Step 2; Section 3.1.6; Chapter III).

Step 3: Balance line into the Shared-machine U-shaped assembly line.

- a) From (c) of Step 2, place a shared machine at a center of the line and place the other machines around U-shaped,
- b) Rebalance U-line to the Shared-machine U-shaped assembly line (Step 4; Section 3.1.6; Chapter III) until the size of line is stable,
- c) Keep the good solution and select the best.

However, the proposed model is subjected to assumptions and identified factors in Chapter III.

5.3 Limitation and recommendations for further research

5.3.1 Research limitation

The limitation of this study related to time to accomplish in this research. When the factor influencing the KPIs of the proposed model has been identified only top 1 to top 4 of factor ranking are selected to determine in the model. Due to the limited time of thesis study in master degree, it was difficult to determine all factors into the proposed model in order to model testing. However, these selected factors are influencing the KPIs of the proposed model around 75% of all factors.

5.3.2 Recommendations for future research

In this study, the result of case study's 36 tasks was not an optimal solution. It should randomize the task sequence into production line or create many new solutions. Several solutions lead to the optimal solutions for the three objective functions. For computational program, a multi-objective evolutionary algorithm may be an optional tool in getting feasible solutions in a short time by extending this research problem and comparing with the traditional straight line and U-shaped line. In addition, the other perspective of performance should be considered.

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APPENDIX A

INFORMATION FOR THE PRACTITIONER

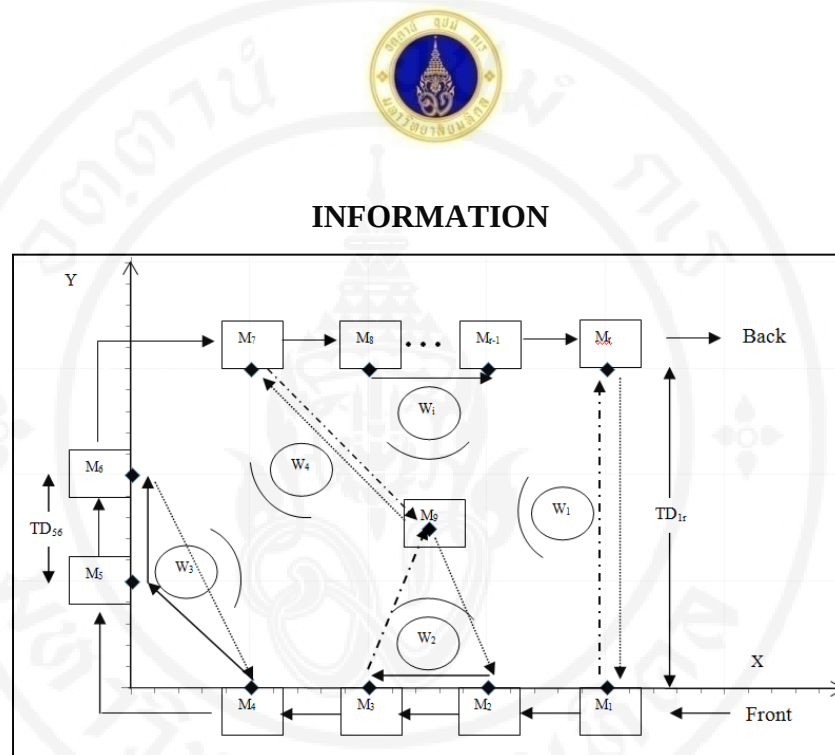


Figure A.1: The Model of Shared-machine U-shaped assembly line

Description

- 1) The Shared-machine U-shaped assembly line has only one U-line and embeds a shared-machine in the center and operators work inside.
- 2) Based on types of the machine, the tasks are assigned to the same machine first, as fully as possible but at a different time.
- 3) A worker will be able to walk and return between the machines within a workstation during a cycle.
- 4) A machine that is located around U-line can operate assigned tasks in the same workstation (worker) only while **a shared-machine that is located on the center of U-line is able to operate assigned task with either same or different workstation (worker)**

The performance measures

The performance measure in this study focuses on the productivity perspective. After reviewing, the productivity and the key performance indicators (KPIs) are presented in Table A.1

Table A.1 Performance measures and KPIs

Performance Measures	KPIs
1. Productivity	1.1 Number of workstations or workers 1.2 Line effectiveness 1.3 Effect of breakdowns 1.4 Labor productivity 1.5 Full work level or worker utilization 1.6 Variation of workloads 1.7 Number of crossover workstations 1.8 Line efficiency 1.9 Total number of containers traveling in the pull system 1.10 Walking time 1.11 Number of machines 1.12 Machine utilization 1.13 Cycle time

The quantitative decision variables (factors)

Definitions were used to determine interesting areas for information and/or data and to the same understanding of an interviewee. The factor definitions were shown in the second column of Table A.2. The extension column describes some details to clarify the meaning of factors and determines some characteristics for the proposed model.

