ASSEMBLY LINE SET UP FOR REAR LAMP CABLE SET

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การสร้างสายการประกอบสำหรับไฟท้ายรถยนต์

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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ธนิก หวงธีระกุล : การสร้างสายการประกอบสำหรับไฟท้ายรถยนต์ (ASSEMBLY LINE SET U FOR REAR LAMP CABLE SET) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร. สมเกียรติ ตั้งจิตสิตเจริญ หน้า.

งานวิจัยนี้มีจุดประสงค์เพื่อสร้างสายการประกอบสายไฟท้ายของรถยนต์ ซึ่งก่อนที่จะใช้วิธีต่าง ในการสร้างสายการประกอบนั้น ทางโรงงานได้สร้างสายการประกอบต้นแบบขึ้นมา ปัญหาที่พบคื กระบวนการประกอบนั้นไม่สามารถตอบสนองการคาดการณ์การสั่งซื้อจากลูกค้าได้ ทั้งนี้สายการประกอ ต้นแบบสามารถผลิตได้ 2104 สายต่อวัน แต่เป้าหมายคือ 2424 สายต่อวัน

ฉนั้นงานวิจัยนี้ได้ประยุกต์ใช้วิธีการ Work Study และ Assembly Line Balancing มาเป็ เครื่องมือในการปรับปรุงกระบวนการประกอบ งานวิจัยนี้ประกอบไปด้วย 5 ขั้นตอนคือ ขั้นตอนการกำหน ปัญหา ขั้นตอน Method Study ขั้นตอน Assembly Line Balancing ขั้นตอน Work Measuremen และ บทสรุป ในขั้นตอนการกำหนดปัญหานั้น กล่าวถึงอุปกรณ์ที่ต้องใช้ในการประกอบสายไฟท้ายรถยน กระบวนการประกอบไฟท้ายรถยนต์ เป้าการผลิต กำหนดคณะทำงานและขอบเขตของงานวิจัย ใ Method Study ได้ศึกษาเกี่ยวกับ micro-motions ของแต่ละขั้นตอนของการประกอบไฟท้ายรถยน เพื่อที่จะพัฒนาประสิทธิภาพในการประกอบไฟท้ายรถยนต์ให้เร็วยิ่งขึ้น ซึ่งผลลัพธ์ของ method study จ ถูกนำไปใช้เป็นมาตรฐานของขั้นตอนในการประกอบไฟท้ายรถยนต์ ในขั้นตอน assembly line balancin ได้จัดเรียงขั้นตอนในการประกอบไฟท้ายรถยนต์ให้กับ workstation ต่างๆ โดยใช้วิธีการสองอย่าง คื Largest Candidate Rule และ Rank Positional Weight ผลลัพธ์ที่ได้คือ workstation จะมีปริมาณงา ที่ใกล้เคียงกัน ในขั้นตอน work measurement กล่าวถึง ระยะเวลาการทำงานของแต่ละ workstatio และระยะเวลาในการพักในแต่ละวัน ตามหลักการของ time study กล่าวว่า performance rating ได้ถูกใ ในการประเมินความเร็วของการประกอบไฟท้ายรถยนต์ของพนักงานเทียบกับมุมมองของหัวหน้าสายกา ประกอบ เพื่อกำหนดระยะเวลามาตรฐานที่ใช้ในการทำงานของแต่ละ workstation นอกจากนี้ ในกา กำหนดระยะเวลาพักในแต่ละวัน ได้ใช้วิธี International Labour Organisation’s metho และ Williams’s method มาเปรียบเทียบกัน

จากขั้นตอนเหล่านี้ เวลาของแต่ละ workstation จะต่ำกว่า takt time ซึ่งอยู่ที่ 16.35 วินา หลังจากการพัฒนาสายการประกอบสามารถผลิตสายไฟท้ายรถยนต์ได้ 2442 เส้นต่อวัน เทียบกับเดิมที่เค ผลิตได้ 1912 เส้นต่อวัน ซึ่งสามารถผลิตได้เพิ่มขึ้นถึง 27% นอกจากนี้ assembly line มีปริมาณงานในแ ละ workstation มีความใกล้เคียงกันมากขึ้น เพราะ smoothness index ลดลงจาก 13.39 เป็น 3.91 ซึ ลดลงถึง 70%

ภาควิชา	ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต	ลายมือชื่อนิสิต	....
		ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
สาขาวิชา	การจัดการทางวิศวกรรม		
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The objective of this research is to establish an assembly line for rear lamp cabl set by improving the prototype assembly line since it is unable to meet the forecaste demand producing 2104 cables per day as compared to the target of 2424 cables per day Work Study, divided into two parts (method study and work measurements), and Assembl Line Balancing techniques are applied. This research consists of five phases includin define, method study, assembly line balancing, work measurement, and conclusion. I define phase, materials and products, procedures and work elements, problems objectives and measurements, and project team are identified. In method study, micro motions of the process are studied in order to generate more efficient method. The resul of this phase is a standardised method for assembling. In assembly line balancing standardised work elements are assigned to workstations by using Largest Candidate Rul and Rank Positional Weight; the results from two methods are examined. Once workstations are defined, in work measurement, workstations' times and rest-pause regim are determined. Under time study, performance rating will evaluate the worker's pac relative to standard performance to determine the standard time. Furthermore, rest-paus regime will be determined by International Labour Organisation's method and Williams' method. The results from two methods will be examined for suitability in assembly lin rest-pause regime.

From all phases, every workstation time is below the takt time, 16.35 seconds the assembly line can now produce 2442 cables per day as compared to old productivit at 1912 cables, 27% increase in productivity. Moreover, assembly line is more balance due to 70% reduction of smoothness index from 13.39 to 3.91.

Department:	Regional Centre for Manufacturing Systems Engineering	Student's Signature	....
		Advisor's Signature	....
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Chapter 1. Introduction

Nowadays, there are many types of vehicles being produced by the automotive industries. Within one year, various versions of vehicles are introduced to the market. This is due to the fact that customers' tastes change unexpectedly. And since there was a 'first car campaign' initiated by the government in 2012 which citizen can get reimbursement from buying his or her first car. The result is apparent: dramatic increase in the number of car purchased of 1.4 million units according to Thailand Automotive Institute. Like a domino, automotive industries and suppliers had to respond quickly to the sudden upsurge in the demand of the market.

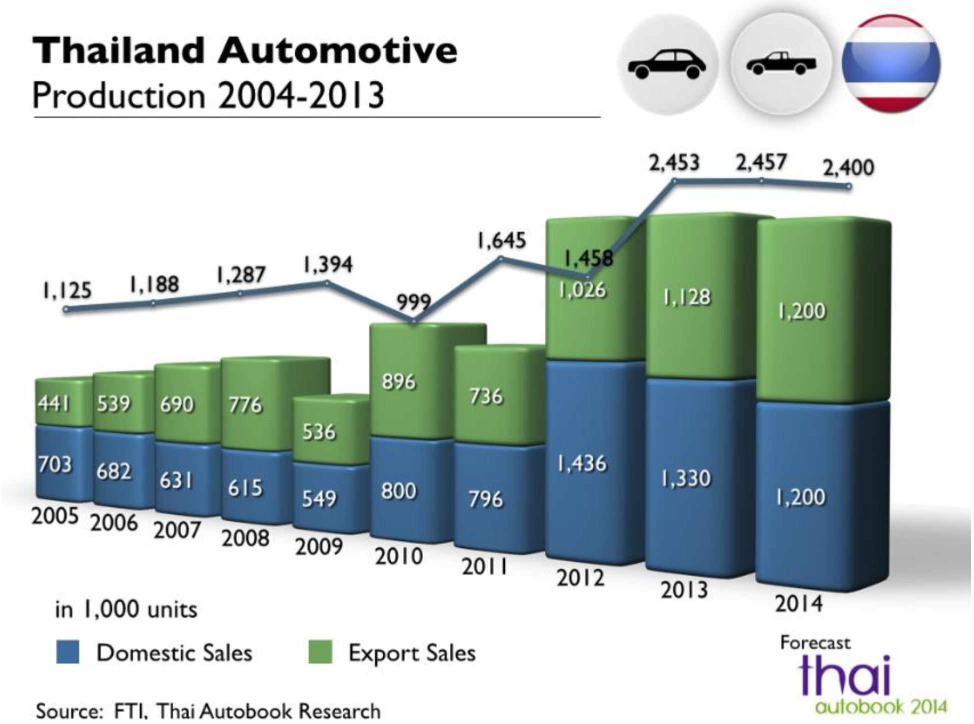


Figure 1-1 Thai Automotive Sales and Production since 2004

Due to a significant increase in automobile demand, most automotive companies have act accordingly to satisfy the demand by increasing production capacity or by improving the current production efficiency. Furthermore, since the outburst of Just-In-Time manufacturing concept by Toyota, who plays a major role in Thailand Automotive economy of 35% (Asawachintachit 2014), many automotive companies have changed the way they operate. Therefore, influenced by Toyota production line, automotive companies are now turning into assembly line production. As stated by (Bukchin and Rubinovitz 2003) the assembly line has to adapt rapidly to the change in market because the product life cycle is becoming shorter and product designs are changing rapidly and more complex. And in order to increase or improve production capacity and efficiency, assembly line layout and efficiency must be assessed.

Assembly line refers to adding value to the unfinished product as it flows pass workers until finished good is produced. To establish an assembly line, there are many factors to be concerned; for instance, how many workers are needed, how many stations are needed, how many workers each station, how long should the assembly line be, how should the product be assembled if it can be assembled in various sequences to obtain the optimum working process, should the assembly process be completely manual, semi-manual, or completely automated. With these questions in mind, company has to plan systematically to achieve high productivity with high efficiency.

There are many factors for a company to compete within the global market; one of which is the '*productivity'.* In general, there are two ways to increase productivity: 1) implementing new tools (technology, automation, and modernization) or 2) utilising existing resources more effectively and efficiently. The former method requires huge capital investment, thus this research will be focused on the latter method (Kayar and Akalin 2014). The improvement of productivity will be focused on manual assembly line of a cables manufacturing company in Thailand, using two fundamental theory, **Work Study** and **Assembly line balancing**. The basic concept of work study aims to improve the productivity of current activity through systematic analysis of the work processes, while the assembly line balancing aims to allocate the work processes equivalently between work stations so that minimal time loss is achieved.

It is found out that the sample company is now facing a new challenge, the new product launch of car. Since the company is cable sets manufacturer, the new task is manufacturing the new model of cable sets for rear lamp light. The sample company has to prepare the necessary production capacity to satisfy the customer forecasted demand. However, with the current preparation, which will be discussed in statement of problem session, the company is now unable to meet the required demand. As a result, it is very crucial for the company to be able to supply the cable sets; if not, the company will suffer from major revenue loss and customer dissatisfaction which might lead to loss of customer. Hence, this research will on improving existing assembly line which the company has been preparing by work study and assembly line balancing.

1.1 Background of Thesis

1.1.1 Company Background

The sample company is established in 1991. It is located within the rapidly growing businesses and industrial areas. With TUV CERT and ISO 9001 Certified, the company has a reliable management and operation processes. Figure 1-2 Figure **1-1** Thai Automotive Sales and Production since 2004 illustrates the company's working area while Figure 1-3 illustrates the structure of the company. According to the company's structure, the company is administrated by different levels of managing position. There are three main departments within the factory. Focusing on the production department, the structure outlines the production process of cable sets. The central production line of the product is assembly line. Within the company, there are 7 assembly lines varying from fully automated to manual. These 7 assembly lines are responsible for assembling more than 50 types of cable sets.

Figure 1-2 Company's Working Area

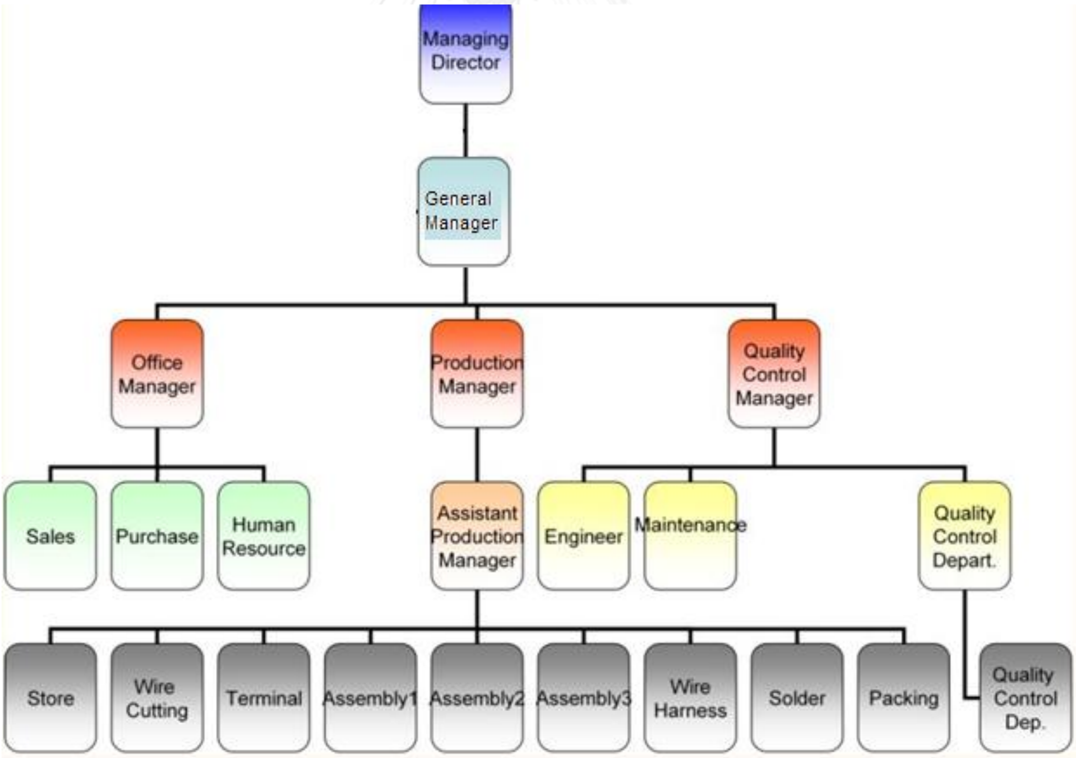


Figure 1-3 Company's Structure

The majority of the company production line is associated with assembly lines and several injection moulding machines (making light sockets). The sample company's main product is cable sets for motor vehicles, which are produced through assembly process. There are many products in which the company manufactures; however, every product is cable-related. The products are wire harness (Figure 1-4), fusible link, connector wire, sleeve terminal, light socket, etc. The six assembly lines have to assemble cable sets, which have different assembly procedures. The company has standardised the assembly line process with tools such as metal rack and polymer container shown in Figure 1-5 and Figure 1-6 respectively.

Figure 1-4 Wire Harness

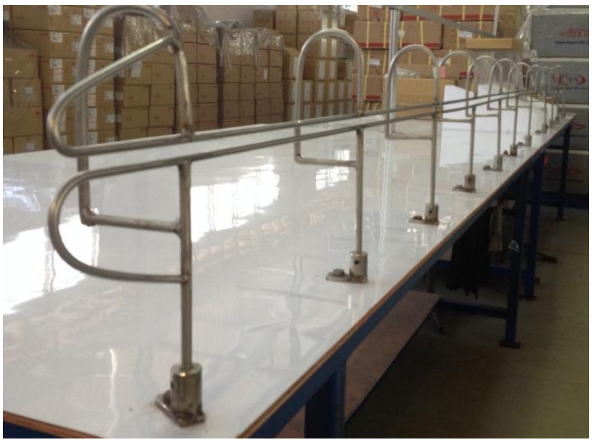


Figure 1-5 Metal Rack

Figure 1-6 Polymer Container

The sample company, an auto parts production industry and supplier of cable sets for motor vehicles, has reacted accordingly to both increases in demand as well as various designs of automotive arisen from the manufacturing company. As automotive designs vary so does the cable sets; the new cable model that has been ordered from customer will be called as N-RLC (new rear lamp cable) in this research for confidentiality.

The core customer is second tier automotive industries who sell cars as the final product. Thus, considered as a tier 3 supplier, the sample company has to serve large quantities of auto parts to these companies. It is widely known that the majority of Japan automotive industries exploit the concept of Just-In-Time (JIT), which, briefly describe, is obtaining zero inventory. Due to this management system of the downstream customers, it is the task of the company to respond accordingly to this system. From the past, the ordering behaviour from the customer has always been day to day ordering; therefore, the only reasonable approaches to deliver the service are safety stock approach and maximum capacity planning.

As for now, the demand of current model uses O-RLC (old rear lamp cable) (Figure 1-7) and will be greatly reduced and replaced by N-RLC (Figure 1-8). Therefore, since the N-RLC will be ordered replacing the old model, new assembly production line has to be set up since two models differ in both quantity forecast and components assembly. Currently, more than 90% of the assembly line is manually assembled with only few procedures that are semi-automated. This is because all components of cables are small and are designed to be manually assembled. The main semi-automated process is crimping the terminal of the wire by which a worker is always stationed at the crimping machine; other than that, the assembly process heavily depends on man-power.

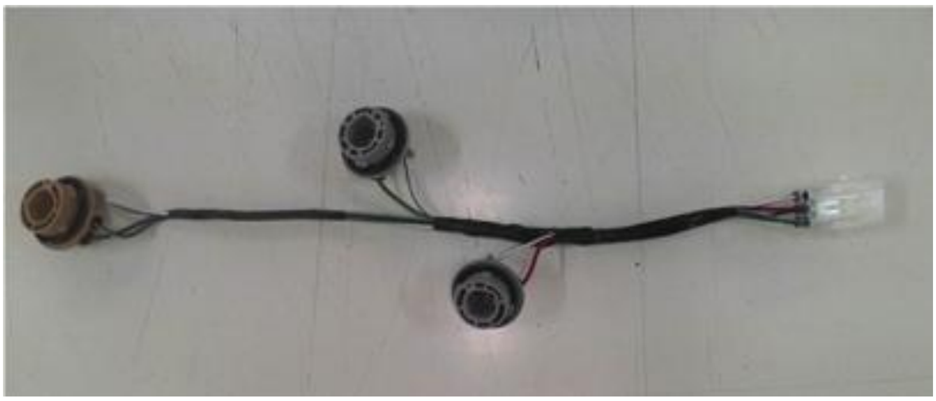


Figure 1-7 O-RLC

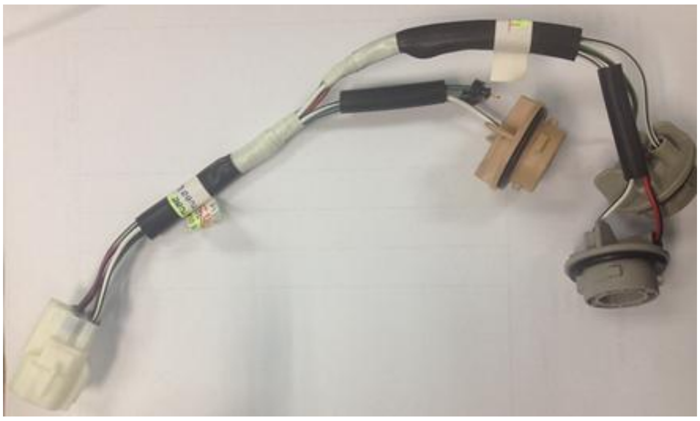


Figure 1-8 N-RLC

1.2 Statement of Problem

1.2.1 Product Overview

Currently, the sample company has modelled an assembly line but with limited testing and preparation because the supplier only orders small quantity before the product launch. The forecasted demand from the sales and marketing department is shown below.

Table 1-1 Forecast Demand of N-RLC

	Import	Export	Total
April	100,000	60,000	160,000
May	100,000	50,000	150,000
June	110,000	50,000	160,000
July	100,000	50,000	150,000
August	110,000	50,000	160,000
September	100,000	50,000	150,000
October	100,000	55,000	155,000
November	105,000	50,000	155,000
December	110,000	60,000	170,000

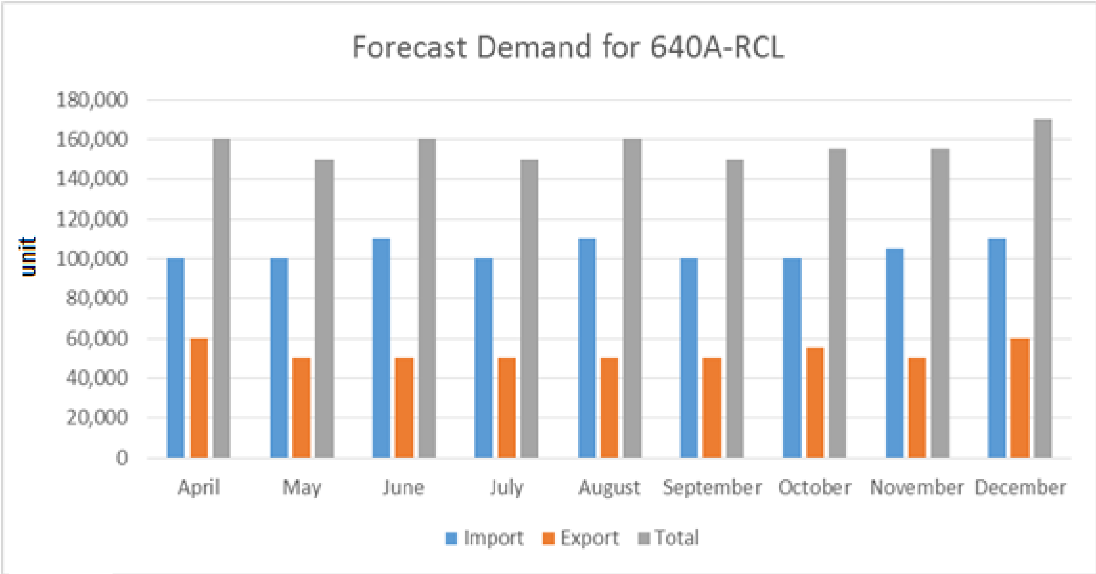


Figure 1-9 Forecast Demand of N-RLC

According to the data above, the monthly demand for N-RLC from the forecast demand of customer is approximately 160,000 cables. The current assembly line of O-RLC has a monthly demand of 90,000 cables with the two assembly lines and total of 12 workers. Therefore, it is impossible to fulfil the customer forecasted order if the assembly line remains the same especially when steps of assembling differ. Using the same approach of maximum capacity planning, the company has to be able to assemble an approximate of 7272 cables per day to satisfy 22 days of supplier's monthly order.

The product model of N-RLC is used for cable sets for rear lights connection in motor vehicles. The usage of N-RLC is similar to O-RLC which is used for rear lamp light. The new designed model will replace the old one.

There are 19 component parts of N-RLC, listed in the table below.

Table 1-2 Components of N-RLC

No.	Name	Description
1	Wire (G/Y)	Wire (Green/Yellow)
2	Wire (G)	Wire (Green)
3	Wire (W/B)	Wire (White/Black)
4	Wire (G/W)	Wire (Green/White)
5	Wire (R/L)	Wire (Red/Blue)
6	Bushing	Rubber bushing plugged inside connector
7	Connector	White connector
8	Tube 66	Black plastic tube with ID 9 mm and OD 10 mm, length 66 mm
9	Terminal Joint	Joining wire (white/black)
10	Heat Shrink Tube Glue	Joining wire (white/black)
11	Terminal	Crimped to wires
12	Bushing	Locking terminal with wires
13	Tape (W)	Tape (white) for tightening of wires together
14	Tube 85	Black plastic tube with ID 7 mm and OD 8 mm, length 85 mm and 40 mm

15	Tube 40	Black plastic tube with ID 7 mm and OD 8 mm, length 40 mm
16	Plug M-086	Brown Socket Plug
17	Plug M-088	Green Socket Plug (straight teeth)
18	Plug M-079	Green Socket Plug (tilted teeth)
19	Gasket	Rubber gasket

1.2.2 Problem

As mentioned previously, the forecasted monthly demand for N-RLC cable is 160,000 cables, which has an increase of 80% compared to old model of 88,000 cables per month. With this given task, the assembly line has to assemble 7272 cables per day for 22 ordering periods per month. Comparing with the old model whose current capacity is 4000 cables per day with two assembly lines (2000 cables per day per line) and total of 12 workers, the new model requires a capacity of almost twice as much.

$$Cables\ per\ day = \frac{160{,}000\ cables\ per\ month}{22\ days\ per\ month} = 7272\ cables\ per\ day$$

Furthermore, the corresponding takt time calculation for assembling N-RLC is shown below.

<u>Takt Time Calculation</u>

Assumption:

- Average of 160,000 orders per month
- 22 working days based on frequency of order from customer
- 11 hours per day (Overtime included)

$$Takt\ Time = \frac{22\ days\ \times\ 11\frac{hrs}{days}\ \times\ 3600\frac{secs}{hr}}{160{,}000\ cables} = \ 5.45\ \frac{secs}{cable}$$

From the calculation, 5.45 seconds per cable is the target takt time with one assembly line. Considering man-power, space, and cost, the engineer team has planned to have three production lines in order to meet the target takt time; the takt time is now 16.35 seconds per cable with three assembly lines. Therefore, rather than aiming for 5.45 seconds with one assembly line, the workers now have 16.35 seconds to assemble one cable since the workload is distributed into three assembly lines. In addition, the aimed production per day is 2424 cables per assembly line. The reason for three assembly lines will be discusses in chapter 3.

The current is problem is that the modelled assembly line could not achieve 16.35 seconds. Furthermore, the time measurement from each trial deviates greatly, indicating inconsistency in assembly method. These two problems will be further evaluated in Chapter 3.2.

1.3 Objective of Thesis

Based on the problems stated above, the aim of this research is to improve the work process and minimise the workload for workers to meet the required output. Thus, this thesis has three objectives:

- Reduce the station time to be less than takt time to increase the productivity
- Standardise assembly method to reduce deviation in workstation time
- Balance workload between workstations

1.4 Scope of study

The thesis will be focused on achieving the targeted takt time. It will involve assessing current assembly line layout efficiency that is simulated by engineering team with work element analysis and line analysis. In summary the scopes of the study are

- Assembling N-RLC within one assembly line
- All processes flow from right hand to left hand (all workers are right handed). (Reason will be discussed in Chapter 3.2)
- Applying work study by using to work measurement and method study to analyse working process
- Applying LCR and RPW methods for assembly line balancing

1.5 Proposed Methodology

The research will be divided into phases.

Phase I: Defining Research

1.1. Define problem of the research

1.2. Define objective of the research

1.3. Define scope of the research

1.4. Define methodology

1.5. Define the time duration of the research

1.6. Define indicators to measure the result

Phase II: Work Study: Method Study

Phase II is method study, which is one of the aspects under work study. This part aims to how the work is being done, how to make it more efficient by reducing unnecessary movements from humans and materials, and standardising method. Steps in method study will be thoroughly discussed in literature review, Chapter 2.1.1.

Phase III: Assembly Line Balancing

Phase III incorporates assembly line balancing by largest candidate rule and rank positional weight method. This part aims to balance the workloads onto each workstation so that the utilisation of assembly line and efficiency of production is increased. Steps in assembly line balancing will be thoroughly discussed in Chapter 2.2.

Phase IV: Work Study: Work Measurement

The last part of phase is work measurement, which is the second aspect of work study. This section aims to establish standard time of the standardised method by incorporating performance rating and allowance time. Steps in work measurement will be discussed in Chapter 2.1.2. Phase 2 to 4 can be viewed in figure below.