Table A.2 Definition of quantitative decision variables (factors) and extension

Quantitative factors	Definition	Extension
Number of tasks (or machines)	The amount of task or machine in production line for each product.	≤ 30 tasks (or 30 machines).
Cycle time (or takt time)	Maximum or average time available for each workcycle (Scholl and Becker, 2006).	Vary from customer demands.
Failure rate & repair rate	<u>Failure rate</u> is rate of failure during the station. <u>Repair rate</u> is rate of repairs when station failures.	<u>Failure rate</u> may depend on the probability of failure per unit of work time required completing task assigned to station. <u>Repairs are complete</u> more quickly when the repair rate is high.
Buffer size	The amount of buffer in production line (or fixed WIP) for each connected point.	Small buffer inventories such as 3-6 for each connected point.
Walking time	The amount of travel time for operator walking to work within a workstation during a cycle.	Depend on walking distance.

Table A.2 Definition of quantitative decision variables (factors) and extension (cont.)

Quantitative factors	Definition	Extension
Number of crossover workstations	The amount of workstation that includes tasks located on different production lines.	≥ 1 workstation(s)
Network density	A characteristic which measures the strength of relation of the assembly network. Network density is defined as the ratio of the total number of precedence relations in the precedence graph (d) and the total number of tasks (N) i.e. $2d/[N(N - 1)]$. (Talbot <i>et al.</i> , 1986).	If the values of network density close to 1 indicate a highly interconnected network, and fewer alternatives available for assigning tasks to a workstation. In other words, if the values of network density close to 0 indicate relatively fewer precedence relationships, and more opportunities for assigning tasks to a workstation.
Operator cost	Regular and overtime wages for a worker.	The wage of a temporary worker per unit time is less than the wage of a permanent worker. Types of the worker depend on to skill-levels.
Number of operators	The number of workers is assigned to assembly line.	

Table A.2 Definition of quantitative decision variables (factors) and extension (cont.)

Quantitative factors	Definition	Extension
Lead time	The amount of time that elapses between when a process starts and when it is complete.	Lead time includes processing time (may depend on skill-levels and efficiency of worker), waiting time, conveyance time and kanban collecting time.
Operator skill level	The working experience of a worker related to familiarity with the factory's processing, knowledge of the specialized equipment, ability to recognize good and bad products, speed, and ability to solve problem.	
Cost of moving machines (or changeover cost)	An amount paid or required in payment for moving some stationary machines and/or for changeover process.	Depend on a factory (may be considering by machine types, process and production policy and so on).
Available space of a workstation	The area of production line.	Depend on a factory (may be considering by size and layout of production plant, size of machines and so on).

APPENDIX B

THE QUESTIONNAIRES



The decision variables (factors) influencing the production line performance of the Shared-machine U-shaped assembly line

These questionnaires will be part of thesis of a master's student in Industrial Engineering, Faculty of Engineering, Mahidol University

Explanation

After having been doing literature review, these questionnaires are designed to study the decision variables (factors) influencing the production line performance of the Shared-machine U-shaped assembly line. The questionnaire is divided into two sections in the following.

Section 1: Respondent's information,

Section 2: The performance measures and decision variables (factors);

2.1 Factor ranking,

2.2 Scoring the factor.

Please read the explanation carefully before answer the questions. The result of the study will be kept in confidential. Thank you for your participation.

Miss Pattarawan Khemyong

A master's student in Industrial Engineering,

Faculty of Engineering, Mahidol University.

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Section 1 Respondent's Information

Name

Workplace

Telephone number.....

2. What is your current position?

☐ President☐ Managing Director☐ Directors☐ Production/ Q.A/ Q.C Manager☐ Technical specialist☐ Academician /Researcher☐ Others. Please specify

3. How many years have you worked in this field?

☐ < 1 year☐ 1 - 2 years☐ 3 - 4 years☐ $\geq$ 5 years**Section 2 The performance measure and decision variables (factors)****2.1 Factor ranking**

Please rank the factors that influence the productivity of the production line when the Shared-machine U-shaped assembly line is implemented.

Number rankings from the most influence to the less influence (1 to 2,3,..., n), and the same number is the same influence. If you think, there are more factors to affect the productivity of the assembly line to be concerned, please specify the factor and rank.

Example:

Factors	Impact on “Productivity” (1)
A	2
B	1
C	3

From the example, it shows that when the proposed model is implemented, (1) factor B is the most influential of all the other factors in the productivity of the assembly line. In addition, factor A is more influential than factor C in the productivity of the assembly line [Factor B > A > C].

Factors	Impact on “Productivity”
Number of tasks (or machines)	
Cycle time (or takt time)	
Failure rate & Repair rate	
Buffer size	
Network density	
Walking time	
Number of crossover workstations	
Operator cost	
Operator skill level	
Number of operators	
Lead time	
Cost of moving machine	
Available space of a workstation	

Remark: [] Others. Please specify and rank.

.....

2.2 Scoring the factor

Please mark ✓ in the blank of **“Productivity”** which matches with your opinion. If you think, there are more factors to affect the productivity of the assembly line to be concerned, please specify the factor, and give scores

Factor vs. Performance

Column

“Productivity” = You think that the influence of each factor in the productivity when the model is implemented.

Impact	None	Very low	Low	Medium	High	Very high
Level	0	1	2	3	4	5
Scores	0	20	40	60	80	100

Factors	Impact on “Productivity”					
	Very high	High	Medium	Low	Very low	None
Number of tasks (or machines)						
Cycle time (or takt time)						
Failure rate & Repair rate						
Buffer size						
Network density						
Walking time						
Number of crossover workstations						
Operator cost						
Operator skill level						
Number of operators						
Lead time						
Cost of moving machine						
Available space of a workstation						

Remark: [] Others. Please specify and give scores.

.....

.....

.....

.....

Thank you for your participation.

Miss Pattarawan Khemyong



APPENDIX C

2013 THE IEEE INTERNATIONAL CONFERENCE ON INDUSTRIAL ENGINEERING AND ENGINEERING MANAGEMENT SUBMITTED PAPER

C.1 ACCEPTANCE LETTER

IEEM 2013 Paper Notification (IEEM13-P-0384)

IEEM 2013 Secretariat <info@ieem.org>
 โทร: pattybluet.pk@gmail.com, ronnachai.sir@mahidol.ac.th, ronnachai_s@hotmail.com

31 กรกฎาคม 2556, 01:49



Wednesday, July 31, 2013

Dear Ms Pattarawan Khemyong,

The organizing committee of the 2013 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM2013) congratulates you on the acceptance of your paper and its presentation at the meeting in Bangkok (please see also important notes below).

IEEM13-P-0384 / Task and Worker Assignment in the Shared-Machine U-Shaped Assembly Line
 Pattarawan Khemyong, Mahidol University, Thailand
 Ronnachai Sirovetnukul, Mahidol University, Thailand

The annual conference gives an opportunity to remain in touch with the industrial engineering and engineering management community and to exchange thoughts and new findings. We look forward to your presence to present the above paper at IEEM2013 in Bangkok.

Important Notes

1. Please incorporate reviewer comments (if any - see P.2) in the final version of your paper. Your final paper has to be camera-ready and prepared following the IEEM2013 paper guidelines (<http://www.ieem.org/public.asp?page=submitFinal.htm>)
2. Please also ensure that your paper is free from serious language mistakes. To maintain the international standard of IEEE conferences, we reserve the right to exclude your paper in the final proceedings if the language is deemed unsatisfactory.
3. Note also that the abstract length accompanying your final paper may not exceed 150 words which is the standard requirement for inclusion in the Book of Program and Abstracts which will be distributed onsite to all participants.
4. You may select your preferred presentation mode (oral/poster) when uploading the paper (there will be no differentiation in the proceedings, only for conference program). We may face schedule and venue constraints when preparing the program, so do be flexible. However, if for funding or other reasons, you need to give oral presentations, make sure that you select it.
5. Only camera-ready manuscripts that are IEEE Xplore® compliant can be included in the IEEM2013 conference proceedings. Please note that this is not an undertaking by the organizers that accepted papers will appear on IEEE Xplore® and be indexed on the EI Compendex. **Indexing decision is made by the organization(s) concerned.**
6. Authors must register and make payment by 01 September 2013 to ensure that their papers are included in the proceedings. Please be sure to sign your copyright transfer form online also by 01 September 2013.
7. The portal for final paper submission and copyright transfer form will open on 07 August 2013. The conference will begin to accept registration and payment as well, from 07 August 2013. Participation will only be confirmed upon receipt of the online registration form and payment. Please register and make payment early.
8. Please bookmark these URLs
 SUBMIT FINAL PAPER: <http://www.ieem.org/public.asp?page=submitFinal.htm> (Opens 07 Aug 2013)
 REGISTER TO ATTEND: <http://www.ieem.org/public.asp?page=register.htm> (Opens 07 Aug 2013)
 CONFERENCE HOTEL & BOOKING: <http://ieem.org/public.asp?page=hotels/hotel.asp>
9. The conference will be held at the SWISSOTEL LE CONCORDE, BANGKOK, THAILAND
 204 Ratchadapisek Road, Huay Kwang, Bangkok
 Tel: (662) 694 2222 Fax: (662) 694 2214
 Website: <http://www.swissotel.com/hotels/bangkok-concorde/>