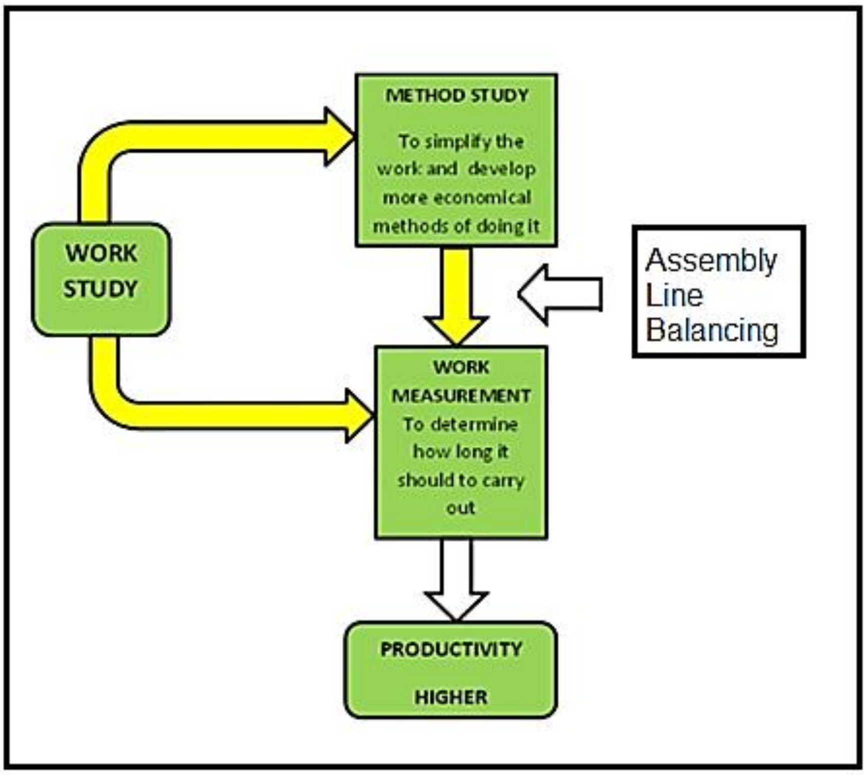


Figure 1-10 Overview of Methodology: Work Study + Assembly Line Balancing

Phase V: Conclusion and Recommendation

Phase IV: Thesis Completion

1.6 Expected Results and Benefits

Expected Results

- Reduce Cycle Time of each station
- Increase assembly line balance efficiency and smoothness index
- Standardisation of assembly process

Expected Benefits

- Reduction in number of workers
- Guideline and method for assembly line

Chapter 2. Literature Review

2.1 Work Study

Work study is a systematic approach of examining how activity is done. This technique examine efficiency of the current activity then establish a new more effective way of doing it, and finally, setting a standard performance for doing the activity (IITG.). The main objective of work study is to increase productivity by implementing two tools: method study and work measurement. (IITG. , Kanawaty 1992, Konnully 2013)

According to IITG, *work* is divided into three levels as shown below. Task refers to the amount of work assigned to a work. Work element refers to activities grouped in a task based on relative function. Basic motion element refers to the physical action of a work element.

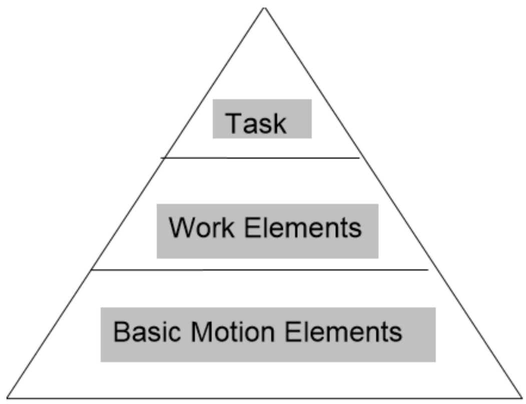


Figure 2-1 Pyramidal Structure of Work

(IITG)

Once *work* is defined, two techniques, method study and work measurement study, can be applied to make the process of doing work more effective and efficient. The figure below displays the overview concept of work study by using both techniques.

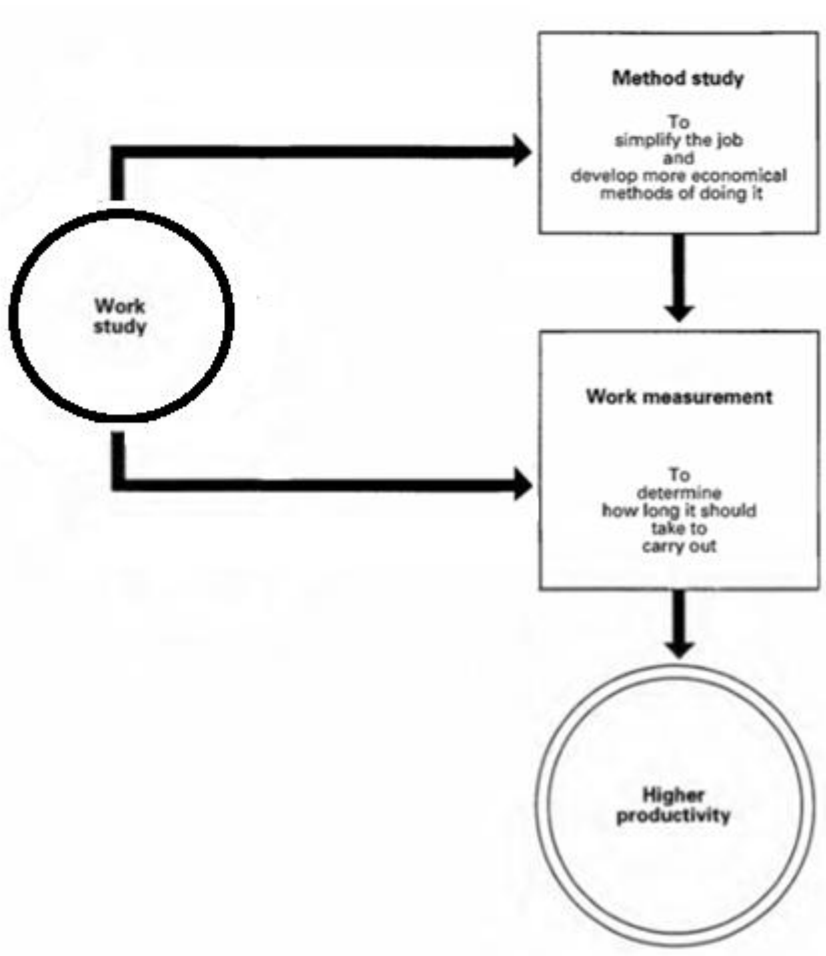


Figure 2-2 Work Study

(Kanawaty 1992)

2.1.1 Method Study

Method Study is a technique by *"…systematic recording and critical examination"* (Kanawaty 1992) current method of doing an activity to propose a more efficient and effective method. In simple term, it is finding a better way of doing things (IITG).

Kanawaty simplifies method study into eight steps as shown below, Figure 2-3. This research will base on this method study approach in developing new method for cable assembly line. Within each step there are frameworks and tools that act as a guide in implementing method study.

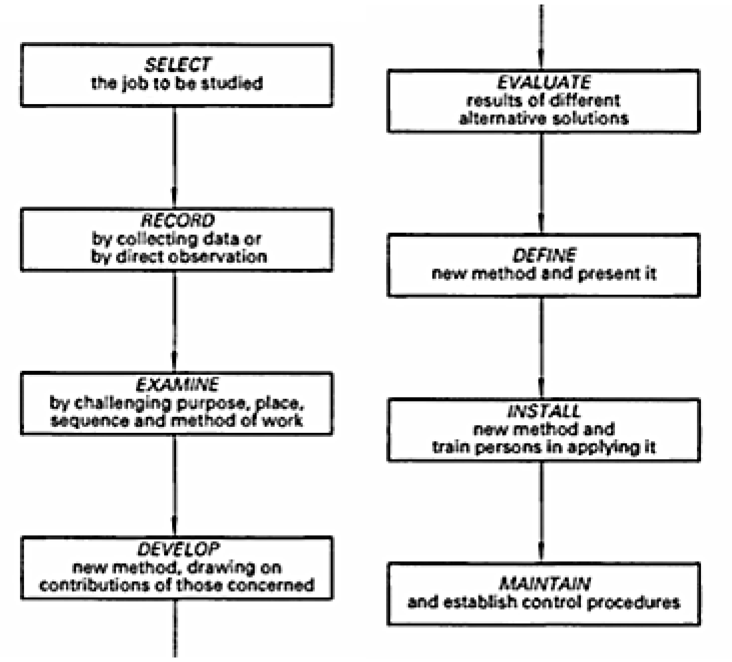


Figure 2-3 Method Study Approach

(Kanawaty 1992)

In simplification, the author has summarised tools within each step as follow:

1. **Select:** tools that can be used to help the selection of activity to be studied are Cause-and-Effect Diagram (Fish-Bone Diagram) and Pareto analysis (Juran and Godfrey 1999).

Cause-and-Effect Diagram

According to Montgomery (2009), it is crucial to analyse the causes of the problem after the problem has been defined; thus, a cause-effect diagram is used to help visualise the analysis process. This cause-and-effect diagram was termed as 'fishbone diagram' in 1950 by Professor Kaoru Ishikawa (Breyfogle 2003). Figure 2-4 depicts the cause-and-effect diagram. The causes on the left hand side of the diagram constitutes to the effect on the right hand side. Accompanying the cause-effect diagram, a group of causes is defined as 5M1E (Materials, Machines, Measurement, Man, Method, and Environment). These causes are then analysed into sub-causes. (Breyfogle 2003).

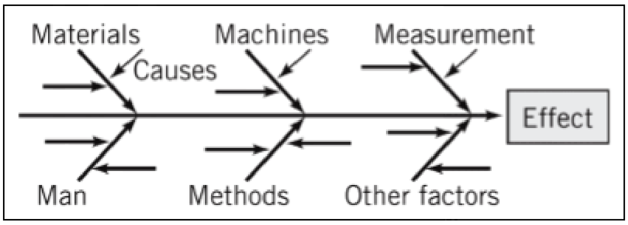


Figure 2-4 Cause-and-Effect Diagram

(Montgomery 2009)

After the causes have been identified according to the type, 5M1E, a cause-and-effect matrix can be constructed.

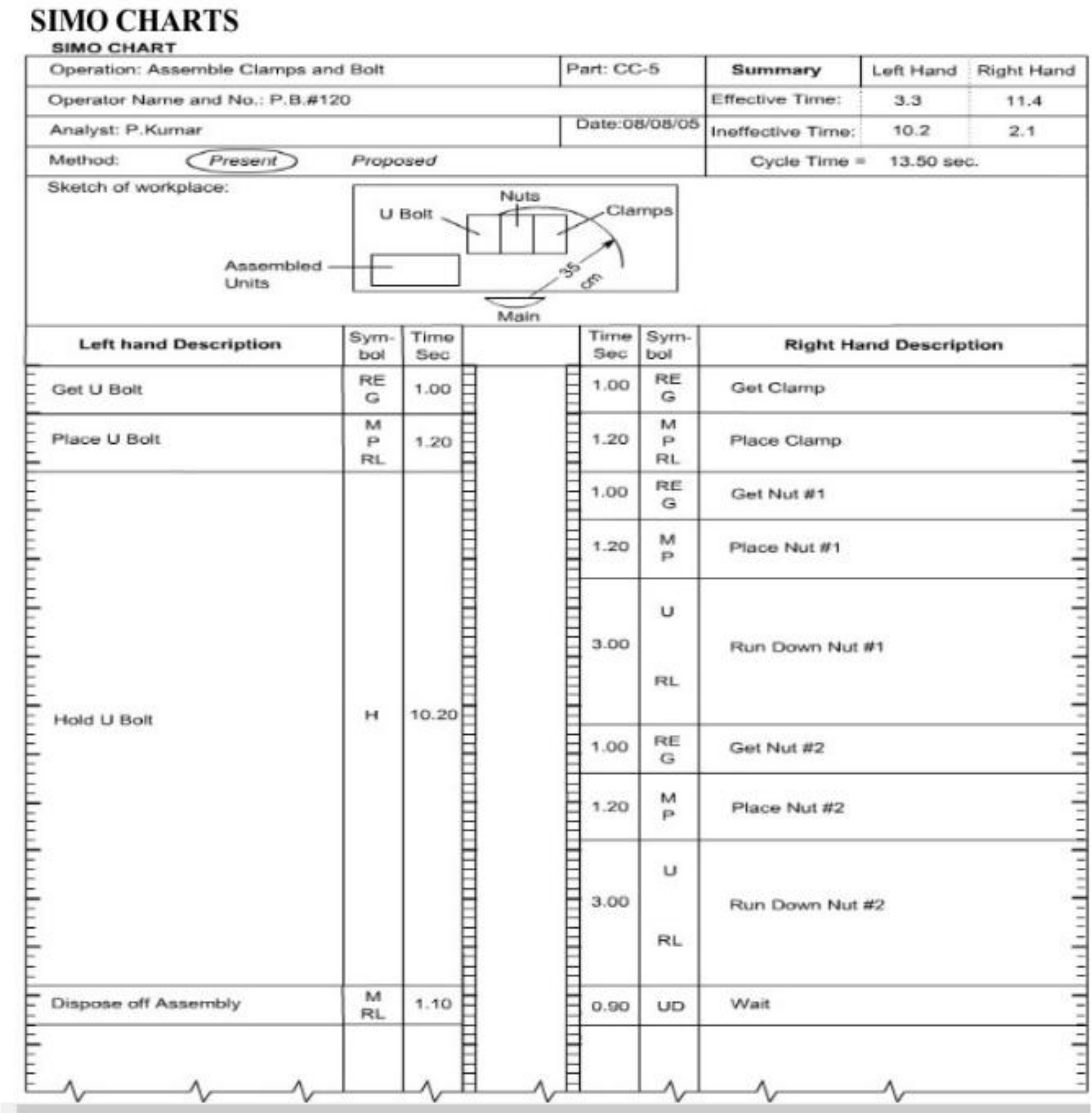
2. **<u>Record:</u>** Kanawaty simplified the recording tools in Figure 2-5

The most commonly used method study charts and diagrams	
A. CHARTS	Indicating process SEQUENCE Outline process chart Flow process chart — Worker type Flow process chart — Material type Flow process chart — Equipment type Two-handed process chart Procedure flowcharts
B. CHARTS	Using a TIME SCALE Multiple activity chart Simo chart
C. DIAGRAMS	Indicating MOVEMENT Flow diagram String diagram Cyclegraph Chronocyclegraph Travel chart

Figure 2-5 Recording Techniques

(Kanawaty 1992)

Within this research, a Simo Chart will be used to record the current assembly line. A Simo Chart studied about the micro-motion of the activities by categorising actions according to therbligs for examining step. Examples of simo chart and therbligs symbols are shown in Figure 2-6 and Figure 2-7 respectively.



SIMO CHARTS

SIMO CHART

Operation: Assemble Clamps and Bolt	Part: CC-5	Summary	Left Hand	Right Hand
Operator Name and No.: P.B.#120		Effective Time:	3.3	11.4
Analyst: P.Kumar	Date:08/08/05	Ineffective Time:	10.2	2.1
Method: Present Proposed		Cycle Time =	13.50 sec.	

Sketch of workplace:

Left hand Description	Sym-bol	Time Sec	Time Sec	Sym-bol	Right Hand Description
Get U Bolt	RE G	1.00	1.00	RE G	Get Clamp
Place U Bolt	M P RL	1.20	1.20	M P RL	Place Clamp
Hold U Bolt	H	10.20	1.00	RE G	Get Nut #1
			1.20	M P	Place Nut #1
			3.00	U RL	Run Down Nut #1
			1.00	RE G	Get Nut #2
			1.20	M P	Place Nut #2
			3.00	U RL	Run Down Nut #2
Dispose off Assembly	M RL	1.10	0.90	UD	Wait

Figure 2-6 Simo Chart

(Konnully 2013)

Therbligs symbols are invented by F. B. Gilbreth and L. M. Gilbreth. They consist of 18 basic motions of human of which are classified as either effective of ineffective therbligs. The aim is to identify and reduce the ineffective ones. The table below indicates which therbligs are effective and ineffective. (Konnully 2013)

Therbligs

Effective Therbligs

(Directly advance progress of work. Can be shortened but difficult to eliminate completely.)

Therblig	Symbol	Description	Example
Reach	RE	Motion of empty hand to or from object; time depends on distance moved; usually preceded by Release and followed by Grasp.	Moving empty hand to grasp a screw on the table.
Move	M	Movement of loaded hand; time depends on distance, weight, and type of move; usually preceded by Grasp and followed by Release or Position.	Carrying a screw driver to the screw head.
Grasp	G	Closing fingers around an object; begins as the fingers contact the object and ends when control has been gained; time depends on type of grasp; usually preceded by Reach and followed by Move.	Closing fingers around a screw lying on the table.
Release	RL	Relinquishing control of object, typically the shortest of the therbligs.	Letting go of a component in a tray.
Pre-Position	PP	Positioning Object in predetermined location for later use; usually occurs in conjunction with Move, as in orienting a wrench for tightening a bolt.	Placing a tapered shank drill in a hole in rack.
Use	U	Manipulating device or tool for intended use; begins when hand starts to work with tool or device, and ends when the hand finishes the application.	Using a spray gun to spray an object.
Assemble	A	Bringing two mating parts together; usually preceded by position or Move; followed by Release.	Fitting friction cap on the pen.
Disassemble	DA	Separaing mating parts; usually preceded by Grasp and followed by Move or Release.	Removing tool from tool post.

Ineffective Therbligs

(Do not advance progress of work. Should be eliminated if possible.)

Therblig	Symbol	Description	Example
Search	S	Eyes or hands hunting for object; begins as the eyes move in to locate an object.	Searching a 5 mm drill from a box containing assorted drills.
Select	SE	Choosing one item from several; usually preceded by Search.	A 5 mm drill is located in a box containing assorted drills.
Position	P	Turning or orienting object during work, usually preceded by Move and followed by Release.	Positioning screw driver to bring its tip into slot of screw head.
Inspect	I	Comparing object with standard, generally with sight, but could also be with the other senses.	Visually checking the presence of any scratch on enambled surface.
Plan	PL	Mental reaction; pausing to determine next action; ususally detected as a hesitation preceding motion.	In making an assembly, an operator decides which parts should be assembled first.
Unavoidable Delay	UD	Beyond the operator's control due to the nature of the operation, usually occurs when left hand is waiting while right hand completes its work.	Using right hand to feed rotaing drill into workpiece while the left hand waits.
Avoidable Delay	D	Operator solely responsible for the delay.	An operator rotates the lathe chuck by hand before switching on the spindle motor.
Rest to overcome Fatigue	R	Relaxation period; appears periodically, not every cycle, depends on the physical workload.	An operator pauses during hand forging or hand filing operation.
Hold	H	One hand supports object while other does useful work.	Holding bolt in one hand while assembling a washer onto it by the other hand.

Figure 2-7 Therbligs Symbols

(Konnully 2013)

3. **<u>Examine</u>**: Kanawaty frames this step with question technique including primary and secondary questions.

<u>Primary Question</u>

The primary question stage concerns with 5 aspects (Purpose, Place, Sequence, Person, and Means) with possible activities to be done with them including eliminating, combining, rearranging, and simplifying.

PURPOSE:	**What** **Why**	is actually done?[3] is the activity necessary at all?	*ELIMINATE* unnecessary parts of the job
PLACE:	**Where**	is it being done? **Why** is it done at that particular place?	*COMBINE* wherever possible or *REARRANGE* the sequence of operations for more effective results.
SEQUENCE:	**When**	is it done? **Why** is it done at that particular time?	
PERSON:	**Who**	is doing it? **Why** is it done by that particular person?	
MEANS:	**How**	is it being done? **Why** is it being done in that particular way?	*SIMPLIFY* the operation.

Figure 2-8 Primary Questions

(Kanawaty 1992)

<u>Secondary Question</u>

The second stage question acts as a "means of improvement upon existing method" (Kanawaty 1992). The listed questions are shown in Figure 2-9, and these questions must be asked systematically.

PURPOSE:	**What** is done?
	Why is it done?
	What **else** might be done?
	What **should** be done?
PLACE:	**Where** is it done?
	Why is it done **there**?
	Where **else** might it be done?
	Where **should** it be done?
SEQUENCE:	**When** is it done?
	Why is it done **then**?
	When **might** it be done?
	When **should** it be done?
PERSON:	**Who** does it?
	Why does **that** person do it?
	Who **else** might do it?
	Who **should** do it?
MEANS:	**How** is it done?
	Why is it done **that** way?
	How **else** might it be done?
	How **should** it be done?

Figure 2-9 Secondary Questions

(Kanawaty 1992)

4. **Develop**: the improved method can be established by asking five fundamental questions: who, what, when, where, and how should it be done (Kanawaty 1992).

In the develop process, Kanawaty (1992) takes into consideration of the motion economy in which he divides into three headings: 1) Use of human body, 2) Arrangement of workplace, and 3) design of tools and equipment; these headings are simplified into simpler ideas as following:

- Use of human body
    a. Two hands should begin and complete at the same time.
    b. Two hands should not be idle at the same time except during rest periods.

c. Motions of arms should be symmetrical, in opposite directions, and made simultaneously.

d. Hand and body motions should be limited to the lowest classification including finger, wrist, forearm, upper arm, and shoulder motions to perform work satisfactorily

e. Momentum can assist worker, yet it should be reduced to minimum whenever the muscular effort is presence.

f. Continuous curved motions are more preferable than straight-line motions that involve sudden and sharp changes in direction.

g. Work should be arranged based on eye comfort or without frequent change of eye focus.

- Arrangement of workplace

  a. Tools and materials should be available at definite and fixed stations to develop habitual working behaviour

  b. Prepositioning tools and materials can reduce searching time and should enable best motion sequences.

  c. Materials should be contained in gravity feeds, bins, or containers.

d. Tools and materials should be located within the maximum area (furthest sweeping area of left and right hands).

e. Adequate working environments such as lighting, height of tables and chairs, and colours of workplace should be provisioned to allow good posture and high working efficiency while reducing body and eye fatigue.

- Design of tools and equipment

    a. Jig or fixture should be used whenever possible to eliminate the action of 'holding'.

    b. Combine tools whenever possible

    c. The workload of fingers should be in accordance with inherent capacities of fingers.

5. **<u>Evaluate</u>**: after the new method has been developed, the result of the method has to be tested to verify the credibility.

6. **<u>Define:</u>** before installing the new method to replace the old method, the new method should be clearly defined to create standardised procedures of performing a given work. In defining the new method, a written

standard practice is preferred including every step and schematic diagram of tools, jigs, etc.

7. **Install**: Gaining acceptance from workers, department levels, and manager levels. (This research will not focus on this stage)

8. **Maintain:** there should always be a control procedure to check whether the steps are being followed according to the redefined method. (This research will be focus on this stage)

Therefore, the working process of assembling N-RLC cable sets is aimed to improve by using these stages as a guideline.

2.1.2 Work Measurement

Work Measurement is "*the application of techniques designed to establish the* (standard) *time for a qualified worker to carry out a task at a defined rate of working*." (IITG. , Kanawaty 1992). Qualified worker refers to one who has skills and knowledge in performing the task in a standard manner. A defined rate of working refers to amount of work produced by a qualified worker under a normal circumstance (IITG.).

While method aims to investigate existing method in order to eliminate unnecessary movement of body and materials, work measurement concerns with investigating and reducing ineffective time, the time in which no effective work is being done. However, in nature, there are ineffective times that can be avoided and reduced while some are inevitable; these times are to be accounted into the process. Moreover, not only can work measurement reduce ineffective time, it can be used to determine standard times in performing a job.

The basic procedure of work measurement mimics method study and is shown below.

- ☐ *SELECT* the work to be studied.
- ☐ *RECORD* all the relevant data relating to the circumstances in which the work is being done, the methods and the elements of activity in them.
- ☐ *EXAMINE* the recorded data and the detailed breakdown critically to ensure that the most effective method and motions are being used and that unproductive and foreign elements are separated from productive elements.
- ☐ *MEASURE* the quantity of work involved in each element, in terms of time, using the appropriate work measurement technique.
- ☐ *COMPILE* the standard time for the operation, which in the case of stop-watch time study will include time allowances to cover relaxation, personal needs, etc.
- ☐ *DEFINE* precisely the series of activities and method of operation for which the time has been compiled and issue the time as standard for the activities and methods specified.

Figure 2-10 Steps of Work Measurement

(Kanawaty 1992)

There are several techniques in which work measurement can be carried out. There are four techniques of work measurement: 1) work sampling, 2) structured estimating, 3) time study, and 4) predetermined time standards. Within this research, the author will apply **time study** technique to establish work measurement.

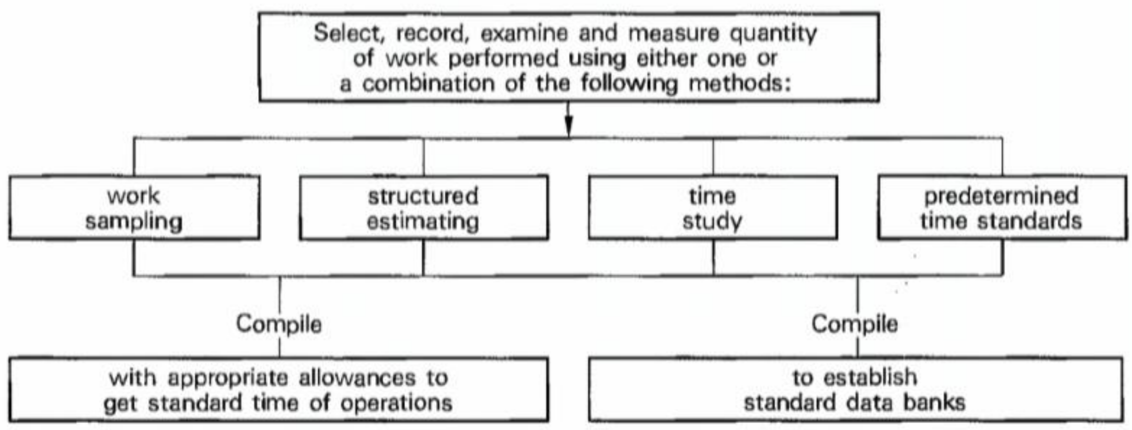


Figure 2-11 Techniques of Work Measurement

2.1.2.1 Time Study

According to Kanawaty (1992), there are 8 steps in time study, which is an extended version from Figure 2-11; however these steps have undergone minor modification for simplicity in understanding.

8 Steps in Time Study:

1. Obtain and record all relevant information about the job.
2. Record a complete description of method

3. Examine and improve the method and motions, and determine the sample size
4. Measure the workstation time with a timing device to record 'observed time'
5. Assess the performance rating or rating factor of the worker
6. Calculate the basic time from rating performance and observed time
7. Determine the allowance time
8. Determine the standard time

However, step 1, 2, and 3 (except determine the sample size) are being done in method study. Thus, phase IV (Work Measurement) will begin from determining the sample size and so on. Ultimately, the objective from time study that this research aims to achieve is determining the standard time of operation. An easy understanding of this objective is depicted in figure below whereby each step adds on to the final objective, the standard time.