Yours truly,
 IEEM2013 Secretariat

C.2 FULL PAPER

Task and Worker Assignment in the Shared-Machine U-Shaped Assembly Line

P. Khemyong¹, R. Sirovetmukul¹

¹Department of Industrial Engineering, Faculty of Engineering, Mahidol University, Nakhonpathom, Thailand
(pattybluet.pk@gmail.com, ronnachai.sir@mahidol.ac.th)

Abstract - This study presents a new approach on a U-shaped line namely, task and worker (double) assignment in the shared-machine U-shaped assembly line. A case study was done on a garment manufacturing company in Thailand. In order to revolutionize and consider the lean concept of waste reduction and synchronous move, three objective functions were considered: minimizing the number of workstations (workers), minimizing walking time, and maximizing full work. The results showed that the shared-machine U-shaped line has the same number of workstations (or workers) as the straight line and traditional U-line but the walking time is less than the latter while the utilization of worker is satisfying. In addition, the utilization of machine is better than other lines. Hence, the proposed model can help improve the double assignment and increase machine and worker utilization of a manufacturing company.

Keywords - Shared-machine, U-shaped assembly line, Task and worker assignment

I. INTRODUCTION

Almost all apparel manufacturers try their best to finish the assembly work fast by increasing machine or worker utilization but at the same time reducing production cost. Assembly line balancing is therefore a critical issue to improve the efficiency and to enhance competitiveness [1]. In traditional U-line, the machines are arranged around U-shaped layout by one task for each machine according to production process. After obtaining the data from the case study, it was observed that the production line has too many workers and machines. There are many types of machines in the factory such as, a sewing machine, a press machine, and an ironing machine. Moreover, any machine of those types can perform many tasks. Hence, the main objective in this study is to determine a way to assign the task to workers or workstations in a case of the shared-machine U-shaped assembly line especially under a production line following a mixed-model.

Furthermore, the interesting issue for assembly lines problems is the assignment of task to workers or workstations in the shared-machine U-shaped assembly line by considering three objective functions i.e. minimized number of workstations (or workers), minimized walking time, and maximized full work.

The remainder of this paper is organized as follows. Previous studies are reviewed in the second section. Third, the proposed approach is presented, and the illustrative example of problem is elaborated. Fourth, the results and analysis are presented. Finally, conclusion and future research are also described.

II. LITERATURE REVIEW

A. U-Shaped assembly line

The U-shaped production line is a special type of cellular manufacturing assembly line used in just-in-time (JIT) production systems [2]. Many benefits of the U-shaped layout are discussed [2]. The U-shaped line requires operators to be multi-skilled [2]. It also requires operators to work standing up and walking according to the layout and the assignment.

The layout of U-lines are divided in terms of its complexity to many types such as, simple U-line, multi-lines in a single U, embedded U-lines, and multi-U-line facility [2]. This study is interested with the embedded U-lines and it was adapted under a real situation for a case study on a garment manufacturing. Its characteristics are as follows, the embedded U-line has a large U-line encircling a small U-line [2]. It may take up a lot of space and require a lot of walking [2]. However, the shared-machine U-shaped assembly line has only one U-line and embeds a shared-machine in the center. It will be able to save space and walking. In addition, it will also increase the utilization of a machine from one task to another.

Nakade and Nishiwaki [3] divide the figures in a U-shaped line into two types based on operation of each machine. This study focus on the first type, that is, there is no automated processing machine. After each worker operates an item at a machine, a worker takes it to the next machine and so on.

The proposed model in this study is based on the U-shaped Assembly Line Balancing Problem of type I (UALBP-I). Finally, the model of the shared-machine U-shaped assembly line that has no automated machines with walking is presented.

B. Double Assignment

Miralles *et al.* [4] describe a double assignment that is a simultaneous assignment of 1) tasks to stations, and 2) available workers to stations. In manufacturing, the consideration of these topics is an extremely complex and difficult matter for a less experienced manager. In this study, a double assignment is presented and named as task and worker assignment to determine the difference. In addition, lean systems often aim to maximize full work that defines many workers as fully utilized as possible [5]. Consequently, this research applies the maximum full work to eliminate the least-utilized worker. In other words, the least-utilized worker in this improved line will be moved to perform other tasks.

III. METHODOLOGY

A. Model descriptions

The main difference between the traditional U-line and the shared-machine U-shaped assembly line (♯) is discussed. In the traditional U-line, a machine is able to operate only one task, which also pertains to a group of tasks in a cycle. In the shared-machine U-shaped assembly line, a machine will be able to operate more than one in a cycle but at a different time. In this study, the shared-machine U-shaped assembly line is presented via a case study of the garment manufacturer in Thailand. The model is subjected to the following assumptions:

- Flow manufacturing on the U-shaped production line is in synchronous movement with a few bundles of work in process (WIP)
- No automated machines in a fixed shared-machine U-shaped layout is presented
- Based on the types of machine, a machine will be able to operate on more than a group of tasks in a cycle but at a different time. A machine that is located around U-line can operate assigned tasks in the same workstation (worker) only while a shared-machine that is located on the center of U-line is able to operate assigned task either same or different workstation (worker)
- A worker will be able to walk and return between the machines within a workstation during a cycle
- All parameters and variables such as task times, walking times, types of machines are known and constant
- Trained workers have the same efficiency and multi-functional skilled and they are able to operate any processes or machines
- Learning effect has no consideration since it is assumed that worker performance runs into steady state already
- Setup times (assumed to be less than 5% compared with task time) are negligible because spared machines are prepared.
- For mixed models, precedence relationships of the problem are consistent from model to model. That is, if task j precedes task k in any model there is no other model where task k must precede task j .
- The sequencing problem is not taken into account.