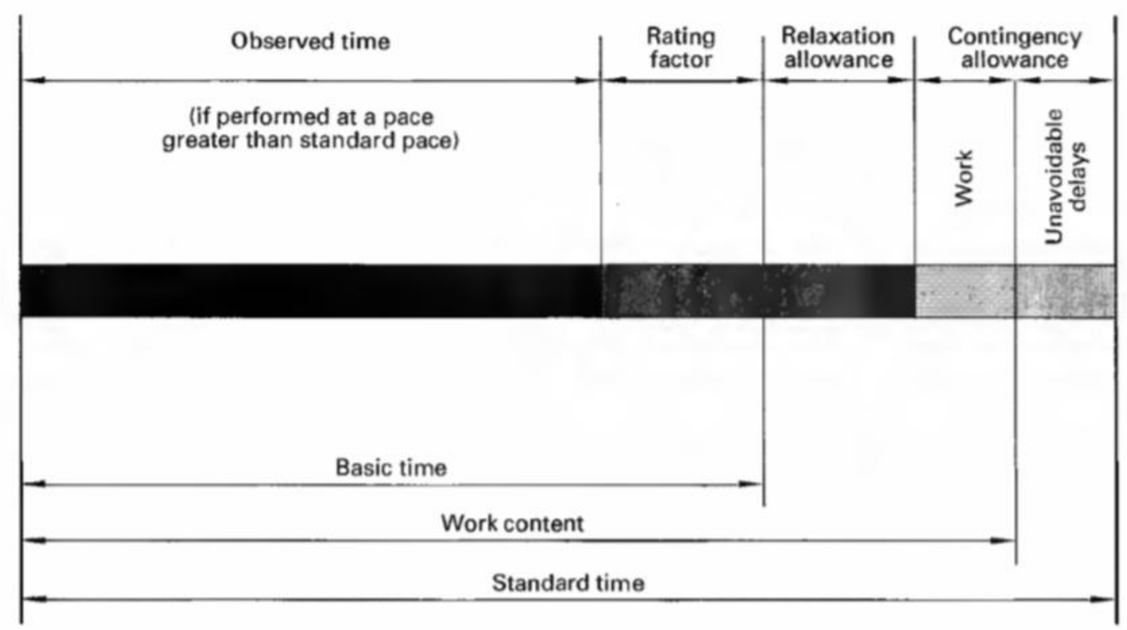


Figure 2-12 Overview of Time Study

Performance Rating (Rating Factor) and Basic Time

Even though only experience, qualified workers are chosen for the job, it is common that human do not work consistently from day to day. Therefore, a process known as rating is applied to assess the worker's rate of working relative to the observer's concept of rate corresponding to standard pace. The standard rating is denoted as 100, while if rated above 100 is considered as faster than usual and if rated below 100 is considered as slower than usual. Within this research, the rating factor will be rated by the assembly line supervisor due to long-working experienced with the workers; as mentioned by Kanawaty (1992) the accuracy in rating is determined by '*long experience and practice*'. Once method study has been established first, rating would be much easier because the method would have been simplified and standardised (Kanawaty 1992).

The rating factor is calculated into the observed time in order to get a 'Basic Time' of a task. The equation that governs the calculation is:

$$Observed\ time \times \frac{Rating}{100} = Basic\ Time$$

For example, if observed time is 0.16 min and the performance is rated as 125, that mean the task is being done faster than standard; thus, elongating the basic time to 0.20 min after calculation. Within this study, rating to the nearest five is used since it is found to give 'sufficient accuracy' to the result.

Relaxation Allowance Time

According to (Kanawaty 1992) and Indian Standards Institution (Institutions 1986), they categorises allowance time into four types relaxation allowance, contingency allowance, policy allowance, and special allowance. However, this research will consider only relaxation allowance into standard time calculation because the process is heavily dependent on labour and relaxation allowance focuses on human factor. Another usage for relaxation time is to determine the rest pause regime or work-rest regime (Kanawaty 1992). Within this research the purpose of relaxation time is used to determine rest-pause regime. Thus, overview of time study is changed into following figure.

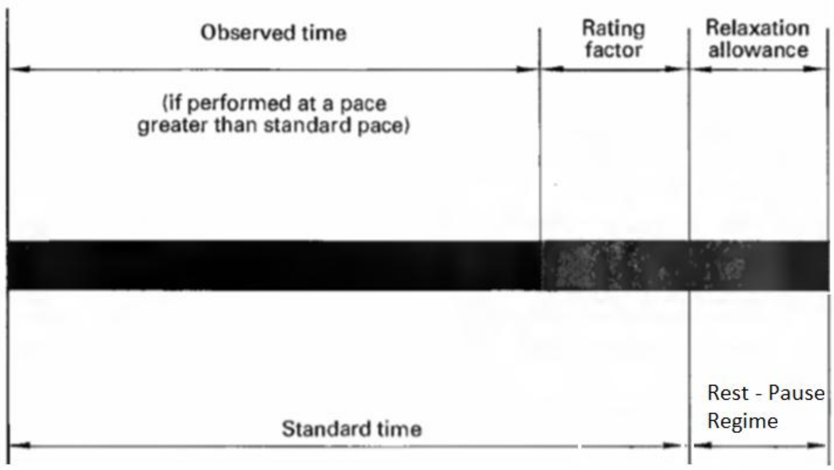


Figure 2-13 Modified Overview of Time Study

Thus, basic time is considered as standard time according to Figure 2-12 and 2-13, since relaxation time will not be considered into basic time but rather computed into rest-pause regime. Kanawaty proposes the four importance of rest pause, which are decrease in variation of worker's performance, break up monotony, period to recover from fatigue and attend personal needs, and reduce time taken off by worker on their own desire.

Relaxation allowance is broken into two components: fixed allowances and variable allowances. Fixed allowances include personal needs (going to toilet, drinking water) which most enterprises apply 5% to 7% of basic time and basic fatigue which considers the energy expended and to alleviate monotony (common figure is 4% of basic time). On the other hand, variable allowances refer to notable environmental conditions as well as additional stress and strain encountered during work. Once relaxation allowance time has been added to the basic time, standard time is obtained.

Percentage of personal needs will be determine experimentally, which will be discussed further in Chapter 6. On the other hand, based on various literatures, fatigue is determined systematically. According to the research done by (Lund and Mericle 2000), ergonomic literatures fail to have a common ground in defining ‘fatigue’, so different methods of measuring fatigue arose. Therefore, Lund and Mericle examined the effectiveness of different methods in measuring fatigue applied in grocery warehouse order selectors. They conducted the experiment within four popular techniques proposed by: 1) Cornman (1970), 2) Page (1964), 3) ILO (1979), and 4) Williams (1973). *It should be noted that within all methods, relaxation allowance is known as fatigue allowance (personal needs is included).* The similarities within these methods lie within the factor considered when applying the method, which are physical, psychological or mental, and environmental strains. Based on these factors, Lund and Mericle mapped out the comparison between maximum values of fatigue factors; in other words, the comparison shows how much each method weighs the importance of each factor.

Factor	Page (%)	ILO (%)	Williams (%)	Comman (%)
Physical	81.3	51.2	46.2	27.3
Psychological	8.8	10.0	13.6	45.5
Environmental	10.0	38.8	40.2	27.3

Figure 2-14 Comparison of Maximum Fatigue Allowance values

It is clear that Page, ILO, and Williams method weighs physical factor as the greatest factor, whereas Cornman gives greatest weight to psychological factor given that former methods weighs this factor the least of all at 8%, 10%, and 13.6% respectively. Lund and Mericle concluded relationship between these methods are low due to lack of validation and application; no validation studies were found. Furthermore, Lund and Mericle performed research on 11 industrial engineers where 6 were practicing union industrial engineers and 5 were academics. The purpose of the research is to determine the degree of variation that engineers score a single job using these 4 methods. The result was:

Group	Cornman (%)	ILO (%)	Williams (%)	Page (%)
Union				
Mean	12.3	30.3	26.9	13.7
Standard deviation	7.3	8.5	4.6	2.5
Coefficient of variation	0.593	0.281	0.171	0.182
Academic				
Mean	14.4	25.2	26.5	14.5
Standard deviation	4.1	13.7	10.7	3.1
Coefficient of variation	0.285	0.544	0.404	0.214
Combined				
Mean	13.3	28.0	26.7	14.1
Standard deviation	5.9	10.9	7.5	2.7
Coefficient of variation	0.444	0.389	0.281	0.191

Figure 2-15 Result of Application of Different Fatigue Allowance Methods

It can be seen that Page and Cornman result in similar value and ILO and Williams result in a much greater percentage. An overall view provides that Page produces the least variation both among union and academic. Based on two figures above, this research has chosen ILO and Williams's methods for several reasons. The reasons are:

1. This research is related to short cycle and repetitive motions in which require workers to perform under constant position. As one workstation has one worker, it results in high concentration, focus, and monotony. Therefore, psychological factor should be weighted. In addition, as assemble parts are very light, less than half a kilogram, physical factor is minimal. From these analyses, Page method is eliminated due to lowest weight of psychological factor and highest weight of physical factors.

2. Cornman's seems to be the best candidate for this research due to highest weight of psychological factor with physical and environmental factors share the same weighed percentage. However, from the application result, under 'union', Cornman's result in the highest coefficient of variation. The reason union was chosen is because the score in this research will be done by engineer in factory, not academic. This means that union engineers rated differently using Cornman's method resulting in high variation; thus, this method is neglected.

ILO method uses tables of comparative strains and conversion table, which have been by many firms including REFA, Germany (Kanawaty, 1992). Strains conversion table is a systematic approach with specific procedures that give relaxation allowance time in final step. There are three types of strains that are being analysed: physical strains, mental strains, and working conditions. Within each strain, there are minor factors that are further scored to determine relaxation allowance.

Table 2-1 ILO's Allowance Factors

Type of Strains	Allowance Factors	Description
Physical	Average force exerted	Considers the nature of the stress (low, medium or high) benchmarked to a number of sample jobs and then apply a table of weight lifted, pulled, pushed or carried to determine value
	Posture	Considers whether the worker is sitting, standing, stooping or in a cramped position and whether the load is handled easily or awkwardly
	Vibration	Considers the impact of the vibration on the body, limbs or hands and the addition to mental effort due to it, or to a series of jars or shocks
	Short Cycle	The shorter the job cycle, the lesser the ability to recover from muscular fatigue
	Restrictive Clothing	Considers the effect of the weight of protective clothing on work effort as well as respiratory protection on breathing
Mental	Concentration	Considers the impact if the operator relaxed their attention, the responsibility involved, the need for exact timing of movements and the accuracy or precision required
	Monotony	Considers the degree of mental stimulation from the job itself
	Eye Strain	Considers lighting conditions, glare, flicker, illumination, colour, and closeness of the work and duration of unfavourable conditions
	Noise	Considers whether the noise affects concentration, its duration and effect on work effort

Environmental	Temperature and Humidity	Considers the atmospheric conditions including temperature and humidity whether or not they affect the job performance
	Ventilation	Considers the air quality and the air circulation
	Fumes	Considers the presence and toxicity of fumes in the air
	Dust	Considers the quantity of dust particles in the air
	Dirt	Considers the dirtiness of the job
	Wet	Considers whether wetness has impact on the job

(Kanawaty 1992, Lund and Mericle 2000)

The procedures are described as followed:

1. Determine the severity for each type of strain related to the work by using tables of comparative strains, Appendix A1.
2. Allocate points associated with the work based on description shown in Appendix A2 – Appendix A4, as well as summing the total points for the work.
3. Convert the points into relaxation allowance by using conversion table Appendix A5.

Williams's method is somewhat different from ILO method. It is much simpler and easier to use since conversion table is not required. The allowance factors are quite similar, but Williams's has fewer factors. The percentage of fatigue is calculated simply by summing all the percentage weighed for each factor. A full method and description of each allowance factor are shown in table below.

Table 2-2 Williams's Allowance Factors

Allowance factors	Description	Range (%)
Standard fatigue recovery allowance	Basic minimum allowance which includes both personal needs and fatigue	10
Energy demands	Considers weight lifted, body pressure or force applied, including duration, severity of strain	0 – 36
Posture and Motions	Considers the posture and motions as they affect energy expenditure and recovery time, particularly awkward postures	0 – 10
Restrictive Clothing	Impact of protective clothing as it restricts movement, breathing and recovery time	0 – 15
Discipline	Assesses demands imposed by the need for exact timing and discipline imposed by machine cycle	0 – 5
Monotony	Takes into account absence of mental stimulation due to tedious tasks	0 – 5
Concentration	Considers impact of consequences of relaxed attention	0 – 8
Thermal and Atmospheric Conditions	Assesses impact of temperature and air circulation (not humidity)	0 – 30
Physical environment (Noise)	Considers impact of physical environment.	0 – 8
Visual (light)	Assesses closeness of work and lighting as it relates to visual strain.	0 – 8
Vibration and Instability	Considers effect of vibration and unstable working positions	0 – 7

(Lund and Mericle 2000)

2.2 Assembly line

According to (Ham and Park 2014) and Stevenson (2009), the manned or manual assembly line is suitable for manufacturing goods with flexibility. In a manned assembly, there are three main factors: worker, machine, and material, which are shown in Figure 2-16. Referred to Stevenson (2009), Ham and Park stated: "*The improvement of assembly line focuses on efficiency maximisation via continuous adjustment of already installed factors*" by assembly work process improvement and improvement of line balancing efficiency. In work process improvement, the assembly process is focused to increase the performance of the work station. Hence, readjusting work process to reduce or eliminate inefficient work process will reduce cycle time of work stations, increase productivity, and ultimately reduce cost per unit assembled.

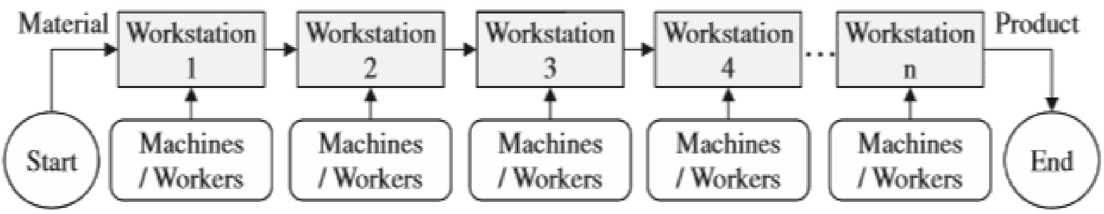


Figure 2-16 Assembly Line Structure

(Ham and Park 2014)

In assembly line balancing improvement, the focus is on the balancing workload within each station to achieve the most efficient assembly line. According to (Heizer and Render 2006), line balancing is a technique that aims to solve the imbalance between workers and workload. According to (Hapaz 2008), line balancing operates under two conditions, which are precedence constraint and takt time restriction. Precedence constraint refers to the relationship between tasks so that the required task can be done first for the next task to start.

The improvement is governed by two main indicators: takt time, the average unit production demanded by customer per unit time, and line efficiency, which measures the degree of balance between workloads on various stations or workers. Hence, an improper line balancing is when the workloads at each station are unevenly distributed; one station is performing more tasks or longer tasks than the other. One critical problem that occurs in assembly line is 'bottleneck', the workstations with highest cycle time which governs the throughput of the assembly line, thus, the production rate. It affects the assembly line by delaying the assembly process following it, which reduces the line efficiency.

According to (Kriengkorakot and Pianthong 2007), assembly line balancing problem (ALBP) refers to assigning assembling tasks to stations in sequence based on the precedence relations between each task. They accumulated several assembly line problem literatures and classified ALBP according to various researchers. Firstly, according to Ghosh and Gagnon (1989), ALBP is categorised into four categories 1) Single Model Deterministic (SMD), 2) Single Model stochastic (SMS), 3) Multi/Mixed

Model Deterministic (MMD) and 4) Multi/Mixed Model stochastic (MMS). The classification of assembly line balancing according to Ghosh and Gagnon is shown below.

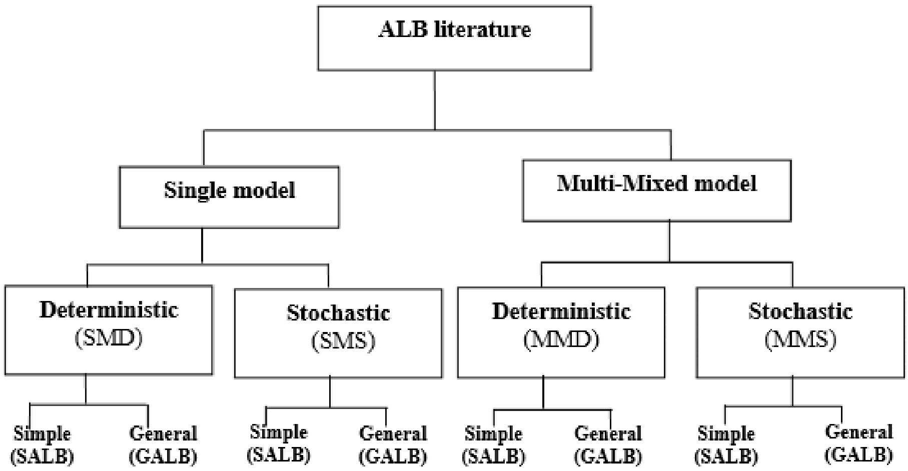


Figure 2-17 Classification of ALBP

(Ghosh and Gagnon, 1989)

Within this thesis, the research will be based upon simple SMS. SMS refers to the task-time variability. It concerns about operation times at each station, and mostly, it deals with manual assembly line. Issues that are associated with SMS are station times exceeding the cycle time (main focus of this research), station length, size and location of work-in-process (WIP) buffers, etc.

Secondly, (Becker and Scholl 2006) classified ALBP based on the objectives and constraints of the assembly line. Their classification is summarised below.

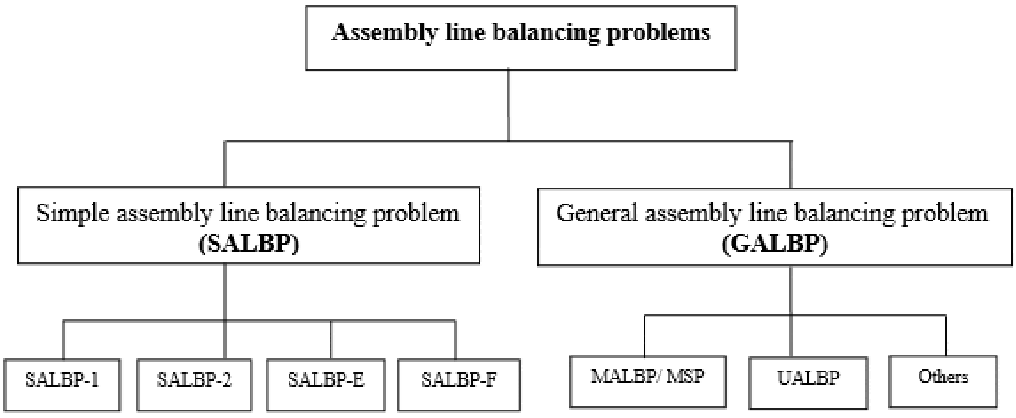


Figure 2-18 Classification of ALBP

(Becker and Scholl 2006, Scholl and Becker 2006)

This research paper will focus on the establishing new assembly line of an automotive part, cable sets, served as a connector for the rear lights. Therefore, this thesis will be classified under SALBP-E, a simple ALBP or SALBP that concerns about assembly line that assembles single product in which precedence constraints of tasks are considered. A SALBP-E is the combination of SALBP-1, focusing on assigning tasks to work stations while minimising the work stations for a fixed cycle time, and SALBP-2, focusing on minimising cycle time for a fixed number of work stations. SALBP-E simultaneously deals with allocating tasks to minimise cycle time and number of stations to maximise line efficiency (Scholl and Becker 2006, Kriengkorakot and Pianthong 2007). There are three methods in Assembly Line Balancing: 1.) Largest Candidate Rule (LCR), 2) Kilbridge and Wester's Method (KWM), 3) Ranked Positional Weights Method (RPW)

This research paper will apply LCR and RPW method since the former is the easiest way while the latter is quite popular, frequent used method in literatures. LCR considers the order of operation time of individual work element where the longest work element is assigned to station first. The latter is one of the first simple heuristic methods in tackling assembly line balancing problem (Rekiek and Delchambre 2006). This method was first developed by Helgeson and Birnie in 1961 by which they combined LCR and KWM methods together. RPW considers the duration of work elements as well as their positions in the precedence diagram. Each work element is assigned to the work station in order of their RPW values. The RPW value is obtained from adding the work element time with all of the elements that follow it in the precedence diagram (NCHU 2014).

Procedure of LCR	Procedure of RPW
1. Arrange work element in descending order of operating time. Select the most feasible work element and assign to a workstation.	1. Calculate the RPW value for each element by adding the work elements time together with the all the elements that follow it in the precedence diagram.
2. Add other work elements to the workstation such that the total time doesn't exceed takt time.	2. List the work elements in the descending order of their RPW values.

3. Repeat Step 1 and 2 until all work elements are assigned.	3. Assign elements to stations according to RPW, avoiding precedence constraint and exceeding the takt time.

2.3 Notations and Definitions

(Rekiek and Delchambre 2006, Kumar and Mahto 2013, Ham and Park 2014)

1. Workstation or Station

A place where tasks are performed that is sequentially ordered for product assembly. The number of work station is noted as 'n'.

2. Work element (WE)

A portion of the total work in assembly process. It can be broken down into smaller unit called unit motion (textbook, Ham & Park). Multiple work elements can be assigned to a workstation. The operation time of each WE is denoted as WE_i where 'i' is the operation time of i^{th} work element.

3. Precedence Constraints:

The order in which tasks must be performed based on the completion of previous task.

4. Takt Time (T)

The average operation time of all workstations in order to meet customer demand for a given period.

$$Takt\ time = \frac{Total\ operation\ time\ availablem\ for\ a\ given\ period}{Customer\ demand\ for\ a\ given\ period}$$

5. Work Content (WC)

The sum of operation time of all tasks

$$WC = \sum_{i=1}^{j} WE_i$$

j = total number of work elements

6. Station Time (S)

The sum of operation time of all tasks at a station.

$$S_i = \sum_{k}^{m} WE_k$$

C_i = operation time of i^{th} station

k = k^{th} work element of assembly process

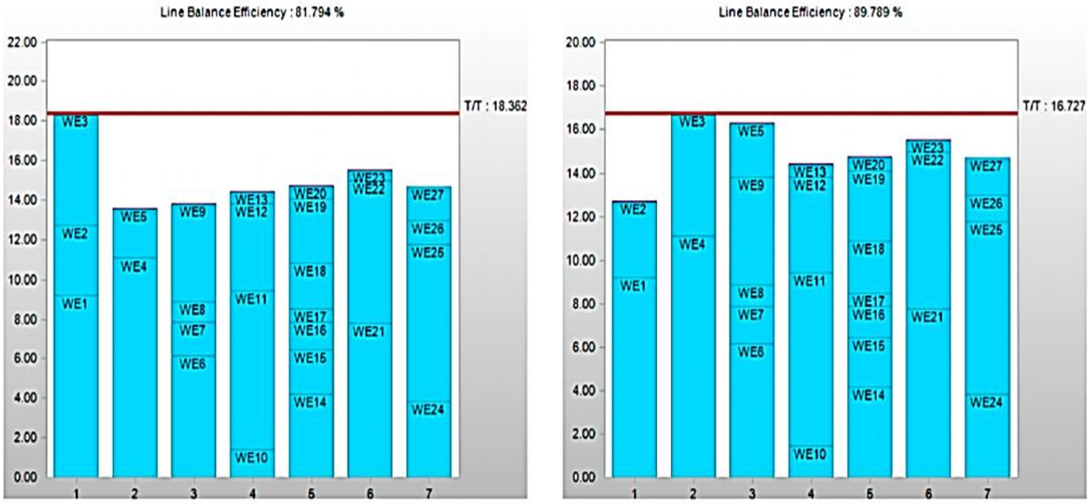
m = number of work elements at i^{th} station

7. Smoothness Index (SI)

The standard deviation of workload distributions among all stations $SI = \sqrt{\sum_{i=1}^{n}(S_{max} - S_i)^2}$

2.4 Related Researches

(Ham and Park 2014) proposed a framework for continuous performance improvement for manual assembly line. They framed the concept into two parts which are assembly work process improvement (workstation analysis) and improvement of line balancing efficiency (line analysis). The former concept is applying time and motion study or also known as work study, while the latter is applying heuristic assembly line balancing method. The research breaks down the manned assembly line into five levels, which are workstation, worker, operation cycle, work element, and unit motion; and then assessed the requirements in each level in bottom-up approach. The workstation level serves the purpose of the improvement of line balancing efficiency, while the other four levels correspond to the improvement of work process. The proposed framework was then applied on a Korean assembly line based manufacturers, and the result was satisfying since the line efficiency improved from 81.8% to 89.9%. Furthermore, the takt time of the activity is reduced from 18.36 seconds to 16.7 seconds. The graph of the result is shown below.

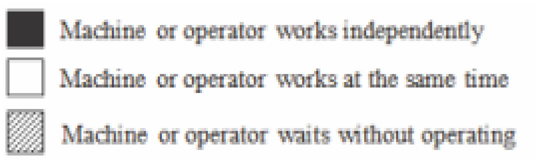


(a) Before reallocation (b) After reallocation

Figure 2-19 Ham W.K. & Park S.C. Result after line balancing

(Hamza and Al-Manaa 2013) investigated the effects on productivity between three different types of assembly line balancing algorithm, namely rank position weight, larger candidate rate, and column method. The research is applied on Two Stages Gear Box (2SGB) by which the components, work elements, and precedence diagram are identified to solve for the best layout. There are three layouts which are single straight line, circle and mixed (circle and straight). After applying different heuristic algorithm, the best layout was found to be the line stations layout by Ranked Positional Weight Method. The layout consists of 4 stations and total assembly time of 4.25 minutes per gearbox. The configuration has one worker for each station with line balancing efficiency and labour efficiency of 94.6% and 88.8% respectively.

(Kayar and Akalin 2014) applied work study and line balancing onto blouse sewing production. The blouse sewing operation is carried out in assembly line as it was required in large volume production. The work study, which consists of method study and work measurement, was applied onto four operations within the blouse sewing assembly line, which are front part puckering, sewing shoulder, assembling cuff to sleeve, and collar overlock. The activities in each operation are timed to study to the working relationship between machine and human. The research classifies the type of activity into three types, shown below:



The analysis from method study is applied to alter the activity length within an operation. The results of before and after method study for front part puckering operation are shown in Figure 2-20 and Figure 2-21. The new method shortens the time required to perform the front part puckering. The new method was changing the operation of transparent elastic band measurement, which results in elimination of sub-operations number 4, 5, and 7. Thus, the time decreases from 0.571 min to 0.462 min. Other operations' times are decrease as well. For sewing shoulder operation, the time decreases from 0.59 min to 0.383 min. For assembling cuff to sleeve operation, the time decreases from 0.423 min to 0.356 min. For collar overlock operation, the new method lasts 0.292 min instead of 0.394 min with old method. Thus, the overall operation's time decreases from 8.957 min to 8.665 min, saving 0.292 min.

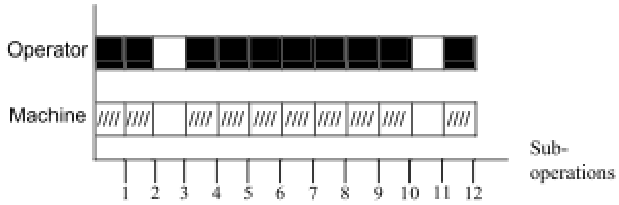


Figure 2-20 Sub operations performed before method study front part puckering operation

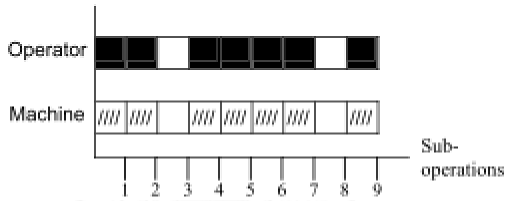


Figure 2-21 Sub operations performed after method study front part puckering operation

As for line balancing, Kayar M. and Akalin M. applied *ranked positional weight* method (RPW). Before the implementation of method study, the assembly line has 15 workstations with cycle time restriction at 0.887 min. The calculated loss of balance is 32.8% while the line efficiency is 67.32%. After applying both method study and RPW, the line efficiency increases to 75.15% while the loss of balance falls to 24.85% with only 13 workstations necessary. Furthermore, since the line efficiency increases, the production of blouse per day also increases from 904 pieces per day to 934 pieces per day, 3.12% increase in production efficiency.