B. Research steps

1) *Shared-machine U-line double assignment* is the following:

Step1: Determine the cycle time

Step2: (For mixed model)

- a) Modify the task time of each model whereby tasks with the same number have the same time and then calculate the weighted average processing time for each task [6]

- b) Merge each model's precedence graph into a single precedence graph [7]

Step3*: Assign a task to a workstation according to the U-line constraints [8]

- a) All tasks are assigned to a workstation
- b) Each task is assigned only once
- c) The precedence constraints are satisfied for each task
- d) The total time in each workstation (the task time + the walking time) does not exceed the given cycle time
- e) The number of workstations will be minimized

*This step can be skipped if production line is already a U-line

Step4: Prepare data for shared-machine U-line double assignment steps

- a) Specify a shared machine that is located on the center of U-line
- b) Determine the locations of the machine on a fixed shared-machine U-line layout* according to the number of machines after the finished line balancing (replace the location of the unused-machine with the machine that the task is assigned to, if required)
- c) Calculate the distance from machine to machine
- d) Transform the distance into the walking time by the coefficient of walking time

* In this research, the side ratio of 1/3 (1:1:1) of U-line is presented

Step5: Assign a task and a worker to a workstation according to the shared-machine U-line constraints

- a) Constraint a-e of U-line in step 3
- b) Every task is located on the front or back or center of the line and is assigned to one worker
- c) All tasks are assigned to a right machine
- d) The tasks are assigned to the same machine as fully as possible but at a different time

Step6: Repeat step 4-5 until the size of a fixed shared-machine U-line is stable

Step7: Evaluate the objective functions and keep the string that the average of utilization is more than 90%

Step8: Repeat step 5, 7 until the terminating condition is met

Step9: Rank the good solutions of three objective functions

Step10: Select the candidates according to the good solution in the first rank.

2) *Model configuration* illustrates the characteristics of ♯ (see in Fig. 1)

3) *Notation* is as follows:

- i = index on workstations or workers,
- j, k = index on tasks,
- a = coefficient of walking time,
- u = total time of the least utilization of workstation,

M = upper bound on the number of workstations,
 N = the number of tasks of each workstation,
 C = given cycle time,
 T_{ij} = task time of task j assigned to workstation i ,
 l_{ij} = task distance of task j assigned to workstation i ,
 c_{ij} = crossover distance of task j assigned to workstation i ,
 r_{ij} = return distance of task j assigned to workstation i .

4) *Objective functions* are as follows:

Minimize the number of workstations (W)

$$f_1(X) = W = \sum_{i=1}^M S_i \quad (1)$$

Minimize the walking time (WT)

$$f_2(X) = WT = \alpha \sum_{i=1}^M \sum_{j=1}^N (l_{ij} + c_{ij} + r_{ij}) \quad (2)$$

Maximize full work (U_i)

$$f_3(X) = U_i = \frac{\sum_{i=1}^M \sum_{j=1}^N T_{ij} + \alpha \sum_{i=1}^M \sum_{j=1}^N (l_{ij} + c_{ij} + r_{ij}) - u}{C \times (M-1)} \quad (3)$$

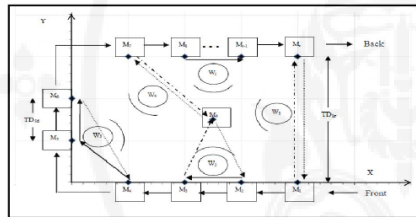


Fig. 1. Mapping a diagram of the shared-machine of a single U-Shaped assembly line for workstation W_i and machine M_r on grid arrangement when TD_{XY} is travel distance between machine X and machine Y (s).

C. Input data

Input data was collected from a case study as shown in Table I. This research presents a fixed shared-machine U-line layout at the side ratio of 1/3 (1:1:1) that is representative for the workable single U-line [9]. The coefficient of walking time (α) is five percentage of Average Processing Time [10] and given cycle time is 1.371 seconds. The walking distance is set at one unit for adjacent machines in the same row. Assume that each of the walking distance between a pair of tasks is directly proportional to Euclidean distance between locations [9].