(Hapaz 2008) studied the problem of poor design layout which affects the productivity and the line efficiency of the assembly line. Thus, Hapaz proposed new layout to the sample company. The research analyses the current layout by identifying the bottleneck workstation, the longest processing time. The identification led to a redesign of current layout by computing the standard time and processing time in each workstation. The method is done by the aid of time study (stopwatch) and simulation data by WITNESS software. Furthermore, line balancing algorithm (RPW) is also used. The findings of the research led Hapaz to propose three layouts while comparing the line efficiency and productivity.

(Yerasi 2011) applied time study, operation analysis, and assembly line balancing in improving the productivity of a manual assembly line within the framework of lean manufacturing. The research evaluated which product family to be studied by ABC classification and Part-matrix methods. Then, time study is implemented by using stopwatch to gather all required information to be further analysed in operation analysis stage. In operation analysis stage, various aspects of assembly line are assessed such as process flow, material handling, working conditions, line layout, and motion economy. These are applied onto a case study within the research related to a packaging industry. The current precedence of assembly method is redesigned from every task follow accordingly to more complex structure shown below (Figure 2-22).

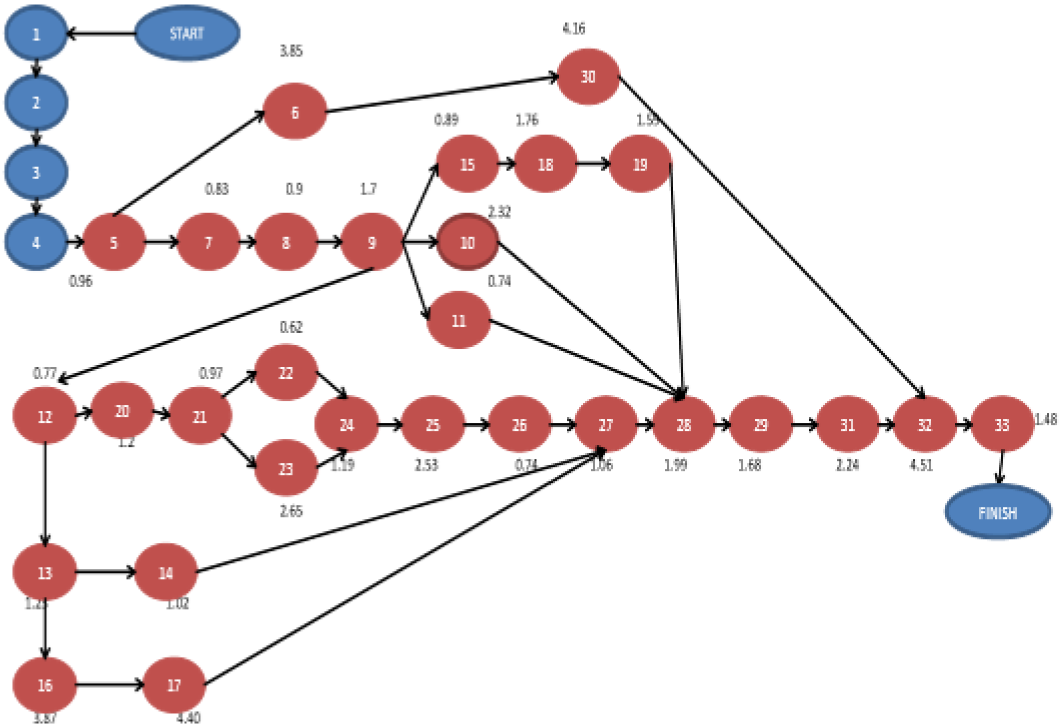


Figure 2-22 Modified Precedence Diagram for Packaging

Yerasi then proposed two types of assembly line configurations: single stage parallel line and five stage serial lines. The comparison between these two assembly lines is done through simulation and assembly line balancing by RPW method. The result showed that five stage serial lines have low utilisation at station 4 with a value of imbalance of 2.73 seconds (variation between station time and cycle time). Based on RPW method, the line utilisation of single stage parallel line is 99.1% which triumphs five stage serial line 86.9%.

Chapter 3. Phase I: Define Phase

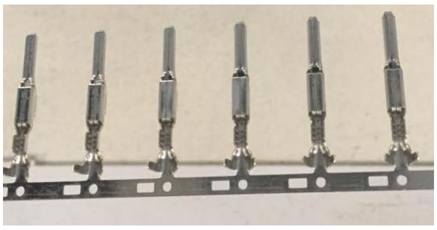
3.1 Materials and Product

This section illustrates the materials that are necessary for assembly process in order to deliver the rear lamp cable. The component parts that will be assembled in the new assembly line are 16 components, shown in table below. (*The reason for crimped and un-crimped wire is discussed in Appendix B.)*

Table 3-1 Assembled Components of N-RLC

No.	Name	Description	Figure
1	Wire (G/Y)	Wire (Green/Yellow)	
2	Crimped Wire (G)	Wire (Green)	

3	Crimped Wire (W/B)	Wire (White/Black)	
4	Crimped Wire (G/W)	Wire (Green/White)	
5	Wire (R/L)	Wire (Red/Blue)	

6	Connector	Connector	
7	Tube 66	Black plastic tube with ID 9 mm and OD 10 mm, length 66 mm	
8	Terminal	Crimped to wires	

9	Bushing	Locking terminal with wires	
10	Tape (W)	Tape (white) for tightening of wires together	
11	Tube 85	Black plastic tube with ID 7 mm and OD 8 mm, length 85 mm	

12	Tube 40	Black plastic tube with ID 7 mm and OD 8 mm, length 40 mm	
13	Plug M-086	Brown Socket Plug	
14	Plug M-088	Green Socket Plug (straight teeth)	

15	Plug M-079	Green Socket Plug (tilted teeth)	
16	Gasket	Rubber Gasket	
17	Crimping Machine	For crimping G/Y and R/L Wires	

3.2 Define Problem

The problem clearly is how to establish an assembly line that can deliver the forecasted monthly demand from customer. As mentioned in chapter 1, the customer demand per month is 160,000 cables for 22 days of daily order. Thus, the company has to produce 7,272 cables per day. With 11 hours of working time (overtime included) per day, this will result in 5.45 seconds required for one cable. The company has come up with 3 assembly lines to serve the demand, which lengthen the time required for one cable from 5.45 seconds to 16.35 seconds or 2424 cables per line. This section will investigate the reasons behind 3 assembly lines as well as the problem with simulated assembly line that the company has established for testing. Moreover, the process of the simulated assembly procedure will be outlined.

Why three assembly lines?

From the industry point of view, there are two main factors which drove the company to aim for three production lines, which are cost, capacity flexibility, and space.

Firstly, since the production is purely man-powered, the majority of the cost will come from labour cost rather than material or overhead cost. From the company cost structure, the average labour cost for a product is approximately 50%-70% of the total cost. Thus, the company has a rule of thumb in which the production strategy will be driven by lowering labour cost – lowering number of workers as low as possible. This means that in order for a process to operate with the lowest number of workers, the operation must be effective and efficient. In addition, labour cost increases every year because of increase in salary. For example, the salary will be increased from 300 (Thailand's minimum wage in year 2015) to 350 per day after 2 years of employment. Therefore, since the price of the product can't be increased, the profit margin of the product will be lowered as years pass. Ultimately, lowest number of labours for an operation process is desired and has been the goal for company's production team.

Secondly, the consideration of capacity flexibility leads to the three production lines. Capacity flexibility means that when the customer's demand fluctuates deviating from the forecasted demand, the company must be able to absorb and respond to the change. As mentioned before, the company production strategy is maximum capacity; that is able to produce at the maximum quantity according to forecasted demand. Since the customer ordering behaviour is day to day order, the company has to be able to produce at that quantity demanded per day. If the assembly line of N-RLC has only one assembly line that can satisfy the maximum order forecasted per day, the company will have problem when the order fluctuate, less than the forecast. The problem is that the cost will dramatically increase since the quantity produced has been reduced. For example, for comparison, if one production line with 10 assemblers can assemble 100 cables per day and two assembly lines with 5 assemblers at each line that can produce 50 cables per day, the production capacity is the same at 100 cables per day. However, with two assembly lines, the company can mitigate the increase in cost if the demand drops to 50 cables as compared to one assembly line that has to produce 100 cables to maintain the cost per cable.

In summary, the goal is to create an effective and efficient assembly line and duplicate the line as the demand change. From the availability of space within the company, one long assembly line is not possible. On average the worker working space within the company is in Figure 3-1, and the available space figures shown graphically and realistically are shown in Figure 3-2 and Figure 3-3 respectively.

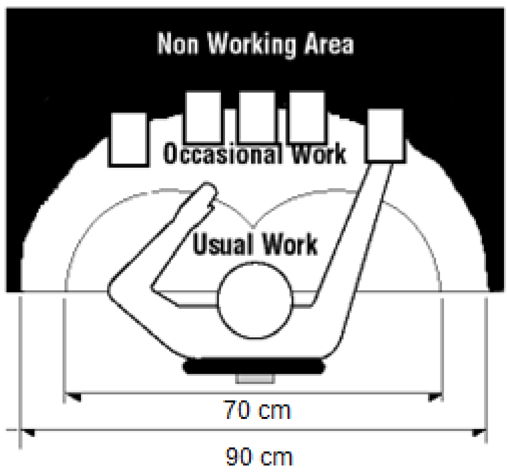


Figure 3-1 Workspace for One Assembler

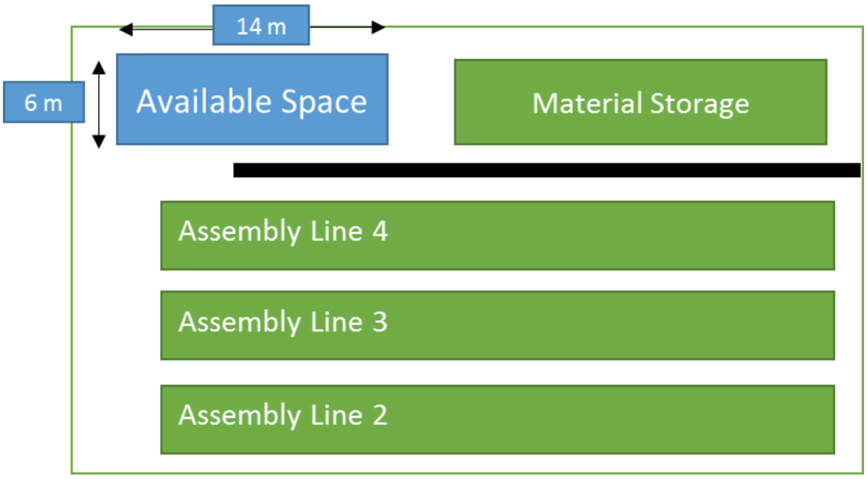


Figure 3-2 Available Space for New Assembly line

Figure 3-3 Actual Available Workspace

Based on the dimension of available spaces and workspace for each assembler, considering the walking area width of 2 meters at both ends of the assembly line with 14 meters in length available, the available assembly line length is 10 meters. To calculate the maximum assemblers per straight assembly line, divide

10 meters by the maximum span, 90 cm, which will result in 11 assemblers per line. The width of the standard table for assembly in the company is 60 cm; therefore, considering the walking path between tables and seating of 1 meter will result in 4 meters in total. The available width is 6 meters minus 4 meters, leaving 2 meters for overall table to be arranged. Dividing 2 meters with 60 cm will result in 3 tables which mean 3 assembly lines available. The overall schematic diagram of the calculation is shown below.

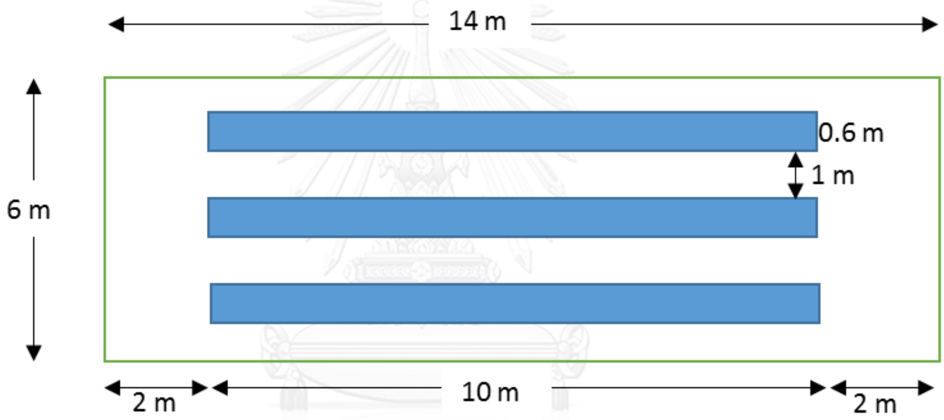


Figure 3-4 Schematic Diagram of Three Assembly Lines

With the given components mentioned above, the current assembly procedure that the company has tested is shown below in term of work elements and the assembly process, Figure 3-5 and Figure 3-6.

Work Elements (WE):

1. Assemble tube 85 with W/B wire
2. Assemble tube 40 with W/B wire
3. Assemble W/B wire with Plug M-088
4. Assemble R/L wire with Plug M-088
5. Assemble R/L wire with Tube 85 and Tube 40
6. Assemble G/Y wire with Plug M-079
7. Assemble W/B wire with Plug M-079
8. Assemble G/Y wire with Tube 85
9. Assemble W/B wire with Tube 40
10. Assemble W/B wire with Plug M-086
11. Assemble G wire and G/W wire with Plug M-086
12. Assemble G wire and G/W wire with Tube 40
13. Assemble all wires with Tube 66
14. Assemble bushing with G/Y and R/L wire
15. Crimping terminal of G/Y and R/L wire
16. Assemble connector to all wires
17. Taping top part of cable (near connector)
18. Taping bottom part of cable (further from connector)
19. Insert Gasket to Plug M-079, M-086, M-088

Motivation behind Research

Whenever a new product is introduced to the market, engineer team outlines new assembly line layout and procedures. What engineer team always does is using previous experiences to establish new assembly line. As a result, there is no justification of which how the process should be assembled; thus, trials and improvements are always in progress, even after the product is produced to the market. This working method consumes time and effort repetitively. Therefore, this research aims to establish a framework for using as a standardised method in setting up assembly line. The following figure displays the precedence diagram of work elements in prototype assembly line.

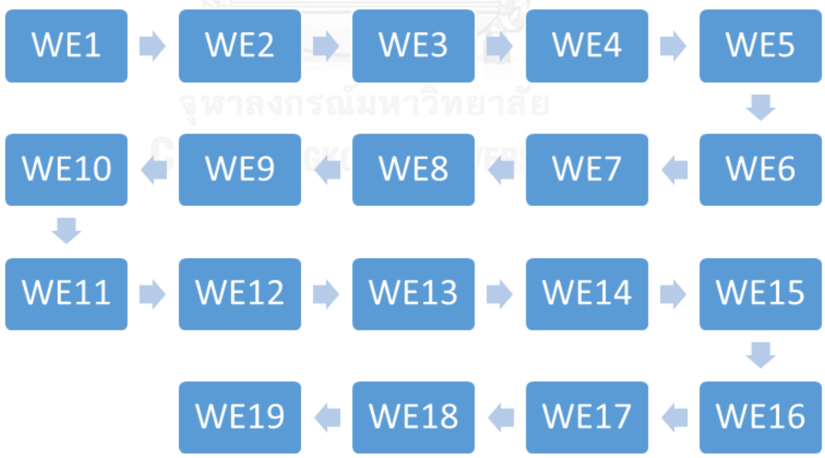
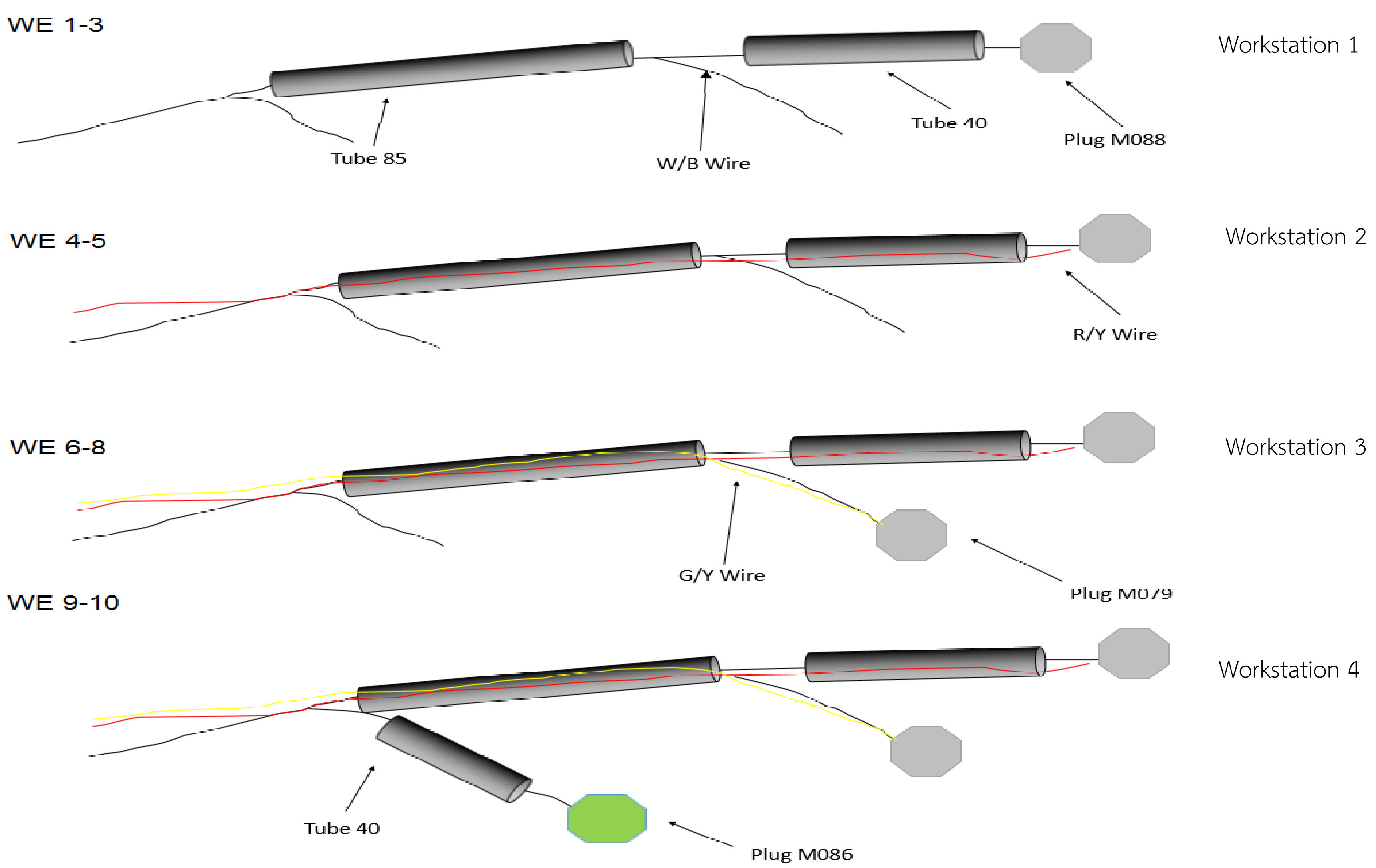
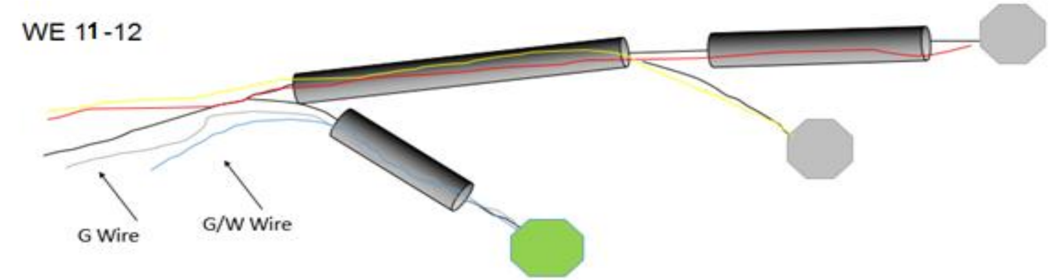


Figure 3-5 N-RLC Work Element Process Flow

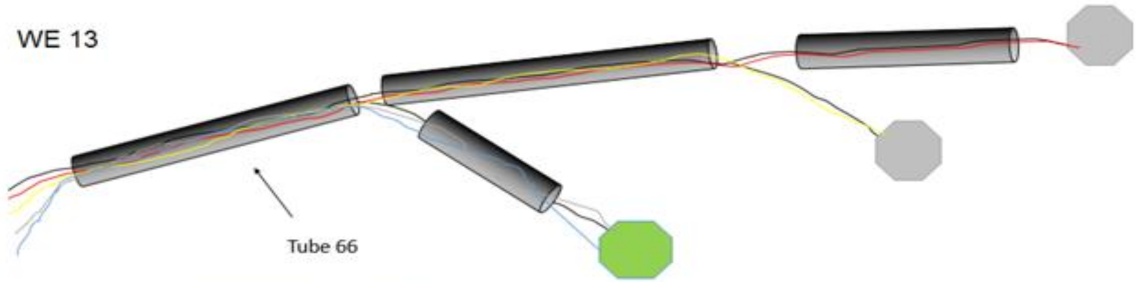

WE 1-3
Tube 85
W/B Wire
Tube 40
Plug M088
Workstation 1
WE 4-5
R/Y Wire
Workstation 2
WE 6-8
G/Y Wire
Plug M079
Workstation 3
WE 9-10
Tube 40
Plug M086
Workstation 4

WE 11-12



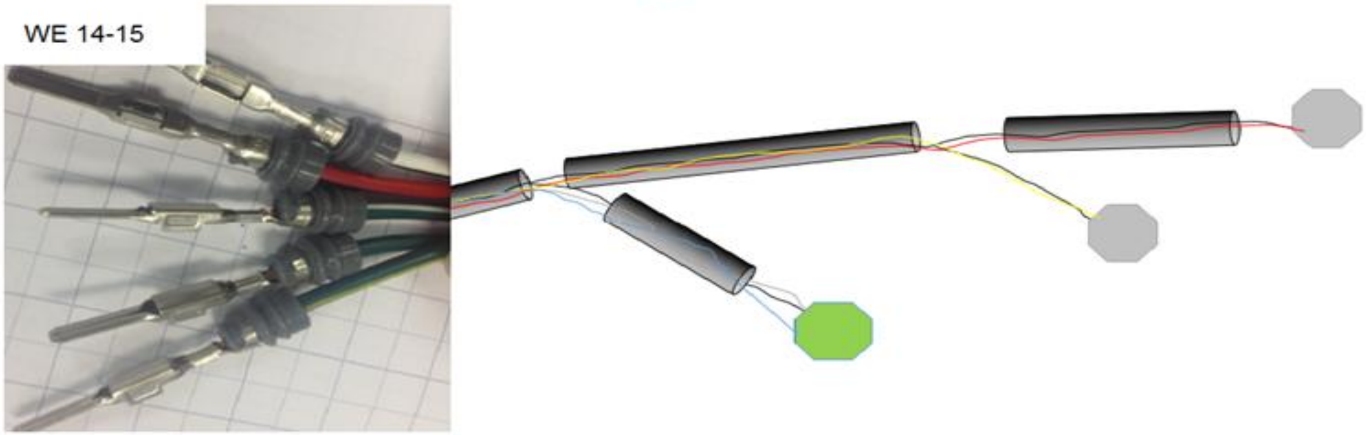
Workstation 5

WE 13



Workstation 6

WE 14-15



Workstation 7

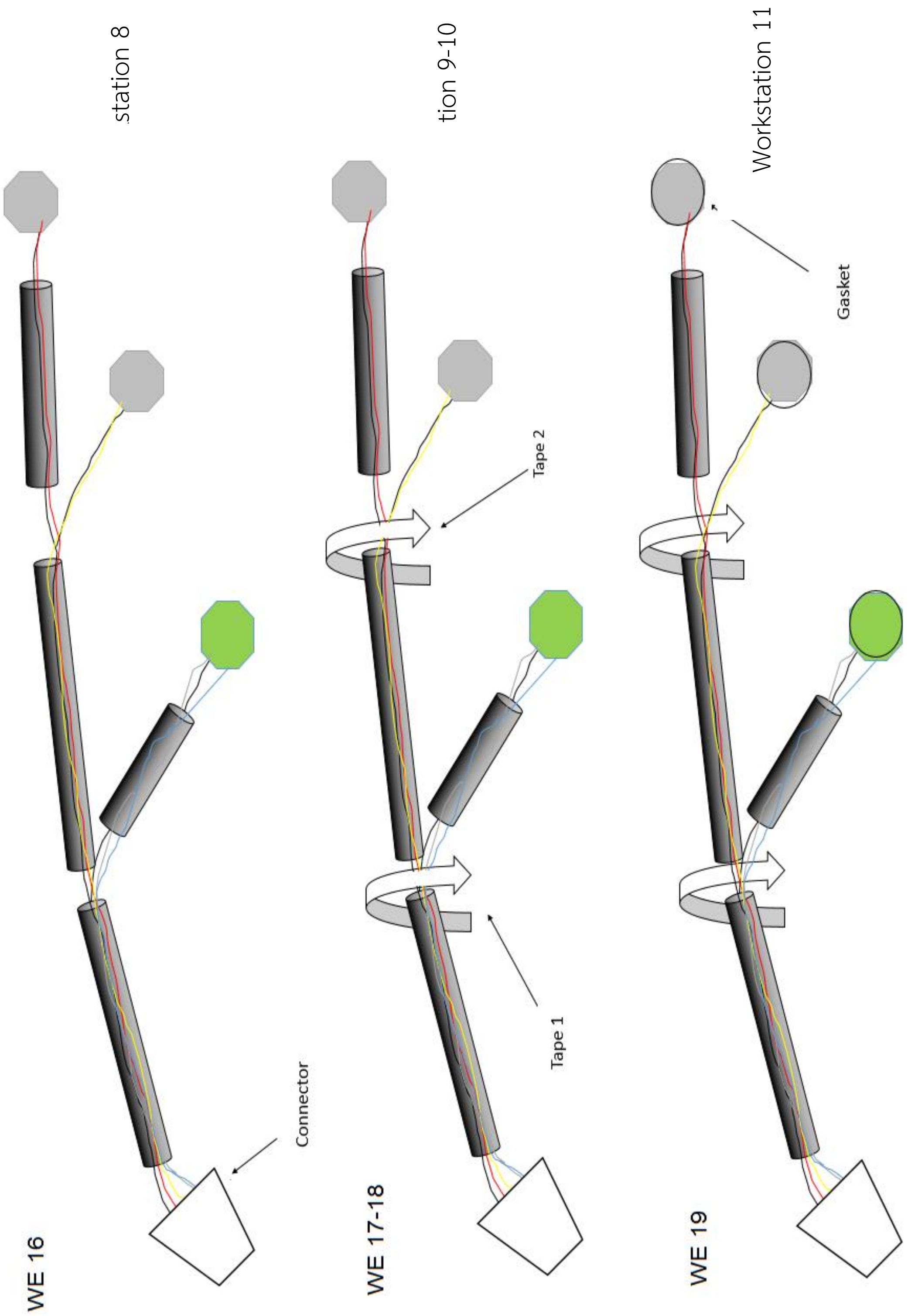


Figure 3-6 N-RLC Assembly Diagram divided by workstation

Figure 3-7 Workstation 1

Figure 3-8 Workstation 4

Station	1	2	3	4	5	6	7	8	9	10	11
Work Element	1,2,3	4,5	6,7,8	9,10	11,12	13	14,15	16	17	18	19
Station Time (S)	16.82	16.12	16.38	13.24	17.13	15.67	15.89	18.6	17.4	16.79	8.78
	16.77	16.34	17.12	14.22	17.35	15.34	15.66	18.55	17.85	17.22	8.34
	16.62	15.4	16.48	12.58	16.77	14.87	15.4	19.34	18.33	16.38	9.2
Average	16.74	15.95	16.66	13.35	17.08	15.29	15.65	18.83	17.86	16.8	8.77

Figure 3-9 Modelled Assembly Line for N-RLC

(Raw data can be viewed in Appendix C)

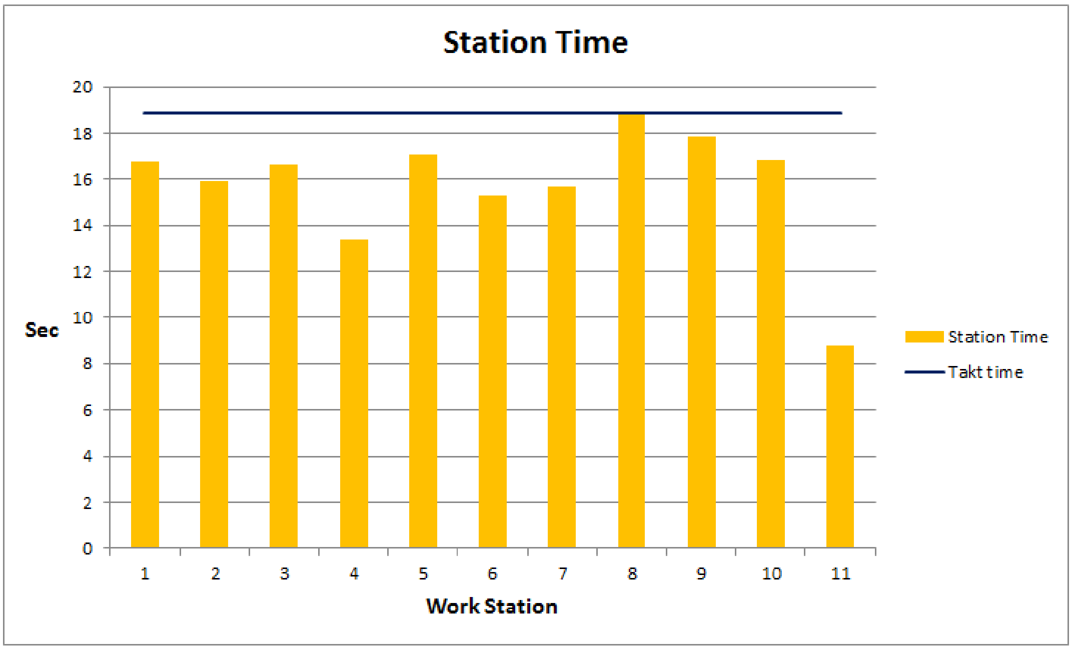


Figure 3-10 Modelled Station Time

According to the result from engineer time, the cycle time of each station exceeds the targeted takt time. And there is a bottleneck at station 8, 18.83 seconds. This means that there will be approximately a cable produced every 18.83 seconds. Therefore, with this configuration, the company will not be able to satisfy the demand of 2424 cables per day. With 18.83 seconds, the total cable per assembly line per day is only 2104 cables, 13% difference.