D. Numerical example of preliminary study

The results of case study's 36-tasks are illustrated. When the size of a fixed shared-machine U-line is stable, the number of machines is reduced from 23 to 15 that is M/C1, M/C2, M/C6, M/C7, F8, M/C9 and M/CS1 = 1; M/C4 and M/C5 = 2; M/C3 = 4. A task and a worker is assigned into a station according to step5 of shared-machine

TABLE I
DETERMINISTIC TASK TIMES (SECONDS) FOR ALL MODELS

Task	Predecessor	Single Model				Machine
		Model 1	Model 2	Model 3	Model 5	
1	-	-	25	-	7.14	M/C1
2	1	-	-	45	10.71	M/C2
3	2	564	564	564	564.00	M/C3
4	-	630	-	-	295.24	M/C3
5	-	-	780	-	222.86	M/C3
6	-	-	-	62	14.76	M/C4
7	6	-	-	939	223.57	M/C4
8	-	334	334	334	334.00	M/C3
9	-	-	-	380	90.48	M/C3
10	9	209	209	209	209.00	M/CS1
11	10	188	188	188	188.00	M/C3
12	-	190	190	-	144.76	M/C3
13	-	-	-	224	53.33	M/C3
14	11,12,13	189	189	189	189.00	M/C3
15	-	158	158	158	158.00	M/C3
16	15	-	-	75	17.86	M/C3
17	15	46	-	-	21.90	M/C3
18	15	-	96	-	27.43	M/C3
19	16,17,18	131	131	131	131.00	M/C3
20	14	257	257	257	257.00	M/C3
21	19,20	160	160	160	160.00	M/C3
22	8,21	224	224	224	224.00	M/C3
23	22	84	84	84	84.00	M/C3
24	23	428	428	428	428.00	M/C3
25	4,5,7,24	92	92	92	92.00	M/C3
26	25	124	124	124	124.00	M/C3
27	3,26	120	120	120	120.00	M/C3
28	27	120	120	120	120.00	M/C3
29	28	53	-	-	13.14	M/C5
30	29	637	637	637	637.00	M/C6
31	30	205	205	205	205.00	M/C7
32	31	467	467	467	467.00	F8
33	32	257	257	257	257.00	F8
34	33	213	213	213	213.00	F8
35	34	210	210	210	210.00	M/CS1
36	35	192	192	192	192.00	M/C9
Total tasks		5419	5767	5768	6308.19	

Note: Task 10 and Task 35 are operated on a shared machine (M/CS1); Area F8 is free workspace that is not relevant to any machine.

U-line double assignment. An example of task and worker assignment in the shared-machine U-shaped assembly line is presented in Table II. Then to evaluate the objective functions of this string, Equation (1) was used to determine the total number of workstations or workers (W) which is $(1+1+1+1+1) = 6$ stations (workers) shown in the first column. For the walking time (WT), in workstation 1 the assignment of task to worker is $[5_1_12_8_6_4_9_2_13]$. From previous runs in [9], the coefficient of walking time (α) is 9.32. The walking time is $(\alpha) \times (l_{5,1} + l_{1,12} + l_{12,8} + l_{8,6} + l_{6,4} + l_{4,9} + l_{9,2} + l_{2,13} + r_{1,5} + r_{6,5} + r_{2,5}) = 9.32 \times (1+1+2+2+3+3+1+2+3) = 167.76$ seconds. After that the walking time of workstation 2 to workstation 6 are computed similarly. Thus, the total walking time (WT) in (2) is $167.76 + 183.30 + 98.46 + 79.64 + 119.22 + 0 = 648.38$ seconds. Equation (3), maximize full work (U_i) that maximizes the average utilization of all but the least-utilized worker [5]. For each worker, utilization is total time (total task time + total walking time) divided by cycle time when the least-utilized worker has total time u [5]. From the last column of Table II, workstation or worker that has the least-utilization is worker 6, thus total time of the least-utilized worker is 637.00 seconds. Then U_i is $(6,331.19 + 648.38 - 637.00)/1.371 \times 5 = 0.925$ shown in last row of Table II. In addition, the result of case study's 36-tasks can be described in Fig. 2. For example, the production line has six workstations (workers). Worker 1 operates a group of tasks of $\{5\ 12\ 8\ 4\ 9\ 13\}$, $\{1\}$, $\{6\}$, and $\{2\}$ by M/C 3 No.1, M/C 1 No. 1, M/C4 No.1, and M/C2 No. 1 respectively at location 1, 2, 3, and 4 of front production line with a walking time

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TABLE II
AN EXAMPLE OF TASK AND WORKER ASSIGNMENT IN THE SHARED-MACHINE U-SHAPED ASSEMBLY LINE

Station (Worker)	Task considered		Assignment					Total time (3)	WT (1)-(2) (seconds)	Given cycle time (5) (seconds)	Idle time (5)-(3)-(4) (seconds)	Utilization (3)+(4)-(5)
	Front graph	Back graph	Task	(2)Task time (seconds)	Machine	Location	(1)WT (seconds)					
1	5	36	5	222.86	M/C3	1	0.00	222.86	0.00	1371.00	1148.14	
1	1	36	1	7.14	M/C1	2	9.32	16.46	9.32		1122.36	
1	12	36	12	144.76	M/C3	1	9.32	154.08	0.00		968.28	
1	8	36	8	334.00	M/C3	1	0.00	334.00	0.00		634.28	
1	6	36	6	14.76	M/C4	3	18.64	33.40	18.64		582.24	
1	4	36	4	295.24	M/C3	1	18.64	313.88	0.00		268.36	
1	9	36	9	90.48	M/C3	1	0.00	90.48	0.00		177.88	
1	2	36	2	10.71	M/C2	4	27.96	38.67	27.96		111.25	
1	13	36	13	53.33	M/C3	1	27.96	81.29	0.00		29.95	0.978
2	10	36	36	192.00	M/C9	14	0.00	192.00	0.00	1371.00	1179.00	
2	10	35	35	210.00	M/CS1	15	29.84	239.84	29.84		909.32	
2	10	34	34	213.00	F8	13	37.57	250.57	9.32		649.43	
2	10	33	33	257.00	F8	13	0.00	257.00	9.32		383.11	
2	10	32	10	209.00	M/CS1	15	37.57	246.57	29.84		106.70	0.922
3	3	32	3	564.00	M/C3	5	0.00	564.00	0.00	1371.00	807.00	
3	7	32	7	223.57	M/C4	6	10.42	233.99	10.42		562.59	
3	15	32	15	158.00	M/C3	5	10.42	168.42	0.00		394.17	
3	17	32	17	21.90	M/C3	5	0.00	21.90	0.00		372.26	
3	16	32	16	17.86	M/C5	7	16.80	34.66	16.80		320.81	
3	20	32	20	257.00	M/C5	7	0.00	257.00	16.80		47.01	
3	18	32	18	27.43	M/C3	5	16.80	44.23	0.00		2.78	0.998
4	19	32	19	131.00	M/C3	8	0.00	131.00	0.00	1371.00	1240.00	
4	21	32	21	160.00	M/C3	8	0.00	160.00	0.00		1080.00	
4	22	32	22	224.00	M/C3	8	0.00	224.00	0.00		856.00	
4	23	32	23	84.00	M/C3	8	0.00	84.00	0.00		772.00	
4	24	32	32	467.00	F8	13	39.82	506.82	39.82		225.36	0.836
5	24	31	24	428.00	M/C5	9	0.00	428.00	0.00	1371.00	943.00	
5	25	31	25	92.00	M/C3	10	10.42	102.42	10.42		830.16	
5	26	31	26	124.00	M/C3	10	0.00	124.00	10.42		695.74	
5	27	31	27	120.00	M/C3	10	0.00	120.00	10.42		565.32	
5	28	31	28	120.00	M/C3	10	0.00	120.00	10.42		434.90	
5	29	31	29	15.14	M/C5	9	10.42	25.56	0.00		409.34	
5	30	31	31	205.00	M/C7	12	28.35	233.35	28.35		147.64	0.892
6	30		30	637.00	M/C6	11	0.00	637.00	0.00	1371.00	734.00	0.465
Total Walking Time								648.38	Max Full Work			0.925

648.38 seconds. Worker 2 operates a group of tasks of {36} by M/C9 No.1 at location 14, operates a group of tasks of {35, 10} by M/CS1 that is a shared-machine at location 15 of the center of production line, and operates a group of tasks {34, 33} with a manual work (no machine) at location 13 of back production line. Worker 3 to worker 6 is also described in a similar manner. Finally, the time chart of operation in each workstation (worker) is shown in Fig. 3. In the time chart, each worker starts to work at the same time after working in the steady state. A group of tasks is assigned to a same machine but at a different time, thus there is no waiting time.

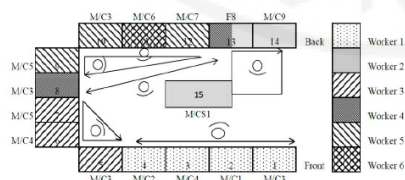


Fig. 2. An exemplified result of case study's 36 tasks on the fixed shared-machine U-shaped assembly line layout.

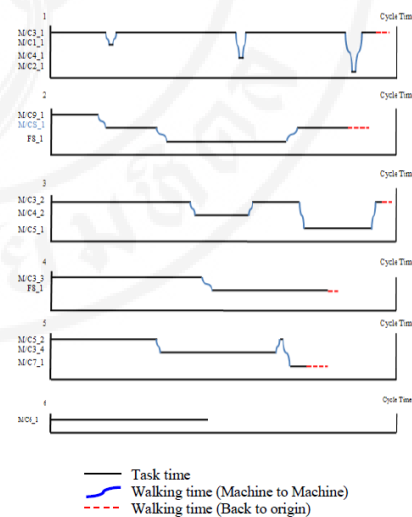


Fig. 3. Time chart of operation in each worker.