This layout requires 11 workers per assembly line, thus a total of 33 workers. From the executive members' feedback, they desire a reduction in the number of worker who will be working on assembling a model. The reason is because the assembly line of N-RLC is planned to be fixed, unlike other assembly line, which is driven by just-in-time demand; so daily man-power planning is very tedious, thus if reduction in numbers of worker for one N-RLC assembly line is possible, it will help the overall daily man-power planning of the company.

Furthermore, the current assembly line has a smoothness index of 13.39, from the calculation shown below. In other words, it represents the deviation of workloads distribution of the assembly line.

$$SI = \sqrt{\sum_{i=1}^{11}(18.83 - S_i)^2} = 13.39$$

In addition, from 20 trials of time measurement, the time distribution of each work station is shown below. The raw data is in Appendix C1. It can be seen that there is high inconsistency in performance of each workstation especially in workstation 4 and 8. The degree of inconsistency arises from the unstandardized WEs within each workstation. Therefore, work study will be used to study how the assembly is done in Chapter 4.

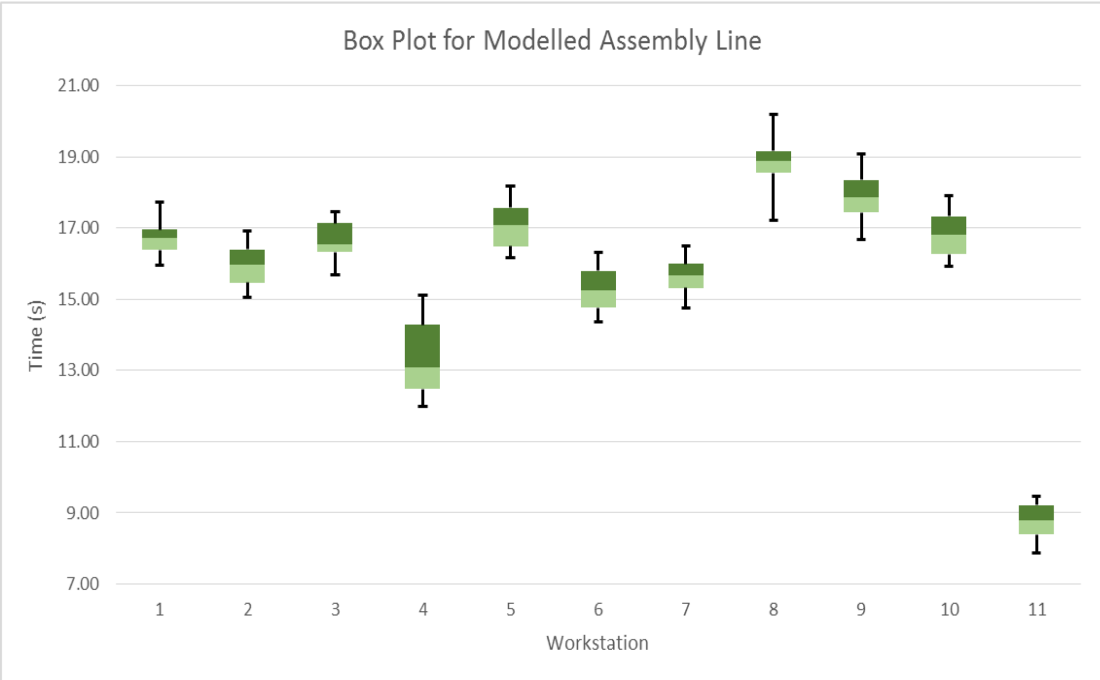


Figure 3-11 Box Plot for Modelled Assembly Line

Since there is a new model introduced into the company, it is certain that assemblers will be unfamiliar with the new model, which will require training and practice. Although some workers are more experienced in term of a specific task, for instance taping the cables or crimping the terminals, the new model has some new procedures while assembling compared the old model, O-RLC. As a result, in order to gain the most accurate testing result from the assembly line, only workers who have an experience of more than 5 years are chosen and have already assembled some of N-RLC from the testing orders from customer.

In order to tackle the problem of how to improve the productivity of the existing assembly line by reducing the cycle time at each work station, 5-level of decomposition model proposed by Ham & Park (2014) is used as a technical approach. The 5 levels are the dissection of factors within a manned assembly line. The level that isn't to be tackled in this research is worker; this is because in establishing new assembly line for N-RLC, only workers whose experience is over 5 years are chosen to assemble this new product. That aside, the problems of this research is divided into 4 levels: workstation, operation cycle, work element, and unit motion. Ham & Park categorised these issues into line analysis and workstation analysis as shown in Figure 3-12 and Figure 3-13. This research will be a bottom-up approach of the analysis of each issue that causes the exceeding of takt time.

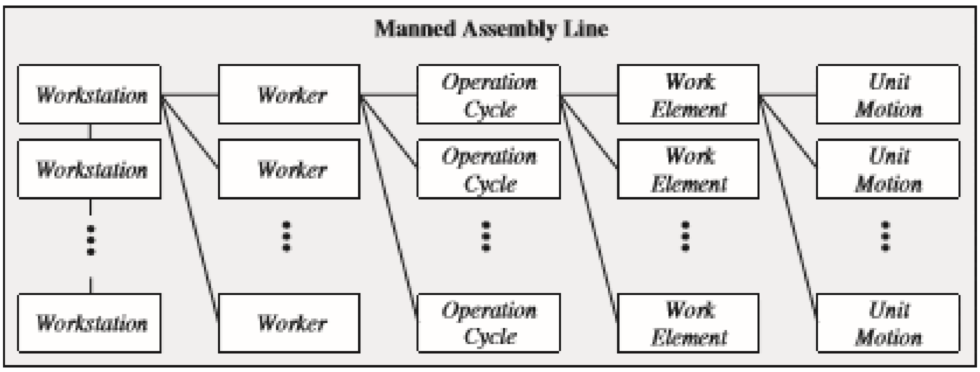


Figure 3-12 5-level Decomposition Model for Manned Assembly Line

(Ham W.K & Park S.C., 2014)

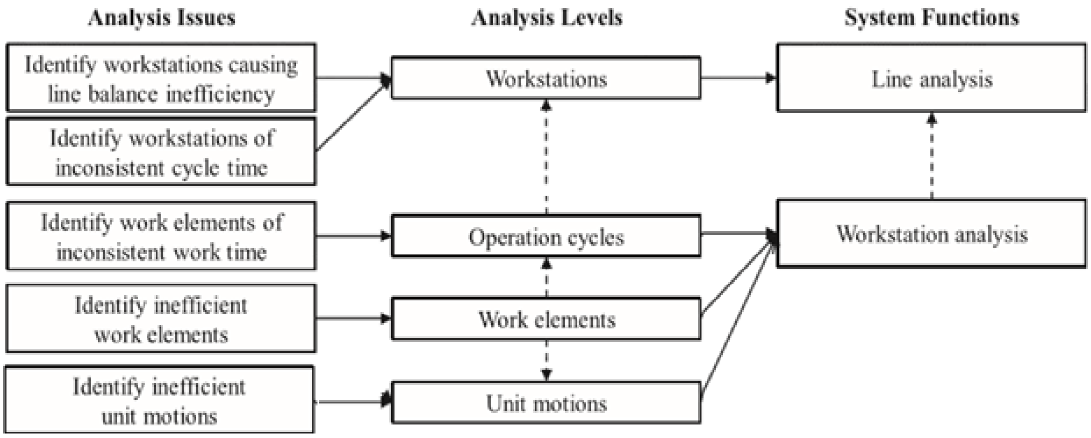


Figure 3-13 Relationship between analysis issues and levels

(Adapted from Ham W.K & Park S.C., 2014)

In summary, the problems that the company is going to face in the upcoming year while accounting for every aspect of assembling cables mentioned above are

- Existing assembly line exceeds the takt time required to produce model N-RLC
- Unbalanced workloads between existing stations formed by engineer team
- Desire to reduce the number of assemblers per line of which the current simulated assembly layout of 11 workers
- Fluctuation in workstations time (high deviation)

In addition, according to the entire company assembly line layout, all materials flow from right hand to left hand, because the majority of the workers are right handed. Left hand acts as a pivot, passing tool, while right hand assembles. Thus, material flow in the new assembly line is scoped from right to left as well.

3.3 Measurement

The measurements that will be used to define the success of this research are the station time, line balance efficiency, smoothness index. The aim is reducing station time to be below takt time as well as minimising the smoothness index. Tools that will be used to measure station time are stopwatch and video recorder. The measurement of the station time will be timed by many trials to obtain the average as well as each WE under workstation.

3.4 Project Team

A cross-functional team responsible for setting up and improving cable assembly line is necessary because by including different functional areas, knowledge, information, and expertise are exchanged, which is vital in solving problem. The team responsible for determine the causes of problem and brainstorming solutions is consisted of:

- Factory Manager
- Production Manager
- Production Engineer
- Assembly line supervisor

3.5 Summary of Define Phase

In define phase, after understanding the materials required for assembly, the constraint of the assembly process, and the current testing of assembly procedures, the major problem is the some workstations' time exceeds takt time and the workloads at each station is not quite balanced yet. These two problems result in the incapability of delivering 2424 cables per day for one assembly line. The root cause of the problem is tackled by using Ham & Park (2014) model in which unit motion, work element, operation cycle, and workstation are studied from bottom-up approach. By looking at the motions of assembly that are unstandardized and inefficient, then balancing the workloads to each station, the author believes that the time at each workstation can be reduced below takt time.

Chapter 4. Phase II: Method Study

In this chapter, the microscopic picture of the assembly line will be studied. Work study is also known for time and motion study. Thus, it is applied to study how the work is done and the time it takes and how long it should take. This chapter consists of the first part of work study which is method study. Method study is used to study of how the work is done by looking at micro-motions. The tools that are used to aid work study are stopwatch and video recorder. For method study, video recorder will be used to record the motions of workers working under simulated procedures. And the method of determining the measured time is by averaging the production of 10 units; further calculation and explanation will be discussed in next sub-section. Furthermore, a simo-chart chart will be used in parallel with video to generate an overview of micro-motions of workers; it explains what and how left and right hands are performing in order to point to the ineffective motions. The examination of simo-chart will be by questioning primary and secondary questions consisting of what, why, when, where, who, and how. The purpose of examination is to eliminate, combine, rearrange, and/or simplify the activities. Then, new procedures will be developed, making the process easier and simpler such as using tools and jigs to reduce the force and fatigue in workers. Finally, the new method will be evaluated and installed for standardisation.

The objectives of method study aim reduce number of motions, reduce distance of movements, reduce eye shift, using best of both hands, and promote natural movements. To achieve this, video recorder will be used to record the motions of assembly in order to establish the unit motions of each WEs. The unit motions will be presented with corresponding time.

4.1 Recording

A video recording program built in camera has been used to capture motions while workers are assembling. Several snapshotted photographs from videos are presented below. The method of determine the most appropriate time for each WE comes from taking the average time to assemble 10 units. For example, if assembling 10 units of tube 85 with W/B wire takes an overall duration of 45 seconds, the average time will be 4.5 seconds per unit of that WE. The following figures illustrate each WE and then followed by a table showing the unit motions and duration of WEs. The table is a reduced version from sets of data collection shown in Appendix C2.

WE1: Assemble tube 85 with W/B wire

Figure 4-1 Assemble Tube 85 with W/B Wire

WE2: Assemble tube 40 with W/B wire

Figure 4-2 Assemble Tube 40 with W/B Wire

WE3: Assemble W/B wire with Plug M-088

Figure 4-3 Assemble W/B Wire with Plug M-088

WE4: Assemble R/L wire with Plug M-088

Figure 4-4 Assemble R/L with Plug M-088

WE5: Assemble R/L wire with Tube 85 and Tube 40

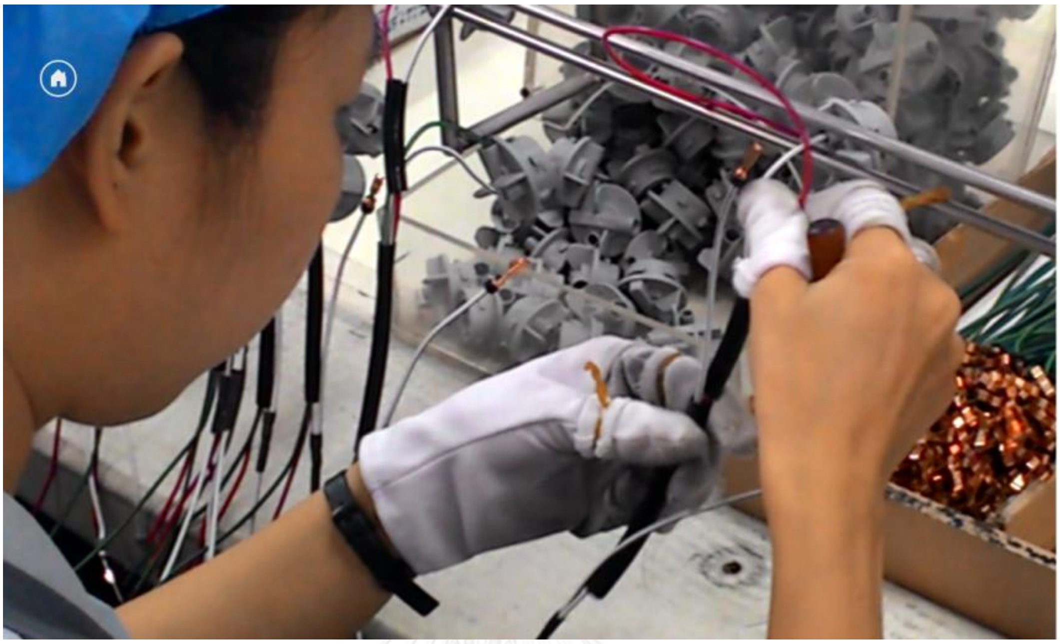


Figure 4-5 Assemble R/L with Tube 85 and Tube 40

WE6: Assemble G/Y Wire with Plug M-079

Figure 4-6 Assemble G/Y Wire with Plug M-079

WE7: Assemble W/B wire with Plug M-079

Figure 4-7 Assemble W/B Wire with Plug M-079

WE8: Assemble G/Y Wire with Tube 85

Figure 4-8 Assemble G/Y Wire with Tube 85

WE9: Assemble W/B Wire with Tube 40

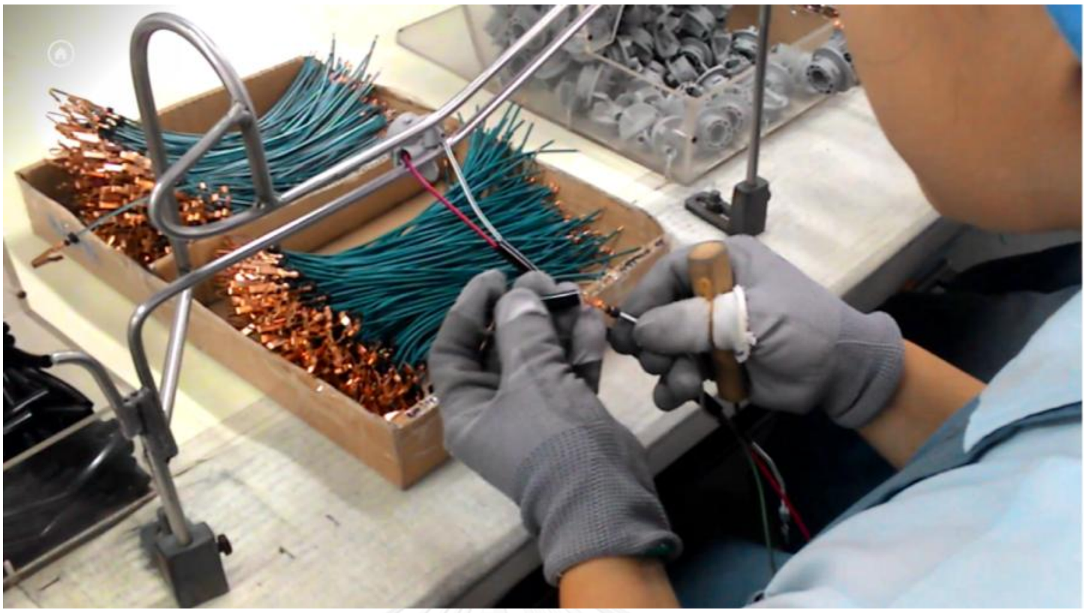


Figure 4-9 Assemble W/B Wire with Tube 40

WE10: Assemble W/B Wire with Plug M-086

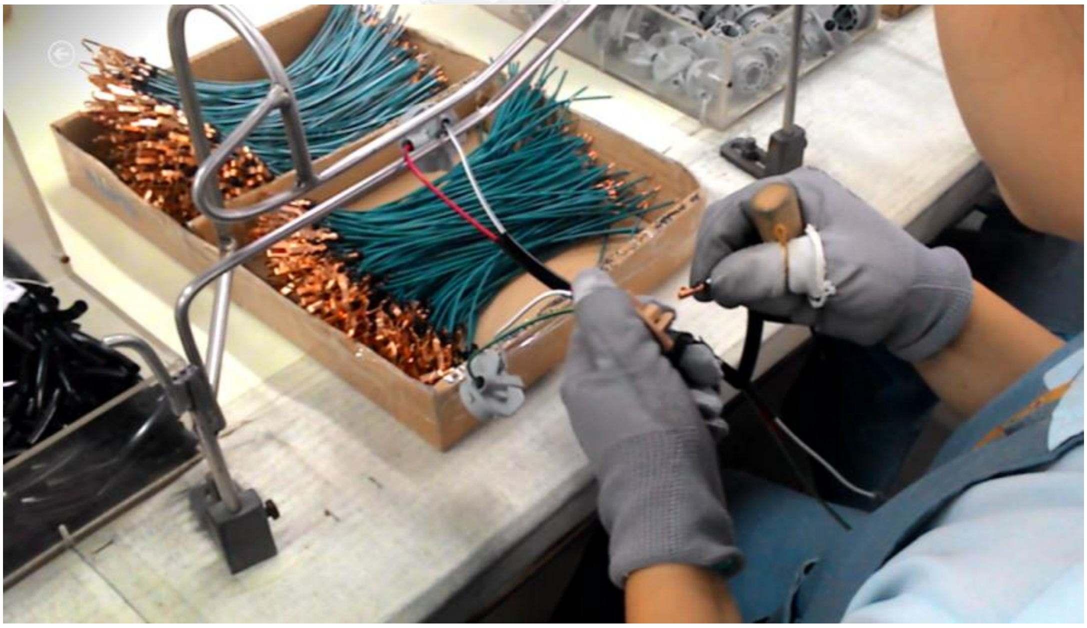


Figure 4-10 Assemble W/B Wire with Plug M-086

WE11: Assemble G wire and G/W wire with Plug M-086

Figure 4-11 Assemble G wire and G/W wire with Plug M-086

WE12: Assemble G wire and G/W wire with Tube 40

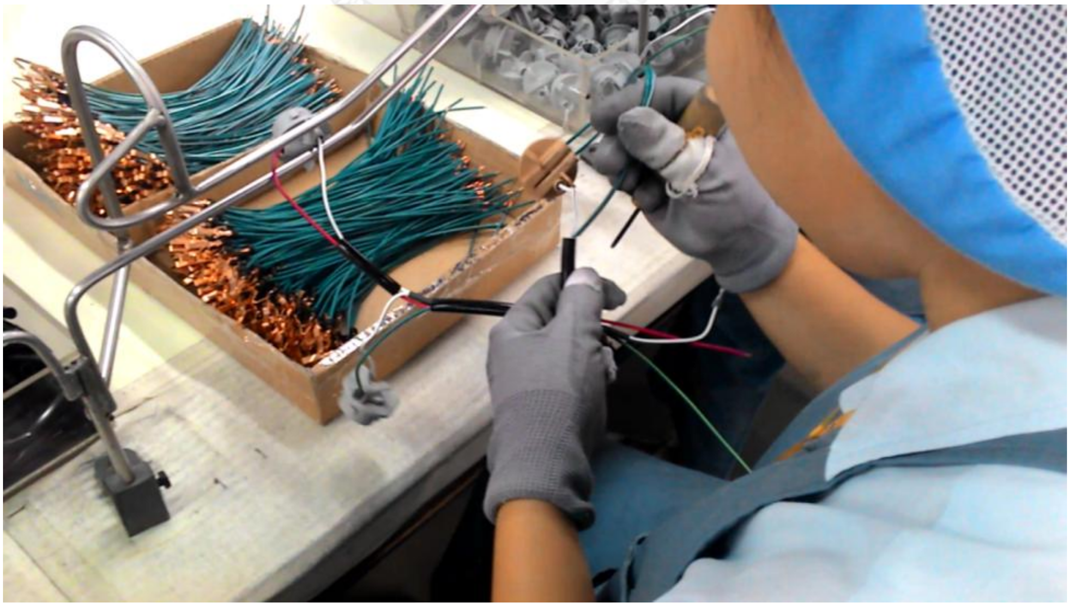


Figure 4-12 Assemble G wire and G/W wire with Tube 40

WE13: Assemble all wires with Tube 66

Figure 4-13 Assemble all wires with Tube 66

WE14: Assemble bushing with G/Y and R/L wire

Figure 4-14 Assemble bushing with G/Y and R/L Wire

WE15: Crimping terminal of G/Y and R/L wire

Figure 4-15 Crimping terminal of G/Y and R/L wire

WE16: Assemble all wires to connector

Figure 4-16 Assemble all wires to connector

WE17: Taping top part of cable

Figure 4-17 Taping top part of cable

WE18: Taping bottom part of cable

Figure 4-18 Taping bottom part of cable

WE19: Insert Gasket to Plug M-079, M-086, M-088

Figure 4-19 Insert Gaskets

4.1.1 Unit Motion and Simo Charts

The unit motion analysis doesn’t account for action between workstation which is associated with transfer of assembled unit (i.e. putting assembled unit onto rack, pulling assembled unit toward, and pushing assembled unit forward; these actions will be mentioned in Simo-Charts). After using video recorder to break down WE into unit motions, a stopwatch is used to time each WE. For better accuracy, duration of assembling 10 units has been measures within 20 trials. A more detailed trial of time measurement is shown in Appendix C1 and C2. The following table summarises the unit motions and duration of each WE showing only the average time.