IV. RESULTS AND ANALYSIS

From Table II, the results of shared-machine U-shaped assembly line according to three objective functions are as follows. The number of workstations or workers (W) is 6, the walking time (WT) is 648.38 seconds and full work (Uf) is 0.925. Moreover, the results of SALBP-I and UALBP-I in the same test-bed problem are presented. The former, workers (W) is 6, no walking time, and Uf is 0.851. The latter, workers (W) is 6, the walking time is 990.12 seconds and Uf is 0.961. In addition, the number of machines of proposed line, straight line, and traditional U-line are 15, 36, and 23 respectively. From the results, while the number of workers of those lines is the same, workers in the shared-machine U-shaped line spend a lot of time in walking less than the traditional U-line because of its nature and the size is smaller. The full work is more than 90%; consequently, the utilization of worker is acceptable. In addition, it provides the opportunity to increase utilization of the least-utilized worker. Finally, the number of machines of the proposed U-line is less than the traditional straight line and U-shaped line.

V. CONCLUSION AND FUTURE RESEARCH

This study presents task and worker assignment in the shared-machine U-shaped assembly line thru a case study of the garment manufacturer in Thailand. To revolutionize and at the same time consider the lean concept of waste reduction and synchronous move, three objective functions are considered i.e. minimized the number of workstations (workers), minimized walking time, and maximized full work. The purpose of the first and second criteria is to save space and walking while the purpose of the third criteria is to increase the utilization of workers. In addition, the least-utilized worker will be moved to do other works. As a result, the shared-machine U-shaped assembly line is suitable for the modern garment industry since the production line has only few workers and machines to respond to a variety of production. It helps them to enhance competitiveness improve task and worker assignment and increase machine and worker utilization. Each machine in this line enables to operate more than a group of tasks in a cycle but at a different time. In practice, the firms will be able to apply this model into their production line if their skilled workers are able to operate any processes or machines with the same efficiency.

However, the result of case study's 36 tasks in this study was not optimal solutions. It should randomize the

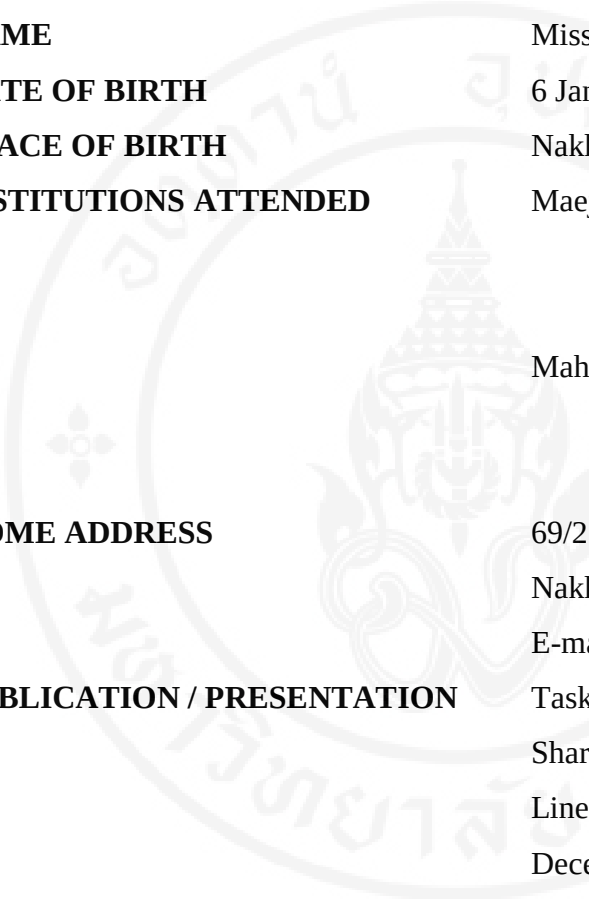
task sequence into production line or create many new strings. Several solutions lead to the optimal solutions for the three objective functions. For computational program, a multi-objective evolutionary algorithm may be an optional tool in getting feasible solutions in a short time by extending this research problem and comparing with the traditional straight line and U-shaped line.

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BIOGRAPHY

NAME	Miss Pattarawan Khemyong
DATE OF BIRTH	6 January 1981
PLACE OF BIRTH	Nakhon Pathom, Thailand
INSTITUTIONS ATTENDED	Maejo University, 1998-2002 Bachelor of Science (Food Technology) Mahidol University, 2010-2014 Master of Engineering (Industrial Engineering)
HOME ADDRESS	69/2 Moo.1, Mahasawat, Phutthamonthon Nakhon Pathom, 73170 E-mail: pattybluet.pk@gmail.com
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