Table 4-1 Unit Motions and Duration of Work Elements

WE	Unit Motions	Time (10 units) (s)	Time (1 unit) (s)
WE1	Grab W/B Wire	60.35	6.04
	Grab Tube 85		
	Insert Tube 85		
	Push Tube 85 down		
WE2	Grab Tube 40	32.42	3.24
	Insert Tube 40		
	Push Tube 40 down		
WE3	Grab Plug M-088	63.71	6.37
	Insert Plug M-088		
	Tighten the insertion		
WE4	Grab R/L Wire	67.51	6.75
	Rotate Plug M-088 upward		
	Insert R/L Wire into Plug M-088		
	Tighten the insertion		
WE5	Insert R/Y Wire into Tube 85 and 40	72.34	7.23
	Pull R/L Wire down		

WE6	Grab G/Y Wire	57.15	5.72
	Grab Plug M-079		
	Insert G/Y Wire into Plug M-079		
	Tighten the insertion		
WE7	Insert W/B Wire into Plug M-079	49.06	4.91
	Tighten the insertion		
WE8	Insert G/Y Wire through Tube 80	36.14	3.61
	Pull G/Y Wire down		
WE9	Grab Tube 40	45.32	4.53
	Insert W/B Wire into Tube 40		
	Push Tube 40 down		
WE10	Grab Plug M-086	64.73	6.47
	Insert W/B Wire into Plug M-086		
WE11	Grab G Wire	107.74	10.77
	Insert G Wire into Plug M-086		
	Grab G/W Wire		
	Insert G/W Wire into Plug M-086		
	Tighten both insertion		

WE12	Grab G Wire and G/W Wire Insert G Wire and G/W Wire into Tube 40	41.77	4.18
WE13	Grab all wires Grab Tube 66 Insert all wires into Tube 66	130.30	13.03
WE14	Select G/Y Wire and R/L Wire Grab bushings Insert bushing into G/Y Wire Insert bushing into R/L Wire	71.14	7.11
WE15	Select G/Y Wire and R/L Wire Place G/Y Wire under crimper Step on machine's paddle Place R/L under crimper Step on machine's paddle Slide assembled unit forward	49.42	4.94
WE16	Grab assembled unit Locate wire colours to holes Insert all wires into connector Lock the connector head	167.33	16.73

<table>
<tr><td rowspan="9">WE17</td><td>Move Tube 66 upward</td><td rowspan="9">150.28</td><td rowspan="9">15.03</td></tr>
<tr><td>Position tape</td></tr>
<tr><td>Rotate Tape</td></tr>
<tr><td>Press the taping area</td></tr>
<tr><td>Move Tube 66 downward</td></tr>
<tr><td>Rotate tape</td></tr>
<tr><td>Tear tape</td></tr>
<tr><td>Grab ruler</td></tr>
<tr><td>Measure Tape Length</td></tr>
<tr><td rowspan="8">WE18</td><td>Move Plug M-086 to the back</td><td rowspan="8">149.26</td><td rowspan="8">14.93</td></tr>
<tr><td>Position tape</td></tr>
<tr><td>Rotate Tape</td></tr>
<tr><td>Move Tube 40 upward</td></tr>
<tr><td>Rotate Tape</td></tr>
<tr><td>Tear Tape</td></tr>
<tr><td>Grab ruler</td></tr>
<tr><td>Measure Tape Length</td></tr>
</table>

	Grab gaskets		
	Insert gasket to Plug M-079		
WE19	Insert gasket to Plug M-086	68.53	6.85
	Insert gasket to Plug M-088		
	Put assembled unit into box		

After process flow and each WE are recorded with corresponding unit motions, another useful tool for thorough recording for analysis is using Simo-Chart. As mentioned in literature review, Simo-Chart is used to record micro-motion activities by analysis right hand and left hand actions with corresponding therbligs symbols, basic motions of human invented by Gilbreth. The following Simo-Chart is depicted from a single

The following Simo-Charts are divided into each workstation designed by the engineer team with corresponding WEs, unit motions, therbligs symbols, and duration of each micro-motion activity as well as the total time for each workstation.

Table 4-2 Simo-Chart for WE 1-3

Workstation 1: WE 1-3				
Left Hand Activity	Therblig	[redacted]	Therblig	Right Hand Activity
Wait	D		RE G	Grab W/B Wire
Grab Tube 85	RE G		H	Hold W/B Wire
Insert Tube 85	M A			
Grab Tube 40	RE G			
Insert Tube 40	M A			
Grab Plug M-088	RE G			
Rotate Plug M-088	P			
Insert W/B Wire into Plug M-088	M A			
Grab screw driver	RE G		H	Hold W/B Wire
Tighten the Plug and expand terminal	U			
Receive W/B Wire	RE		M	Pass W/B Wire to Left Hand
Put onto rack	M RL		UD	Wait

Table 4-3 Simo-Chart for WE 4-5

<table>
<tr><td colspan="4">Work Station 2: WE 4-5</td></tr>
<tr><td>Left Hand Activity</td><td>Therblig</td><td>Therblig</td><td>Right Hand Activity</td></tr>
<tr><td rowspan="3">Wait</td><td rowspan="3">D</td><td>RE</td><td rowspan="3">Pull assembled unit toward</td></tr>
<tr><td>G</td></tr>
<tr><td>RL</td></tr>
<tr><td>Hold Plug M-088</td><td>H</td><td>G</td><td>Grab R/L Wire</td></tr>
<tr><td>Rotate Plug M-088</td><td>P</td><td>M</td><td rowspan="2">Insert R/L Wire into Plug M-088</td></tr>
<tr><td rowspan="5">Hold Plug M-088</td><td rowspan="5">H</td><td>A</td></tr>
<tr><td>RE</td><td rowspan="2">Grab screw driver</td></tr>
<tr><td>G</td></tr>
<tr><td>U</td><td rowspan="2">Tighten the plug</td></tr>
<tr><td>RL</td></tr>
<tr><td rowspan="2">Hole assembled unit</td><td rowspan="2">H</td><td>G</td><td>Grab R/L Wire</td></tr>
<tr><td>A</td><td>Insert R/L Wire through Tube 85 and Tube 40</td></tr>
<tr><td rowspan="4">Hold Plug M-088</td><td rowspan="4">H</td><td>RE</td><td rowspan="2">Grab screw driver</td></tr>
<tr><td>G</td></tr>
<tr><td>U</td><td rowspan="2">Expand terminal inside Plug M-088</td></tr>
<tr><td>RL</td></tr>
<tr><td rowspan="2">Push assembled unit forward</td><td>M</td><td rowspan="2">UD</td><td rowspan="2">Wait</td></tr>
<tr><td>RL</td></tr>
</table>

Table 4-4 Simo-Chart for WE 6-8

Work Station 3: WE 6-8			
Left Hand Activity	Therblig	Therblig	Right Hand Activity
Wait	UD	RE	Pull assembled unit toward
		G	
		RL	
Grab Plug M-079	RE	RE	Grab G/Y Wire
	G	G	
Rotate Plug M-079	P	M	Insert G/Y Wire into Plug M-079
Hold Plug M-079	H	A	
		RE	Grab screw driver
		G	
		U	Tighten the plug
		RL	
		RE	Grab W/B Wire
		G	
		M	Insert W/B Wire into Plug M-079
		A	
		RE	Grab screw driver
		G	
		U	Expand terminal inside Plug M-079
		RL	
Hold assembled unit	H	G	Insert G/Y Wire through Tube 85
		M	
		A	
Push assembled unit forward	M	UD	Wait
	RL		

Table 4-5 Simo-Chart for WE 9-10

Work Station 4: WE 9-10			
Left Hand Activity	Therblig	Therblig	Right Hand Activity
Wait	D	RE	Pull assembled unit toward
		G	
Grab Tube 40	RE	H	Hold W/B Wire
	G		
Insert W/B Wire through Tube 40	M		
	A		
Grab Plug M-086	RE		
	G		
Rotate Plug M-086	P	M	Insert W/B Wire into Plug M-086
Hold Plug M-086	H	A	
		RE	Grab screw driver
		G	
		U	Tighten the plug and expand terminal
		RL	
Push assembled unit forward	M	UD	Wait
	RL		

Table 4-6 Simo-Chart for WE 11-12

Work Station 5: WE 11-12			
Left Hand Activity	Therblig	Therblig	Right Hand Activity
Wait	D	RE	Pull assembled unit toward
		G	
Hold Plug M-086	H	RE	Grab G Wire
		G	
Rotate Plug M-086	P	M	Insert G Wire into Plug M-086
Hold Plug M-086	H	A	
		RE	Grab G/W Wire
		G	
		M	Insert G/W Wire into Plug M-086
		A	
		RE	Grab screw driver
		G	
		U	Tighten the plug and expand terminal
		RL	
Hold assembled unit	H	G	Insert G and G/W Wire through Tube 40
		A	
Push assembled unit forward	M	UD	Wait
	RL		

Table 4-7 Simo-Chart for WE 13

Work Station 6: WE 13			
Left Hand Activity	Therblig	Therblig	Right Hand Activity
Wait	UD	RE	Pull assembled unit toward
		G	
Hold assembled unit	H	G	Grab all wires facing upward
Grab Tube 66	RE	UD	Wait
	G		
Hold Tube 66	H	A	Insert all wires through Tube 66
Push assembled unit forward	M	UD	Wait
	RL		

Table 4-8 Simo-Chart for WE 14-15

Work Station 7: WE 14-15			
Left Hand Activity	Therblig	Therblig	Right Hand Activity
Wait	UD	RE	Pull assembled unit toward
		G	
Select R/L and G/Y Wire	SE	SE	Select R/L and G/Y Wire
Grab bushing	RE	H	Hold R/L and G/Y Wire
	G		
Insert bushing with R/L Wire	M		
	A		
Grab bushing	RE		
	G		
Insert bushing with G/Y Wire	M		
	A		
Bring assemble unit to crimping machine	M	M	Bring R/L and G/Y Wire under crimping machine
Crimping R/L and G/Y Wire	H	H	Crimping R/L and G/Y Wire
Inspect	I	I	Inspect
Put assembled unit on rack	M	UD	Wait
	RL		

Table 4-9 Simo-Chart for WE 16

Work Station 8: WE 16			
Left Hand Activity	Therblig	Therblig	Right Hand Activity
Wait	UD	RE	Pull assembled unit toward
		G	
Hold assembled unit	H	G	Grab all wires' terminals
Grab connector	RE	H	Hold all wires' terminals
	G		
Rub connector on silicon	M		
Hold connector	H	SE	Insert Wires with connector
		A	
		A	Press the lock of connector
Push assembled unit forward	M	UD	Wait
	RL		

Table 4-10 Simo-Chart for WE 17

Work Station 9: WE 17			
Left Hand Activity	Therblig	Therblig	Right Hand Activity
Wait	UD	RE	Pull assembled unit toward
		G	
Hold assembled unit	H	G	Move Tube 66 upward
		M	
		P	Position Taping area
		M	Rotate Tape around assembled unit
Press taping area	H	G	Move Tube 66 downward
		M	
Hold assembled unit	H	M	Rotate Tape around assembled unit
		G	Tear tape
		M	Grab ruler
		G	
		I	Measure tape length
		RE	Release Ruler
Push assembled unit forward	M	UD	Wait
	RL		

Table 4-11 Simo-Chart for WE 18

Work Station 10: WE 18			
Left Hand Activity	Therblig	Therblig	Right Hand Activity
Wait	UD	RE	Pull assembled unit toward
		G	
Hold assembled unit	H	G	Move Plug M-086 to the back
		M	
		P	Position Taping area
		A	Rotate Tape around assembled unit
Press taping area	H	G	Move Tube 40 upward
		M	
Hold assembled unit	H	A	Rotate Tape around assembled unit
		G	Tear tape
		M	Grab ruler
		G	
		I	Measure tape length
		RE	Release Ruler
Push assembled unit forward	M	UD	Wait
	RL		

Table 4-12 Simo-Chart for WE 19

<table>
<tr><th colspan="4">Work Station 11: WE 19</th></tr>
<tr><th>Left Hand Activity</th><th>Therblig</th><th>Therblig</th><th>Right Hand Activity</th></tr>
<tr><td rowspan="2">Wait</td><td rowspan="2">UD</td><td>RE</td><td rowspan="2">Pull assembled unit toward</td></tr>
<tr><td>G</td></tr>
<tr><td rowspan="5">Hold assembled unit</td><td rowspan="5">H</td><td>G</td><td rowspan="2">Grab 3 gaskets</td></tr>
<tr><td>M</td></tr>
<tr><td>A</td><td>Insert gaskets into Plug M-088</td></tr>
<tr><td>A</td><td>Insert gaskets into Plug M-079</td></tr>
<tr><td>A</td><td>Insert gaskets into Plug M-086</td></tr>
<tr><td rowspan="2">Push assembled unit forward</td><td>M</td><td rowspan="2">UD</td><td rowspan="2">Wait</td></tr>
<tr><td>RL</td></tr>
</table>

After all micro-motions of each WE has been recorded, the examination process follows where primary and secondary questions will be considered.

4.2 Examination

This section will examine 5 aspects of how activities are being done including purpose, place, sequence, person, and means. The ultimate goals of examination stage are to eliminate unnecessary actions, simplify, combine and rearrange activities in the most effective manner. The examine process neglect the consideration of person or as mentioned previously, human factor is neglected because every worker working on this assembly line has an experience of assembling for 5 years; thus, every one of them knows the basic concept of assembling cable parts and assumed to have equal amount of skills. In simplification, this section aims to make all unit motions of WEs more effective and efficient.

4.2.1 Examine Workstation 1 (WE 1-3)

Based on the Simo-Chart, the very first motion of right hand is reaching out to grab W/B Wire, but the left hand is waiting idly, hence the symbol 'D' indicating avoidable delay. Therefore, rather than working both hands on different materials at the same time, the time is delayed by 1.14 seconds. The first motion of left hand is grabbing Tube 85 which is independent of grabbing W/B Wire, so these motions can be done simultaneously.

In addition, based on the video and the time measured, the reaching of grabbing tube are done by fully extended arm; put simply, the location of tube's container is far from left hand as shown in Figure 4 20. This indicates that the location of the container is not effective and should be relocated or the tube should be grabbed by right hand due to closer distance, which will replace left hand activity by grabbing W/B Wire.

Figure 4-20 Reach for Tube 66

Furthermore, the micro-motion of passing W/B Wire from right hand to left hand in order to put the assembled unit onto the rack doesn't add any value to the product and should be considered as wasted action. The additional time from this action can be eliminated by initially holding the W/B Wire with left hand.

Moreover, every workstation that involves insertion between plugs and wires requires the action of reaching for screw driver. Since the size of the size driver is relatively small compared to hand, worker can hold the screw driver while assembling other parts. This will reduce the overall time of the process since most workstations involve grabbing a screw driver.

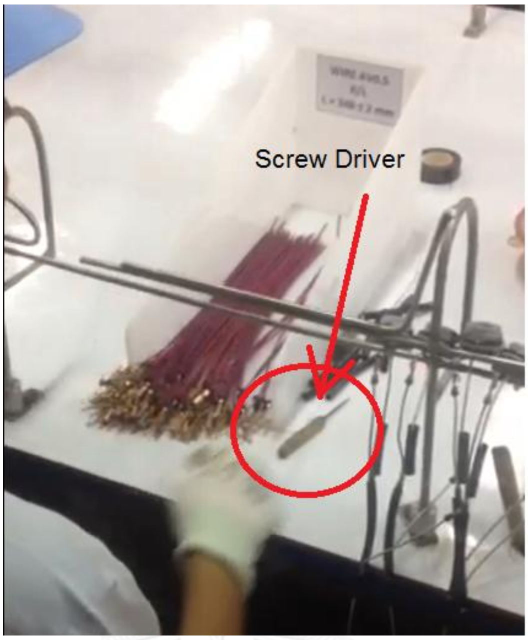


Figure 4-21 Worker reaching for screw driver

Another issue is the way W/B Wire is grabbed in the beginning. Sometimes when the worker reaches to grab W/B Wire with right hand, the wire is clustered together and it requires the aid from left hand to disintegrate them. W/B Wire is the main body of the cable which contains multiple terminals; therefore, it is easily to get clustered. This extends the assembly duration by about 3-4 seconds, so new technique is needed to reduce this ineffective action.

Finally, according to Therbligs symbol (Figure 2 7), symbol ‘P’ which represents position or orienting object is considered to be ineffective Therbligs. As a result, the act of positioning plug’s hole and wire’s terminal should be eliminated. However, symbol ‘H’ can’t be eliminated since one hand needs to be supporting the assembled unit for additional part assembling.

4.2.2 Examine Workstation 2 (WE 4-5)

Firstly, this workstation exhibits two times of grabbing screw driver for tightening the plug and expanding the terminal inside the plug; this wastes a lot of time compared to if screw driver was primarily held by the worker all the time. In addition, looking further down latter workstations, every insertion between wires and plugs requires the actions of terminal expansion inside the plug and tightening. Therefore, as these two are the purposes of grabbing a screw driver, grabbing screw driver should be viewed as one job by combining grabbing screw driver, tightening plugs, and expansion of terminals under one WE. This will definitely reduce time since not only grabbing of screw driver is eliminated, every individual action of tightening plugs and expansion of terminals at different workstations is reduced into one WE and should be performed with faster pace because one worker can perform this action rather than many workers from different workstations. The action of grabbing screw driver should be given to the worker who inserts the last plug to the assembly unit.

Furthermore, as mentioned in examine workstation 1, while inserting wires with the plugs, position action is witnessed yet should be avoided. In addition, similar to examine workstation 1, the first action of left hand could do something else rather than waiting. Rather than right hand pulling the assembled unit forward from the rack, left hand could do the work while right hand grabs components for assembly.

Occasionally worker experiences clustering of R/L Wire grabbing from the body of wire with right hand. The clustering occurs due to right hand grabbing the wire upward.

4.2.3 Examine Workstation 3 (WE 6-8)

While inserting G/Y wire and W/B wire into Plug M-079, 2 – 3 seconds is wasted on grabbing and releasing screw driver; the suggestion for improvement has already been discussed in examine workstation 2. In addition, plug should be prepositioned (Therbligs symbol ‘PP’) rather than position before inserting it with wire.

The first action of left hand is waiting but Therbligs symbol is ‘UD’, unavoidable delay, which is different from workstation 1 and 2 because following the action of pulling assembled unit forward, both right hand and left hand requires synchronised action of inserting Plug M-079 (grabbed by left hand) and G/Y Wire (grabbed by right hand).

Finally, the action of pulling assembled unit toward the worker could be rearranged and doesn’t have to start as the first action. This is because the actions that follow don’t require assembling onto the assembled unit. Pulling the assembled unit first only blocks the way that worker reaches for Plug M-079 and G/Y Wire as shown in Figure 4 22. It can be seen that the right hand has to go around the assembled unit that was previously pulled first; the action is not smooth. If Plug-M079 and G/Y Wire are to be reached and assembled first, right hand could simply grab G/Y Wire more easily followed by pulling the assembled unit forward.

Figure 4-22 Worker reaching for Plug M-079 and G/Y Wire

As illustrated in above figure, the way worker grasps G/Y Wire will require an upward motion, which could face wire clustering. Similar to workstation 2 while grabbing R/L wire, it would be more effective to pull G/Y Wire outward.

4.2.4 Examine Workstation 4 (WE 9-10)

Workstation 4 has minor issues which all have been discussed in previous workstations including elimination of grabbing screw driver, prepositioning rather than position of Plug M-086 for insertion, rearranging expansion of terminal at other workstation, and grabbing Tube 40 with left hand while right hand pull the assembled unit instead of waiting idly.

4.2.5 Examine Workstation 5 (WE 11-12)

Workstation 5 exhibits three issues that appear in other workstations including orientating Plug M-086 to insert with G Wire, rearranging expansion of terminal, and grabbing screw driver. Another issue arises is the position of wire supplies. Rather than facing the G Wire's and G/Y Wire's terminal head outward in perpendicular with the worker, it is placed in parallel (Figure 4 23); this creates difficulty for grabbing wires. Moreover, it would require arm extension to grab G/W Wire since it is located further behind the rack.

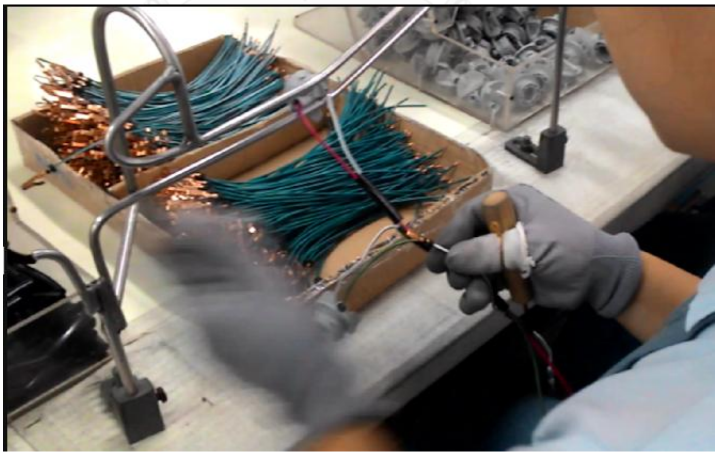


Figure 4-23 Position of G Wire and G/Y Wire

Moreover, the insertion of G Wire and G/Y Wire into Tube 40 requires quite an effort. This is because both end of G Wire and G/Y Wire are crimped with terminals; therefore, the action will require squeezing both wires through Tube 40 downward.

Figure 4-24 Downward Insertion of G Wire and G/Y Wire through Tube 40

4.2.6 Examine Workstation 6 (WE 13)

The only simplification that can be done on WE13 is the way all wires are inserted into Tube 66. On average, this action extends to more than 10 seconds. As a result, finding new ways to insert all wires into Tube 66 more efficiently will greatly behind the assembly time.

4.2.7 Examine Workstation 7 (WE 14-15)

The symbol ‘I’, inspect, is considered as ineffective Therbligs; however, it couldn’t be avoided for WE15, crimping terminal, because terminal is considered as the main function of the wire. If the wire is crimped wrongly, the entire cable will be a defect.

4.2.8 Examine Workstation 8 (WE 16)

WE16 is connecting all wires to connector while considering the colours of wires and connector's holes. There are five colours of wires (W/B, R/L, G/Y, G, and G/W) which are to be inserted according to specific holes of connector shown below. There are six holes, but only five holes to be inserted. This action requires a lot of searching of wires and positioning to match the wire with its location in connector. It is tedious when separation of colours is required. This WE should be disintegrated into simplest form where separation of colours is minimal; that is, wires should be inserted into connector whenever possible before more wires are added to the assembled unit to reduce confusion and searching for the right colour inserting to the right hole.

Moreover, worker claims that in the long run pressing the lock of the connector will cause the thumb to feel fatigue and pain since it requires some force of pressing. Therefore, tool could be used to help worker feel less fatigue at the thumb.

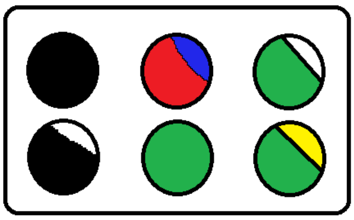


Figure 4-25 Position of Colours of Wires with Connector

4.2.9 Examine Workstation 9 and 10 (WE 17-18)

Workstation 9 and 10 are examined together since WE17 and WE18 are similar (taping). Workers responsible for taping are very experienced in this area because most of the car cables produced by the company require taping as well. Therefore, this action is knowledge based and is already efficient in term of personal skills. Thus, improving WE17 and WE18 is on additional action which is measuring tape length to fit to the requirement. Measuring tape length requires around 3-4 seconds duration while neglecting measuring tape length, other actions within WE17 and WE18 are about 13-14 seconds long; thus, there should be a more effective way to measure tape length. By simplifying WE17 and WE18, rather than grabbing ruler and measuring tape length, markings or positioning tape with respect to the assembled unit could reduce or even eliminate measurement action.

4.2.10 Examine Workstation 11 (WE 19)

The assembled unit arriving WE19 will have the connector facing upward hanging down from the rack while three plugs (M-088, M-079, and M-086) facing downward. The insertion of three gaskets into Plug M-088, M-079, and M-086 requires lifting of the plugs which are facing downward to face upward. However, from WE1 until WE18, there is no other activity being done on the plugs other than wire insertion into plugs' holes, so gaskets could be inserted to the plug in the first place before the cable is being assembled. It is expected to be even faster than 8-9 seconds if gasket is to be inserted to plug individually before the assembly.

4.2.11 Examine Actions between Workstations

As mentioned in the beginning of this section, actions between workstations (putting assembled unit onto rack, pulling assembled unit toward, and pushing assembled unit forward) are tracked with Simo-Chart. A graphical presentation of actions between workstations is shown below while collected data is shown in Appendix C3.

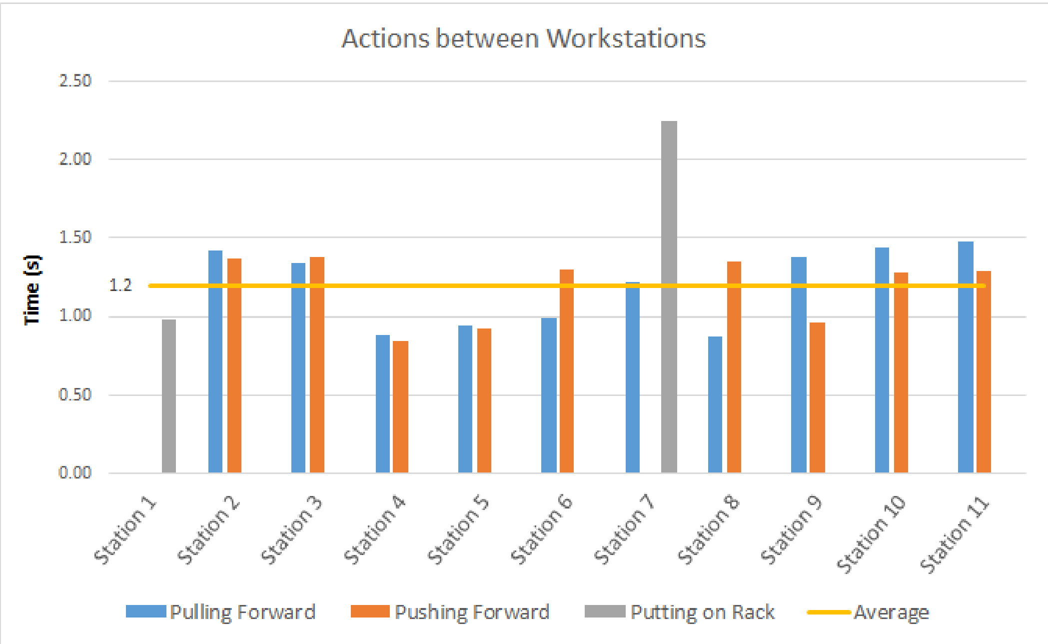


Figure 4-26 Actions between Workstations

It can be seen from above that the overall average time to transfer assembled unit from one station to another is approximately 1 second, except for station 7 where WE14 and WE15 are assigned. Putting assembled unit onto the rack took 2.24 seconds in station 7 which is very long compare to other workstations. This is because the worker has to extend the left arm to put assembled unit onto the rack since the rack is located further on the left side due to obstruction of crimping machine.

That aside, referring to the data collected, when assigning WEs to workstations, 1 second should be taken into account for actions of pulling cable toward and either putting cable onto rack or pushing cable forward, except for station 1 since the assembly starts here.

4.3 Development

After every WE is examined via micro-motions, new ways in doing certain WE is developed for faster assembly time. Old WEs have been re-studied, modified, and disintegrate into new WEs based on unit motion study obtained from Simo-Chart and examine stage.

Table 4-13 Old and New Work Elements

Old Work Elements		New Work Elements	
WE1	Assemble tube 85 with W/B wire	N1	Assemble Plug M-079, M-086, and M-088 with Gaskets
WE2	Assemble tube 40 with W/B wire	N2	Assemble tube 85 with W/B wire
WE3	Assemble W/B wire with Plug M-088	N3	Assemble tube 40 with W/B wire

WE4	Assemble R/L wire with Plug M-088	N4	Assemble W/B wire with Plug M-088
WE5	Assemble R/L wire with Tube 85 and Tube 40	N5	Assemble R/L wire with Plug M-088
WE6	Assemble G/Y wire with Plug M-079	N6	Assemble R/L wire with Tube 85 and Tube 40
WE7	Assemble W/B wire with Plug M-079	N7	Assemble G/Y wire with Plug M-079
WE8	Assemble G/Y wire with Tube 85	N8	Assemble W/B wire with Plug M-079
WE9	Assemble W/B wire with Tube 40	N9	Assemble G/Y wire with Tube 85
WE10	Assemble W/B wire with Plug M-086	N10	Assemble W/B wire with Tube 40
WE11	Assemble G wire and G/W wire with Plug M-086	N11	Assemble W/B wire with Plug M-086
WE12	Assemble G wire and G/W wire with Tube 40	N12	Assemble G wire with Plug M-086
WE13	Assemble all wires with Tube 66	N13	Assemble G/W wire with Plug M-086

WE14	Assemble bushing and G/Y and R/L wire	N14	Expansion of all terminals inside all plugs
WE15	Crimping terminal of G/Y and R/L wire	N15	Assemble G wire and G/W wire with Tube 40
WE16	Assemble connector to all wires	N16	Assemble all wires with Tube 66
WE17	Taping top part of cable (near connector)	N17	Assemble bushing with R/L wire
WE18	Taping bottom part of cable (further from connector)	N18	Assemble bushing with G/Y wire
WE19	Insert Gasket to Plug M-079, M-086, M-088	N19	Assemble Wires (W/B, G, G/W) with connector
		N20	Crimping terminal of G/Y and R/L wire
		N21	Assemble G/Y and R/L wire with connector
		N22	Taping top part of cable
		N23	Taping bottom part of cable

Note: the rest of the thesis refers abbreviated 'N' as the new work element

The develop stage transforms old WE and creates new WE shown below.

Table 4-14 Transformation of work elements

<table>
<tr><th>Old Work Elements</th><th></th><th>New Work Elements</th></tr>
<tr><td>WE19</td><td>→</td><td>N1</td></tr>
<tr><td>WE1</td><td>→</td><td>N2</td></tr>
<tr><td>WE2</td><td>→</td><td>N3</td></tr>
<tr><td>WE3</td><td>→</td><td>N4</td></tr>
<tr><td>WE4</td><td>→</td><td>N5</td></tr>
<tr><td>WE5</td><td>→</td><td>N6</td></tr>
<tr><td>WE6</td><td>→</td><td>N7</td></tr>
<tr><td>WE7</td><td>→</td><td>N8</td></tr>
<tr><td>WE8</td><td>→</td><td>N9</td></tr>
<tr><td>WE9</td><td>→</td><td>N10</td></tr>
<tr><td>WE10</td><td>→</td><td>N11</td></tr>
<tr><td rowspan="2">WE11</td><td rowspan="2">→</td><td>N12</td></tr>
<tr><td>N13</td></tr>
<tr><td>-</td><td>New</td><td>N14</td></tr>
<tr><td>WE12</td><td>→</td><td>N15</td></tr>
<tr><td>WE13</td><td>→</td><td>N16</td></tr>
<tr><td rowspan="2">WE14</td><td rowspan="2">→</td><td>N17</td></tr>
<tr><td>N18</td></tr>
<tr><td rowspan="2">WE16</td><td rowspan="2">→</td><td>N19</td></tr>
<tr><td>N21</td></tr>
<tr><td>WE15</td><td>→</td><td>N20</td></tr>
<tr><td>WE17</td><td>→</td><td>N22</td></tr>
<tr><td>WE18</td><td>→</td><td>N23</td></tr>
</table>

These new WEs corresponds to a modification of the old method based on examination from the process and micro-motions from Simo-Chart. Therefore, using the examination analysis, the development stage combines all aspects in all workstations discussed above and is divided into two parts: process development and micro-motion development.

4.3.1 Process Development

It is to be noted that the process development will not use jig or fixture for improvement, because jig or fixture, as mentioned in Chapter 2, is used for holding. As the cable runs along the rack, other components are added onto it; thus, rack itself is already acted as fixture. Before looking into micro-motions of each WE, compared to old work content which consists of 19 WEs, the new work content consists of 23 WEs. There are several modification and disintegrations of WE into smaller WEs for several reasons.

Firstly, the insertion of gaskets to plugs is rearranged from final step to the first step. This is because it is much easier to assemble gasket with plug individually before wires are connect to the plug. When plug is connected with wires and run along the metal rack, worker has to tilt downward-facing-plugs upward to insert gaskets, which isn't efficient. It is much faster to assemble gasket and plug separately from the cable before assembly. The action is shown in Figure 4-27.

Secondly, assembly of G Wire and G/W Wire with Plug M-086 has been disintegrated into two separate WEs. These two actions have been mistakenly combined into one WE because of the thought of assembling into the same plug at the same station. This also happens to assembly of bushing with R/L Wire and G/Y Wire; thus, these actions are divided into two separate WEs. The benefit in disintegrating WEs into smaller components will help in the process of assembly line balancing because rather than viewing these assembly process as one WE and exhibit long assembly time, breaking them down and dividing jobs into separate work stations can enhance line balancing.

Figure 4-27 Inserting Gasket Separately

Thirdly, connecting wires with connector is disintegrated into two WEs, Assemble W/B, G, and G/W Wire with connector and Assemble G/Y and R/L wire with connector. This is because, as discussed in previous section, connecting every wire with different colours to a specific holes of terminal requires quite an effort; not only there will be five wires of different colours of wire to be picked, there are five different positions of connector to be inserted as well. Assembling wires with connector whenever possible rather than waiting for all wires to be assembled with connector at once will reduce eye fatigue under one worker. It is easier to assemble three wires then two wires with connector than five wires just in one time. Therefore, Assemble W/B, G, and G/W Wire with connector is aimed to be done before crimping of R/L Wire and G/Y Wire, followed by Assemble G/Y and R/L wire with connector. It is very simple to pick W/B Wire, G Wire, and G/W Wire since they all have terminals connected while R/L Wire and G/Y Wire aren't as shown in Chapter 3.1 Materials and Product. Thus, the insertion of first three wires into connector can be sequenced as shown in Figure 4-28. W/B Wire will be inserted first followed by G Wire then G/W Wire. After these three wires are inserted, it is very simple to distinguish R/L Wire from G/Y and hence its corresponding hole in connector.

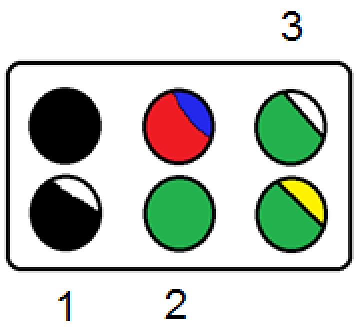


Figure 4-28 First Sequence for connecting wires with connector

Fourthly, locking the connector is now done by using tool (holder of screw driver) to decrease the fatigue in worker's thumb. Using the holder of screw driver to press the lock downward reduces the fatigue in thumb by altering exertion of force by the hand rather than the thumb, Figure 4-29.

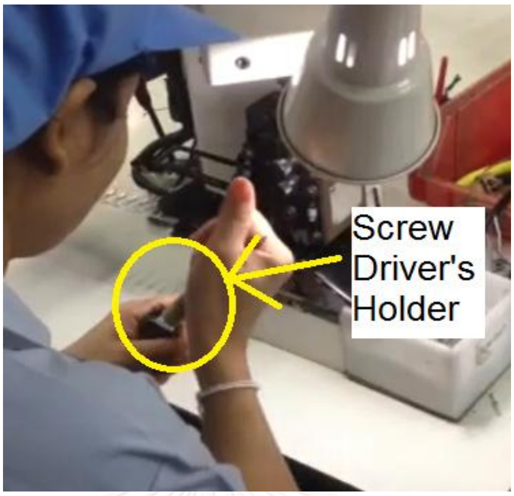


Figure 4-29 Locking Connector with Screw Driver's Holder

Fifthly, workstation where left hand is idle when right hand is pulling assembled unit from previous workstation will be reconfigured so that left hand is being productive, or vice versa. For example, for N5, when left hand is pulling assembled unit, right hand can grab R/L Wire; for N10, rather than left hand waiting for right hand to pull W/B Wire forward, left hand can grabbing Tube 40.

Sixthly, the orientation of wires should be in perpendicular to the worker rather than parallel to ease to motion of grabbing, Figure 4-30. For example, based on examine workstation 5, G Wire and G/W Wire should be aligned in perpendicular to the worker so that the worker wouldn't have to reach further to grab the wire.

Figure 4-30 Perpendicular Orientation of Wire

Seventhly, the rack besides crimping machine is too short when worker tries to load assembled unit onto it at N20. It should be extended for worker to load assembled unit onto rack more easily with left hand. Thus, reconstruction of rack length is assigned to engineering team.

Eighthly, expansion of terminal is created as a new WE because at every workstation that involves the insertion of wire into plug, wire terminal that is inside the plug has to be expanded for assurance that the cable will work once electricity runs through. Therefore, combining the actions of expansion of terminal at workstation 2, workstation 2, workstation 4, and workstation 5 will greatly reduce the time required to expand terminal because doing the same action under one workstation is logically faster than doing the same action at different workstations. However, as seen in Simo-Chart, tightening the plug is done sequentially with terminal expansion, but this action couldn't be separated as a new WE because it is mandatory to tightened plug after insertion so that the wire wouldn't fall off from the plug during assembly process. Conversely, terminal expansion can be done at the very end of the process since it is considered as quality assurance.

Lastly, WEs that involve wire insertion into plug requires the action of grabbing screw driver to fasten the plug. Looking at the size of the screw driver, workers can easily hold on to it with their little finger versus palm while assembling. As a result, the action of reaching to grab screw driver is eliminated since workers are prompted to use it once wire insertion is done.

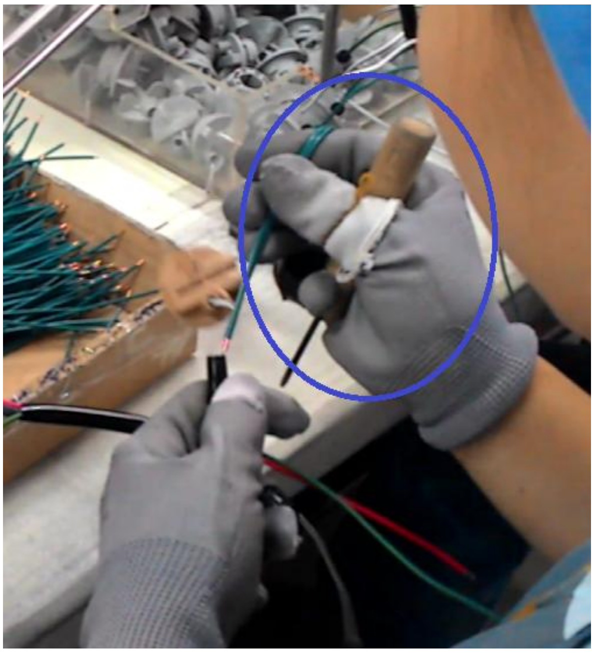


Figure 4-31 Holding Screw Driver while Assembling

4.3.2 Micro-motion Development

Micro-motion development is studying how to improve a specific assembly action to achieve faster time of completion. This process is done experimentally by brainstorming ways that an action can be done based on the examined stage on different workstations.

N2 (WE1): Assemble Tube 85 with W/B wire

As analysed in examine stage of workstation 1, the passing of assembled unit onto rack is done with left hand, thus, left hand should be holding the assembled unit while right hand should grab and assemble, so left hand will be holding W/B Wire while right hand will assemble Tube 85. Secondly, grabbing W/B Wire can sometimes face clustering of wires. The technique introduced is to grab W/B Wire with right hand at the terminal joint area, Figure 4-32, and using left hand to quickly pull W/B Wire upward. As this eliminates the time to disintegrate wire clustering, right and left hands can't grab W/B Wire and Tube 85 simultaneously because right hand requires helping left hand grab W/B Wire firstly. But right hand is still able to grab Tube 85 first then grab W/B Wire joint area. This is more effective than previous method because disintegrating wire clustering prolongs the process by 3-4 seconds while left hand will only be waiting idly for 1-2 seconds for right hand to grab Tube 85 and grab W/B Wire.

Figure 4-32 Grabbing W/B Wire

N4 (WE3): Assemble W/B Wire with Plug M-088

Based on examine workstation 1, before inserting W/B Wire with Plug M-088, worker has to position the plug to be ready for insertion. According to Therbligs, micro-motion desires preposition rather than position. Thus, a new way for which worker can preposition Plug M-088 is when the worker grab Plug M-088 at the orientation that is ready for W/B Wire to be inserted once the plug is brought near, Figure 4-33.

Figure 4-33 Preposition Plug M-088

N5 (WE4): Assemble R/L wire with Plug M-088

To avoid R/L Wire clustering, new grabbing method would be to grab the terminal of R/L wire and pull it outward (toward the worker), Figure 4-34, which would eliminate the tendency of wire clustering when grabbing wires upward.

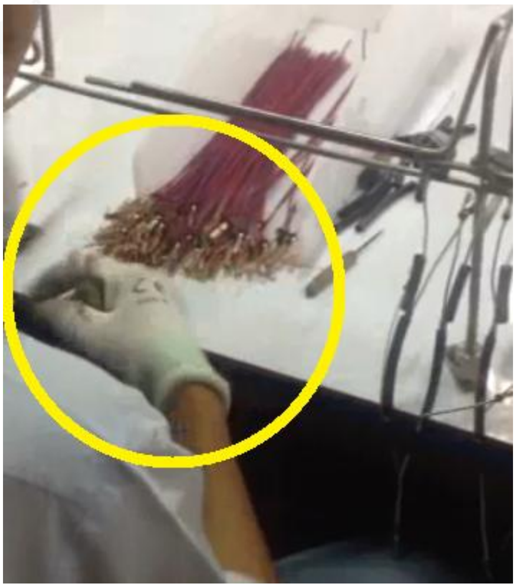


Figure 4-34 Pulling R/L Outward

N7 (WE6): Assemble G/Y wire with Plug M-079

Firstly, rather than grabbing Plug M-079 and position it to G/Y Wire, Plug M-079 should be preposition once it is grabbed, Figure 4-35. This eliminates the time to position Plug M-079. Moreover, G/Y Wire is inserted into Plug M-079 before the assembled unit is pulled forward for G/Y Wire and Plug M-079 to be added onto. This is to avoid the blockage of assembled unit when grabbing G/Y Wire with right hand, Figure 4-36. In addition, to avoid G/Y Wire clustering, the terminal of G/Y wire is pulled outward (toward the worker), which would eliminate the tendency of wire clustering when grabbing wires upward.

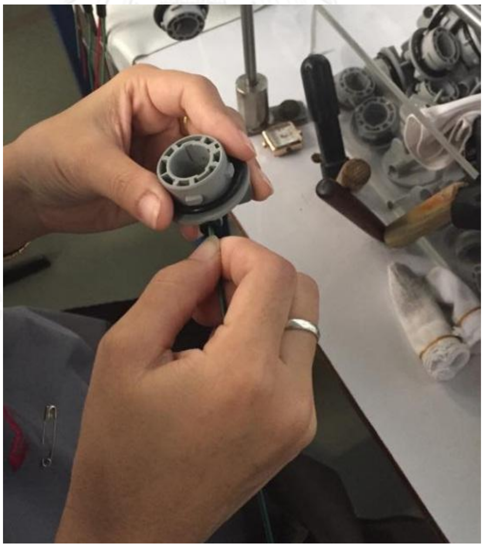


Figure 4-35 Preposition Plug M-079

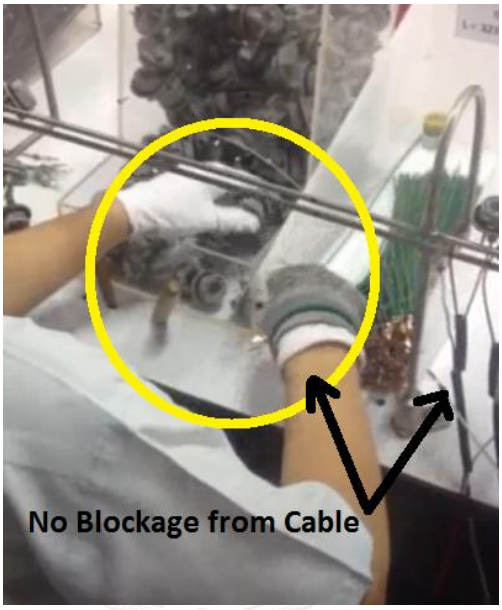


Figure 4-36 Insert before pulling Assembled Unit

N11 (WE10): Assemble W/B wire with Plug M-086

Plug M-086 will be prepositioned once it is grabbed (Figure 4-37) so the action of positioning to rotate Plug M-086 to fit W/B Wire is eliminated.

Figure 4-37 Preposition Plug M-086

N12 (WE11): Assemble G wire with Plug M-086

The first development is grabbing the wire outward to avoid wire clustering. The second development is the prepositioning of Plug M-086 to eliminate rotating the plug to fit with G Wire.

N13 (WE11): Assemble G/W wire with Plug M-086

The grabbing of G/W should be pulled outward to avoid wire clustering.

N15 (WE12): Assemble G wire and G/W wire with Tube 40

The easier way to assemble G Wire and G/W Wire into Tube 40 is inserting them upward simultaneously rather than squeezing them into Tube 40 downward, (Figure 4-38). This action can't be done effectively if wires are to be inserted through Tube 40 downward.

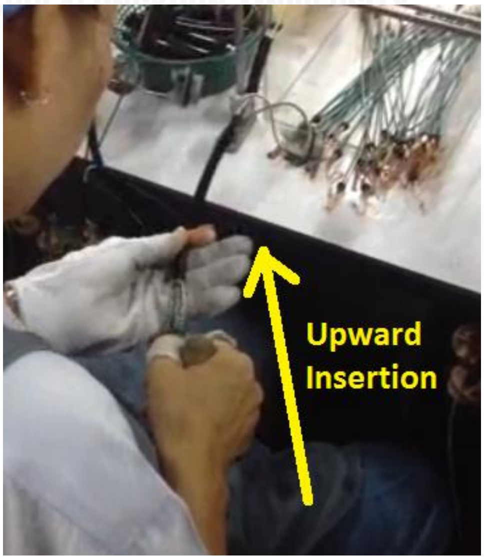


Figure 4-38 Insert G and G/W Wire Upward

N16 (WE13): Assemble all wires with Tube 66

Rather than inserting 5 wires through Tube 66 at the same time, the action is broken down into simpler method in which G Wire and G/W Wire are inserted first, followed by R/L, G/Y, and W/B Wire. This is because after N15, G Wire and G/W Wire will be facing upward while other wires are downward, and rather than squeezing every wire through Tube 66, G Wire and G/W Wire can be grabbed easily to be inserted first followed by other wires.

N22 (WE17): Taping top part of cable (Connector's end)

N23 (WE18): Taping bottom part of cable (Plugs' end)

Before examining N22 and N23, the requirement of taping has to be studied. According to the document, the required length of taping of top and bottom part of cable is shown below. The required length between connector and Tube66 is 40 mm (+10 mm and -0mm). The required length between Plug M-088 and Tube85 is 50 mm (+10 mm and -0mm). The required length of top and bottom parts is 30 mm (+10 mm and -0mm).

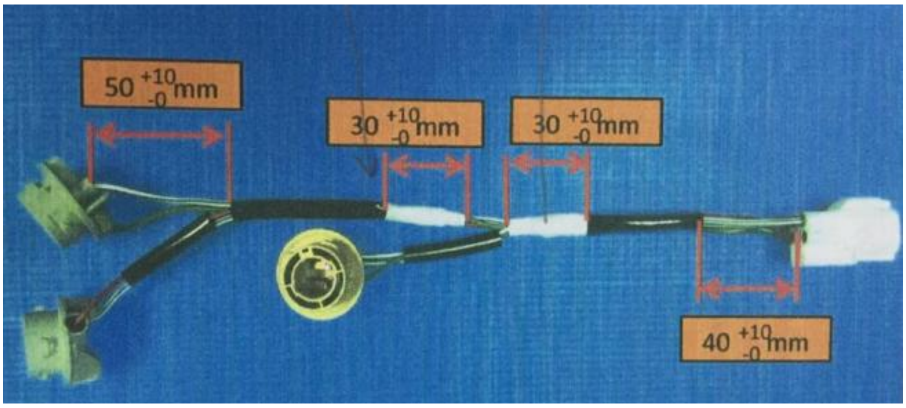


Figure 4-39 Required Length of Taping

The new technique that aims to assure all the required dimensions of tape length, distance of tube to connector, and distance of tube to plug shortens the assembly duration by eliminating all necessary measurement (grabbing ruler and measuring tape length).

For the top part, firstly, taping begins below the joint area of W/B Wire, Figure 4-40. Since the purpose of taping is to fasten tubes in place and the width of the tape is 2.0 cm, afterwards Tube66 is pulled downward half-way of the tape width, Figure 4-41. Theoretically, tape width will be 10 mm by now. Then, one round of taping is done around Tube66, Figure 4-42, in order to add 20 mm to 10 mm, resulting in 30 mm theoretically; and then multiple rounds are taped between Tube66 and the cable to fasten Tube66 in place, Figure 4-43.

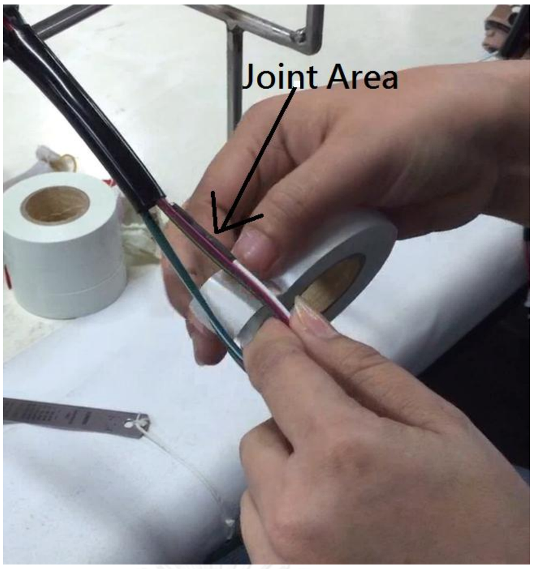


Figure 4-40 Taping below Joint Area of W/B Wire

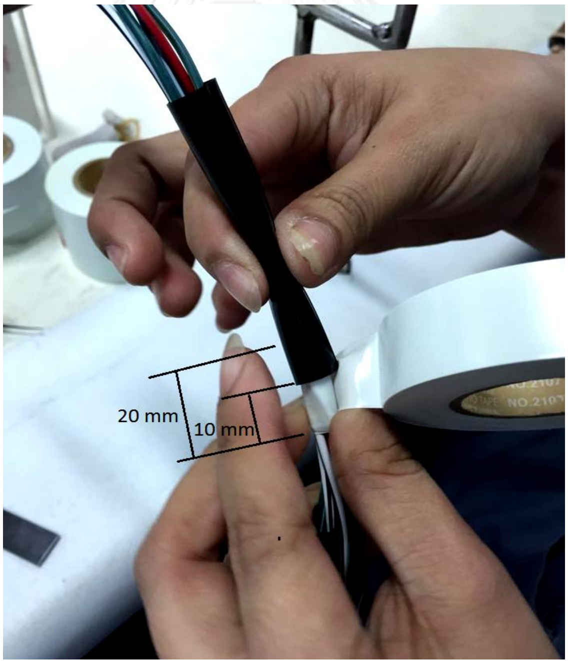


Figure 4-41 Tube66 pulled half-way of Tape Width

Figure 4-42 Taping around Tube66

Figure 4-43 Fasten Tube66

For the bottom part, firstly taping is done around the other side of W/B Wire, separated by one index finger (shown below).

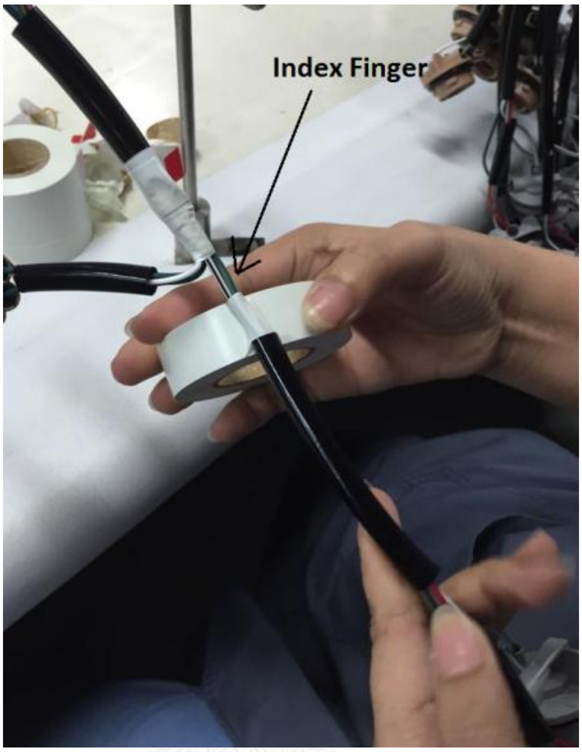


Figure 4-44 Taping Bottom Part, separated by index finger

Then Tube85 is pushed upward such that half of the tape width is presence (Figure 4-45). Afterwards, one round of taping is taped around Tube 85 to ensure at least 30 mm is achieved. Then, multiple rounds are taped around Tube85 and cable to fasten Tube85 in place (Figure 4-46).

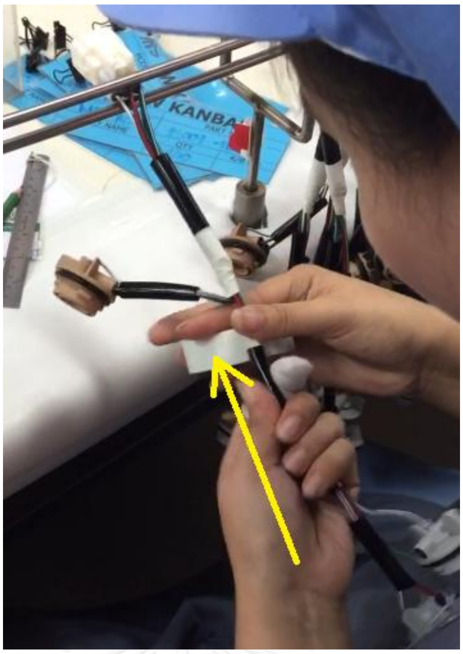


Figure 4-45 Tube 85 pushed upward

Figure 4-46 Tape around Tube 85 and Cable

4.4 Evaluation

Evaluating the proposed developments is done by time measurement of each WE and compared to original time of WE, Table 4-1. Table 4-15 shows the work element duration comparing old and new methods. The raw data for time measurement of new WEs is shown in Appendix C2. The improvement from method study has proven an average time reduction of 22 seconds, about 17% reductions or time being saved. While some WEs were not improved, most of the WEs were modified by either process development and/or micro-motion development. Not only the does the time of each WE is reduced, the degree of time fluctuation also decreased. Table 4-16 displays the comparison of standard deviation between old and new WEs within 20 trials. In other words, based on the numbers, the method is more standardised than before.

Moreover, as the actions between workstations are standardised to 1 second per transfer action, the time to transfer from one station to another is expected to decrease. The original transfer time for the task is 25.91 seconds, while the total transfer time for new workstations is expected to be lower and will be discussed in Chapter 5.

Table 4-15 Time Comparison between Old and New Work Elements

Old Work Element	New Work Element	Old Time Average	New Time Average	Improve	Description
WE19	N1	6.85	5.86	-0.99	faster
WE1	N2	6.03	4.96	-1.07	faster
WE2	N3	no improve			
WE3	N4	6.37	4.58	-1.79	faster
WE4	N5	6.75	6.21	-0.54	faster
WE5	N6	7.23	4.61	-2.63	faster
WE6	N7	5.72	5.01	-0.70	faster
WE7	N8	4.91	3.49	-1.41	faster
WE8	N9	no improve			
WE9	N10	no improve			
WE10	N11	6.47	4.38	-2.09	faster
WE11	N12	10.77	4.11	-2.75	faster
	N13		3.91		
New	N14		5.18		-
WE12	N15	4.18	3.14	-1.04	faster
WE13	N16	13.03	9.22	-3.81	faster
WE14	N17	no improve			
	N18				
WE16	N19	16.73	8.99	-1.77	faster
	N21		5.97		
WE15	N20	no improve			
WE17	N22	15.03	11.90	-3.13	faster
WE18	N23	14.93	11.76	-3.16	faster
Total Time		125.01	103.31	-21.70	

Table 4-16 Standard Deviation Comparison between Old and New Work Elements

Old Work Element	New Work Element	Old SD	New SD
WE19	N1	1.35	0.94
WE1	N2	1.09	0.85
WE2	N3		
WE3	N4	1.49	0.70
WE4	N5	1.16	0.59
WE5	N6	1.04	0.74
WE6	N7	0.86	0.76
WE7	N8	0.95	0.33
WE8	N9	1.42	0.34
WE9	N10		
WE10	N11		
WE11	N12	2.10	0.39
	N13		0.60
New	N14		0.55
WE12	N15	1.44	0.60
WE13	N16	2.02	1.40
WE14	N17		
	N18		
WE16	N19	2.31	0.89
	N21		0.89
WE15	N20		
WE17	N22	2.38	1.09
WE18	N23	2.85	1.73

Moreover, new taping technique is verified by comparing the requirements with 20 cables. The result is shown in Table 4-17. It can be seen that every single cable passes the length requirements. However, for safety and being cautious, 10 cables will be measured periodically every hour to ensure the requirements are met.

Table 4-17 Taping Technique Result

Criteria	Trials (Length Measured in mm)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Between Connector and Tube66	45	43	44	44	45	44	46	43	43	44	44	44	45	45	43	46	46	43	45	44
Between Plug M-088 and Tube 85	54	54	54	53	55	55	56	54	55	56	56	55	55	53	53	54	56	54	53	55
Top Part Tape	35	36	36	34	35	35	35	35	35	34	35	34	36	35	35	35	34	35	35	36
Bottom Part Tape	33	35	33	33	35	34	34	34	34	35	35	35	35	34	33	33	33	35	33	34

4.5 Defining

As suggested by Kanawaty (1992), after the affirmation of how each WE is done, a very simple written practice should be done for all workers to understand how this WE is done in the same manner and to follow as a standard method of assembly. However, the standard paper works related to this product acknowledged by the company are drawing of the product and process standard (Appendix D2). The process standard refers to steps in which WEs are sequenced, not micro-motions associated with each WE. Therefore, a new written description of how each WE is done is introduced as attached document with process standard. An example of a simple written practice proposed by Kanawaty is shown in Appendix D3. A written description is expressed in term of Simo-Chart and used as standardised process within the company.

Table 4-18 Standard Simo-Chart for WE

Standard Simo-Chart for Work Elements						
WE	Description	Left Hand Activity	Symbol		Symbol	Right Hand Activity
N1	Insert Gaskets	Grab Plug	H		G	Grab 3 gaskets
					M	
					A	Insert gaskets into Plug

N2	Assemble tube 85 with W/B wire	Grab W/B Wire	RE	RE	Grab Tube 85
			G	G	
		Hold W/B Wire	H	M	Insert Tube 85
				A	
N3	Assemble tube 40 with W/B wire			RE	Grab Tube 40
				G	
				M	Insert Tube 40
				A	
N4	Assemble W/B wire with Plug M-088	Hold W/B Wire	H	RE	Grab Plug M-088
				G	
				PP	
				M	Insert Plug M-088
				A	
N5	Assemble R/L wire with Plug M-088	Hold Plug M-088	H	G	Grab R/L Wire
				M	Insert R/L Wire into Plug M-088
				A	
N6	Assemble R/L wire with Tube 85 and Tube 40	Hole assembled unit	H	G	Grab R/L Wire
				A	Insert R/L Wire through Tube 85 and Tube 40
N7	Assemble G/Y wire with Plug M-079	Grab Plug M-079	RE	RE	Grab G/Y Wire
			G	G	
			PP	M	Insert G/Y Wire into Plug M-079
		Hold Plug M-079	H	A	
N8	Assemble W/B wire with Plug M-079			RE	Grab W/B Wire
				G	
				M	Insert W/B Wire into Plug M-079
				A	

N9	Assemble G/Y wire with Tube 85	Hold assembled unit	H	G	Insert G/Y Wire through Tube 85
				M	
				A	
N10	Assemble W/B wire with Tube 40	Grab Tube 40	RE	H	Hold W/B Wire
			G		
		Insert W/B Wire through Tube 40	M		
			A		
N11	Assemble W/B wire with Plug M-086	Grab Plug M-086	RE		
			G		
			PP		
		Hold Plug M-086	H	M	Insert W/B Wire into Plug M-086
				A	
N12	Assemble G wire with Plug M-086	Hold Plug M-086	H	RE	Grab G Wire
				G	
		Rotate Plug M-086	P	M	Insert G Wire into Plug M-086
		Hold Plug M-086	H	A	
N13	Assemble G/W wire with Plug M-086			RE	Grab G/W Wire
				G	
				M	Insert G/W Wire into Plug M-086
				A	
N14	Expansion of all terminals inside all plugs	Hold Plug M-086	H	RE	Grab screw driver
				G	
				U	Tighten the all plugs and all expand terminals
				RL	

<table>
<tr><td rowspan="2">N15</td><td rowspan="2">Assemble G wire and G/W wire with Tube 40</td><td rowspan="2">Hold assembled unit</td><td rowspan="2">H</td><td>G</td><td rowspan="2">Insert G and G/W Wire through Tube 40</td></tr>
<tr><td>A</td></tr>
<tr><td rowspan="5">N16</td><td rowspan="5">Assemble all wires with Tube 66</td><td rowspan="2">Grab Tube 66</td><td>RE</td><td rowspan="2">G</td><td rowspan="2">Grab G Wire and G/W Wire</td></tr>
<tr><td>G</td></tr>
<tr><td rowspan="3">Hold Tube 66</td><td rowspan="3">H</td><td>A</td><td>Insert G Wire and G/W Wire through Tube 66</td></tr>
<tr><td>G</td><td>Grab R/L Wire, G/Y Wire, and W/B Wire</td></tr>
<tr><td>A</td><td>Insert R/L, G/Y, and W/B through Tube 66</td></tr>
<tr><td rowspan="5">N17</td><td rowspan="5">Assemble bushing with R/L wire</td><td>Select R/L and G/Y Wire</td><td>SE</td><td>SE</td><td>Select R/L and G/Y Wire</td></tr>
<tr><td rowspan="2">Grab bushing</td><td>RE</td><td rowspan="8">H</td><td rowspan="8">Hold R/L and G/Y Wire</td></tr>
<tr><td>G</td></tr>
<tr><td rowspan="2">Insert bushing with R/L Wire</td><td>M</td></tr>
<tr><td>A</td></tr>
<tr><td rowspan="4">N18</td><td rowspan="4">Assemble bushing with G/Y wire</td><td rowspan="2">Grab bushing</td><td>RE</td></tr>
<tr><td>G</td></tr>
<tr><td rowspan="2">Insert bushing with G/Y Wire</td><td>M</td></tr>
<tr><td>A</td></tr>
</table>

N19	Assemble Wires (W/B, G, G/W) with connector	Wait	UD	SE	Select W/B , G , G/W Wire
		Grab Connector	RE	UD	Wait
			G		
		Rub Connector with Silicon	M		
		Hold connector	H	SE	Insert W/B, G, G/W Wire into Connector
				A	
N20	Crimping terminal of G/Y and R/L wire	Bring assemble unit to crimping machine	M	M	Bring R/L and G/Y Wire under crimping machine
		Crimping R/L and G/Y Wire	H	H	Crimping R/L and G/Y Wire
		Inspect	I	I	Inspect
N21	Assemble G/Y and R/L wire with connector	Wait	UD	SE	Select G/Y and R/L Wire
		Hold connector	H	SE	Insert G/Y and R/L Wire into Connector
				A	
				A	Press Lock of Connector

N22	Taping top part of cable	Hold assembled unit	H	G	Move Tube 66 upward
				M	
				P	Position Taping area
				A	Rotate Tape around assembled unit
		Press taping area	H	G	Move Tube 66 downward
				M	
		Hold assembled unit	H	A	Rotate Tape around assembled unit
				G	Tear tape
N23	Taping bottom part of cable	Hold assembled unit	H	G	Move Plug M-086 to the back
				M	
				P	Position Taping area
				A	Rotate Tape around assembled unit
		Press taping area	H	G	Move Tube 40 upward
				M	
		Hold assembled unit	H	A	Rotate Tape around assembled unit
				G	Tear tape

4.6 Installing

The installation has to happen after all analytical processes are completed including work measurement and assembly line balancing. Yet, the installation process should be done by managerial level to achieve effectiveness in workers' trustworthiness and gain complete acceptance of the method. Kanawaty divides install process into five stages:

1. Gaining acceptance of change by management
2. Gaining acceptance of change by department supervision
3. Gaining acceptance of the change by the workers and their representatives
4. Preparing to make the changes
5. Controlling the change-over

However, acceptance from workers is very easily achieved when the assembly time is reduced. The only challenge is for manager to initialise how the process should be done.

4.7 Maintaining

Similar to installation process, the maintaining process is will be done after assembly line balancing and work measurement because in order for the whole process to be evaluated, WE has to be assigned to workstations first then standardising the time. The basic procedure is evaluating performance once every two weeks for a period of two months for the method to stabilise. The evaluation is done in the manner of time measurement and method in performing each WE within a workstation. Takt time of the workstation determined in work measurement will be used as a controlling tool. Method in assembly will be compared to the Simo Chart produced in defined process. The recording form is shown in Appendix D4.

4.8 Summary of Method Study

In this chapter, the work of assembling cable is studied to determine the ineffective, unnecessary movements of body motions and materials in order to modify the method of assembly into a more productive, efficient process. Firstly, video recorder is used to record the time associated with body motions and material movements. The video is then analysed and transferred into individual WE as well as onto Simo-Chart where micro-motions are being studied. Following recording is examining stage. In this stage, WEs and work process are studied. The findings from examine stage suggest several ineffective movements such as idle left hand while right hand is in motion, extending arm to grab material, locating eyes on materials, and positioning material in right position before assembling. Combining all information obtained from examine stage, the develop stage improves the process by means of process development and micro-motion development. Process development improves the flow of assembly while micro-motion development improves left and right hand assembly techniques. Afterward, evaluation stage tests the validity of the improvements by timing each WE and compared with old data. It is clear from the comparison table that under the same activity, the developed method can be performed faster than old method. Once the method is valid, it should be defined to all workers on how each WE should be done on paper work; the method is presented in form of Simo-Chart. In order to install the process, it is the duty of higher ranking of manager level to initiate since acceptance from workers is extremely important for the method to work effectively. Finally, to maintain the process, a control plan is formed between production line and engineer to consistently record the performance of the assembly line.

Chapter 5. Phase III: Assembly Line Balancing

The improvements of assembly method of WEs have been discussed in previous chapter. In this chapter, WEs will be distributed into workstations such that the workloads are balanced throughout the assembly line, so there is no worker that is working too much or too less. As discussed in chapter 2, assembly line, there are several ways in which WEs can be divided into workstations.

The first step is to construct a precedence diagram. A precedence diagram displays the relationship between preceding WEs. The table below displays the precedence diagram followed by illustration of WEs relationship. WEs are going to be placed into workstations based on Largest Candidate Rule (LCR) and Rank Positional Weight Method (RPW), which have been discussed in Chapter 2 section 2. These two balancing methods will be compared in this chapter.

Before assigning WEs to workstations, some constraints and factors relating process flow have to be considered. Firstly, the similarity in shape and colour of plug M-088 and M-079 will cause problem if these two components were to be assembled in the same workstation or located near one another. As quoted by one of the workers: “there was a time when a cable requires plug M-088 and M-079, and they were assembled in different workstations but near one another; the problem was two workers responsible for the assembly of plug M-088 and M-079 messed up the plugs and the whole process had to stop and recheck for quality. The only difference between these two plugs is their teeth. The difference is shown in Figure 5-2.

Table 5-1 Work Elements Precedence Table

WE	Description	Time	Preceded by
N1	Assemble Plug M-079, M-086, and M-088 with Gaskets	5.86	-
N2	Assemble tube 85 with W/B wire	4.96	-
N3	Assemble tube 40 with W/B wire	3.20	2
N4	Assemble W/B wire with Plug M-088	4.58	1,3
N5	Assemble R/L wire with Plug M-088	6.21	4
N6	Assemble R/L wire with Tube 85 and Tube 40	4.61	5
N7	Assemble G/Y wire with Plug M-079	5.01	1
N8	Assemble W/B wire with Plug M-079	3.49	6,7
N9	Assemble G/Y wire with Tube 85	3.59	8
N10	Assemble W/B wire with Tube 40	4.51	9
N11	Assemble W/B wire with Plug M-086	4.38	1,10
N12	Assemble G wire with Plug M-086	4.11	11
N13	Assemble G/W wire with Plug M-086	3.91	11
N14	Expansion of all terminals inside all plugs	5.18	12,13
N15	Assemble G wire and G/W wire with Tube 40	3.14	12,13
N16	Assemble all wires with Tube 66	9.22	15
N17	Assemble bushing with R/L wire	3.50	16
N18	Assemble bushing with G/Y wire	3.42	16
N19	Assemble Wires (W/B, G, G/W) with connector	8.99	16
N20	Crimping terminal of G/Y and R/L wire	5.97	17,18,19
N21	Assemble G/Y and R/L wire with connector	4.93	20
N22	Taping top part of cable	11.90	21
N23	Taping bottom part of cable	11.76	22

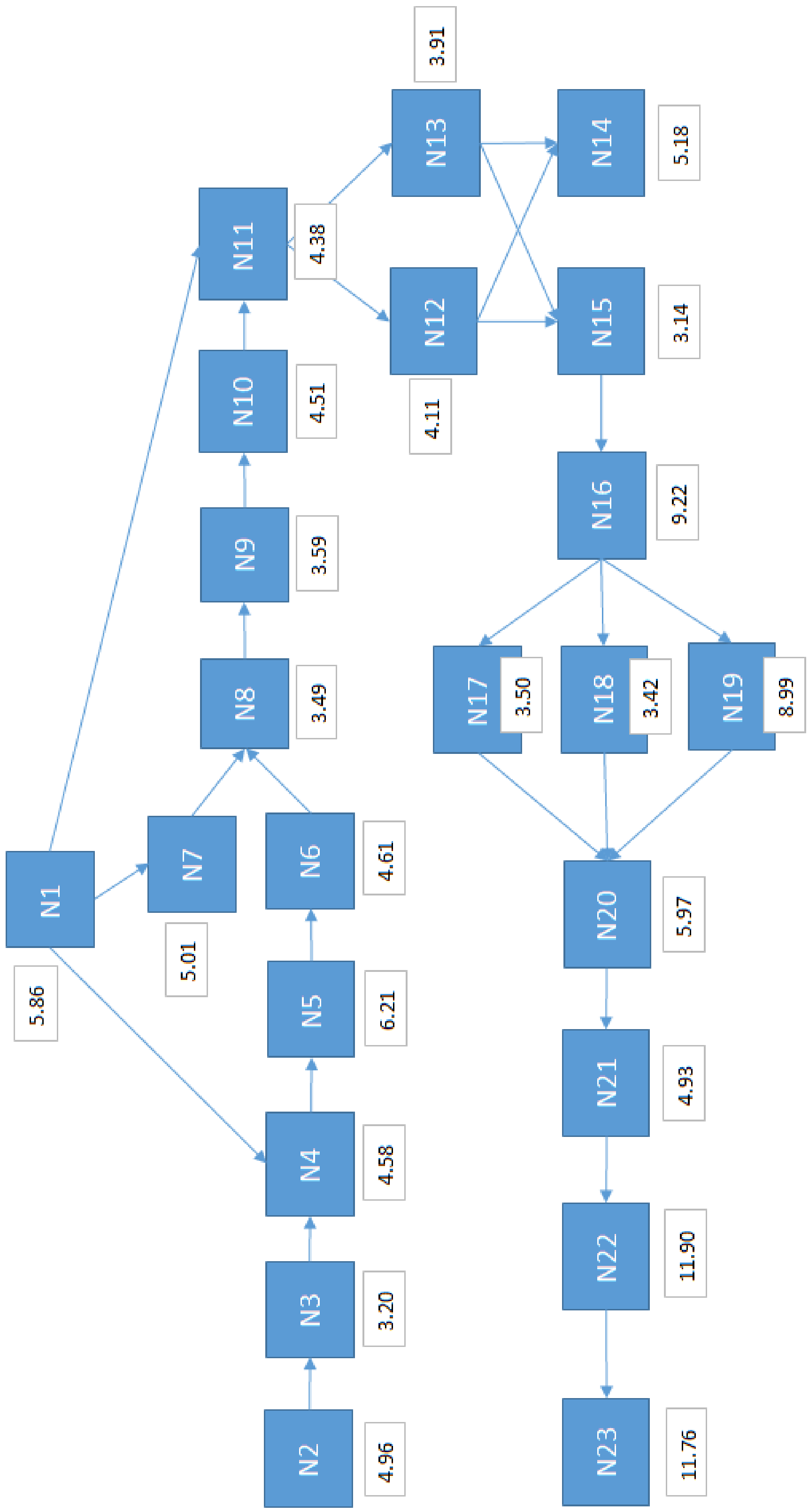


Figure 5-1 Precedence Diagram

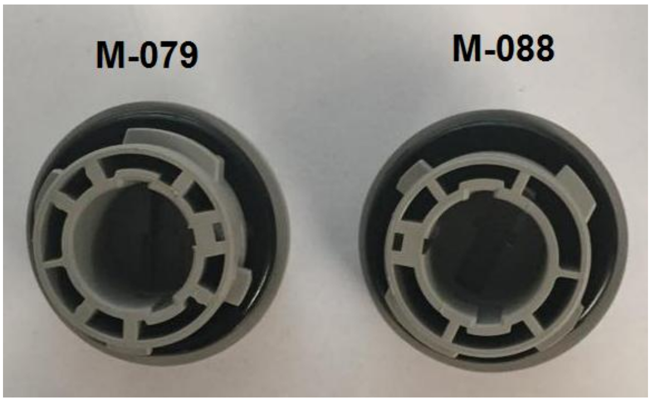


Figure 5-2 Difference between M-079 and M-088

Secondly, as agreed among engineers and manager based on new time measurement, inserting gaskets (N1) will be separated from the line due to two reasons: 1) the time to assembled three gaskets to three plugs took about 5-6 seconds. As there will be a total of three assembly lines in the final stage, only two assemblers are needed to match the takt time; that is, every 16.35 seconds there will be 2-3 cables produced, so 1-2 workers are suffice to produce at this rate as 1 worker takes only 15-18 seconds to assemble 3 gaskets. 2) The assembly doesn't need rack but rather replenishing supply for other WEs that need the plugs, so it is more effective for this WE to work on its on without the rack blocking while working; the plugs and gaskets are now considered as one components. Therefore, N1 will not be treated in the same manner as other WEs and while now it is considered as a part of the entire assembly line, it doesn't fall under assembly line balancing since it is a workstation already (Figure 5-3).

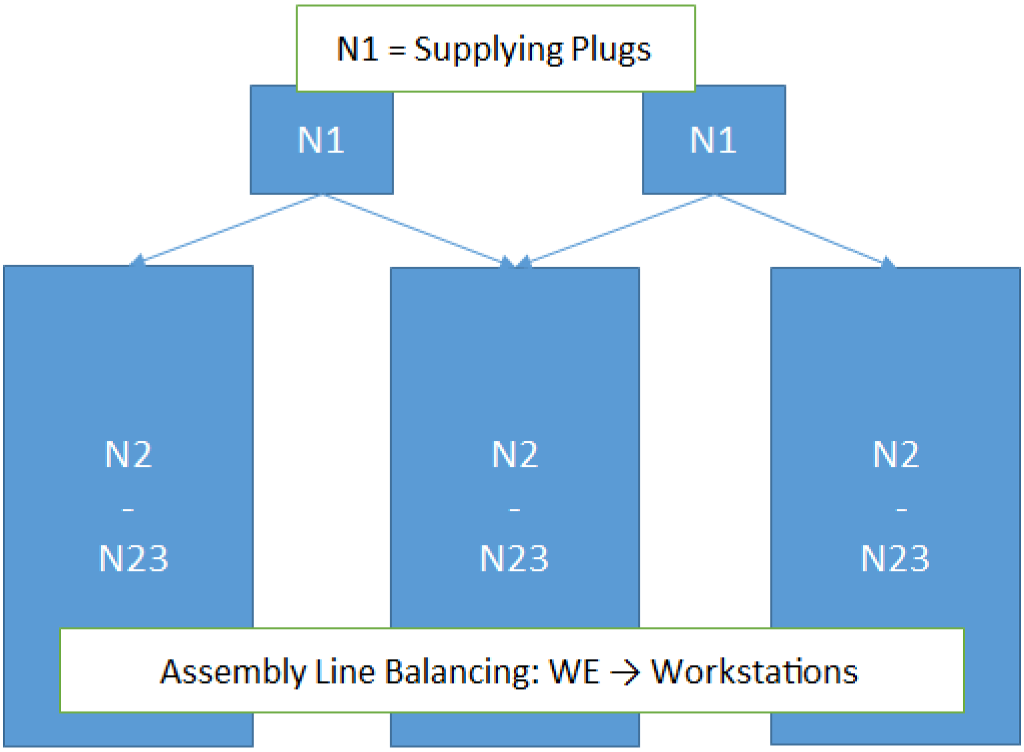


Figure 5-3 Proposed Idea of Assembly Line Balancing

The theoretical ideal number of workstations can be calculated from the equation:

$$Ideal\ Number\ of\ Workstations = \frac{WC}{T}$$

The work content (WC) of the assembly line can be found by summing every WE (except N1), resulting 120.6 seconds. The takt time (T) is already calculated in Chapter 1, 16.35 seconds. However, since the WEs obtained from Chapter 4 do not consider actions between workstations; the number needs to be readjusted. From Chapter 4.2 (Examine Actions between Workstations), the average time per action is 1.2 seconds. Therefore, since each workstation requires 2 out of 3 actions mentioned (pulling toward, pushing forward, and putting onto rack), each station will be added with 2.4 seconds (2 x 1.2 second) in addition to other WEs. Hence, rather than calculating the takt time to be 16.35 seconds, takt time in calculation will be equal to $16.35 - 2.4 = 13.95$.

$$Ideal\ Number\ of\ Workstations = \frac{120.6}{13.95} = 8.7 \approx 9\ workstations$$

However, this number is an ideal approximation, so it is considered as the minimum number of workstations required to allocate every WEs including actions between workstations, which will be a guided number when LCR and RPW method is applied.

5.1 Largest Candidate Rule (LCR)

Following the LCR method, the first step is to pick the most feasible WE; that is the WE with least constraint. The overall procedure of LCR will be demonstrated through table shown below. Based on the precedence table, the most feasible WE aside from N1 is N2.

Table 5-2 Steps of Largest Candidate Rule

Work Station	WE	Time	Remaining Unassigned Time	Feasible WEs	Feasible For Next Station
Station 1	-	13.95	13.95		
	N2	4.96	8.99	N3, N7	
	N3	3.20	5.78	N4, N7	
	N4	4.58	1.20	-	N5, N7

Station 2	-	13.95	13.95		
	N5	6.21	7.74	N6, N7	
	N6	4.61	3.13	-	N7
Station 3	-	13.95	13.95		
	N7	5.01	8.94	N8	
	N8	3.49	5.44	N9	
	N9	3.59	1.85	-	N10
Station 4	-	13.95	13.95		
	N10	4.51	9.44	N11	
	N11	4.38	5.06	N12, N13	
	N12	4.11	0.95	-	N13
Station 5	-	13.95	13.95		
	N13	3.91	10.04	N14, N15	
	N14	5.18	4.86	N15	
	N15	3.14	1.72	-	N16
Station 6	-	13.95	13.95		
	N16	9.22	4.73	N17, N18	
	N17	3.50	1.23	-	N18, N19

Station 7	-	13.95	13.95		
	N18	3.42	10.53	N19	
	N19	8.99	1.54	-	N20
Station 8	-	13.95	13.95		
	N20	5.97	7.98	N21	
	N21	4.93	3.04	-	N22
Station 9	-	13.95	13.95		
	N22	11.90	2.05	-	N23
Station 10	-	13.95	13.95		
	N23	11.76	2.19	-	-

After every work element has been assigned to each work station, the transfer time or actions between workstations will be incorporated. Two seconds will be added to every workstation while 1 second will be added to Station 1, because Station 1 only requires one action of putting assembled unit onto rack rather than pulling assembled unit toward and pushing assembled unit forward, or pulling assembled unit toward and putting assembled unit onto rack. The table below summarises the each station time including actions between workstations.

Table 5-3 New Workstation Time after applying LCR

Work station	WE Time	Transfer Time	Total Time
Station 1	12.75	1	13.75
Station 2	10.82	2	12.82
Station 3	12.10	2	14.10
Station 4	13.00	2	15.00
Station 5	12.23	2	14.23
Station 6	12.72	2	14.72
Station 7	12.41	2	14.41
Station 8	10.91	2	12.91
Station 9	11.90	2	13.90
Station 10	11.76	2	13.76

By comparing standard time of transferring assembled unit between workstations of new workstations with old workstations, the total transfer time for new workstations is 19 seconds while the old time is 25.91 seconds, which gives about 7 seconds reduction.

5.2 Rank Positional Weight Method (RPW)

Another method in balancing the line assembly is by rank positional weight method. While accounting for the precedence constraint and duration, the RPW value for each WE is calculated before assigning WEs to workstations. RPW value is obtained by summing all WEs time that precede the WE being calculated according to the precedence diagram. Using Figure 5-1, the following table displays the proceeding WEs as well as RPW value of a WE; keeping in mind that WE1 is neglected from assembly line balancing. The table is arranged from highest to lowest RPW value for ease of assigning WEs to workstations.

Table 5-4 RPW Value of Work Elements

WE	Description	Time	Preceded by	RPW Value
N2	Assemble tube 85 with W/B wire	4.96	-	115.04
N3	Assemble tube 40 with W/B wire	3.20	2	111.60
N4	Assemble W/B wire with Plug M-088	4.58	1,3	108.30
N5	Assemble R/L wire with Plug M-088	6.21	4	102.80
N7	Assemble G/Y wire with Plug M-079	5.01	1	96.49
N6	Assemble R/L wire with Tube 85 and Tube 40	4.61	5	96.21
N8	Assemble W/B wire with Plug M-079	3.49	6,7	91.48
N9	Assemble G/Y wire with Tube 85	3.59	8	87.98
N10	Assemble W/B wire with Tube 40	4.51	9	84.39
N11	Assemble W/B wire with Plug M-086	4.38	1,10	80.42
N12	Assemble G wire with Plug M-086	4.11	11	72.13
N13	Assemble G/W wire with Plug M-086	3.91	11	71.93
N15	Assemble G wire and G/W wire with Tube 40	3.14	12,13	62.83
N16	Assemble all wires with Tube 66	9.22	15	59.69
N19	Assemble Wires (W/B, G, G/W) with connector	8.99	16	43.56
N17	Assemble bushing with R/L wire	3.50	16	38.07
N18	Assemble bushing with G/Y wire	3.42	16	37.98
N20	Crimping terminal of G/Y and R/L wire	5.97	17,18,19	34.57
N21	Assemble G/Y and R/L wire with connector	4.93	20	28.59
N22	Taping top part of cable	11.90	21	23.66
N23	Taping bottom part of cable	11.76	22	11.76

After RPW value has been calculated, the procedure in assigning WEs is described in table below.

Table 5-5 Steps of Rank Positional Weight

Work Station	WE	Time	Remaining Time	Feasible WEs	Feasible For Next Station
Station 1	-	13.95	13.95		
	N2	4.96	8.99	N3	
	N3	3.20	5.78	N4	
	N4	4.58	1.20	-	N5, N7
Station 2	-	13.95	13.95		
	N5	6.21	7.74	N6, N7	
	N6	4.61	3.13	-	N7
Station 3	-	13.95	13.95		
	N7	5.01	8.94	N8	
	N8	3.49	5.44	N9	
	N9	3.59	1.85	-	N10
Station 4	-	13.95	13.95		
	N10	4.51	9.44	N11	
	N11	4.38	5.06	N12	
	N12	4.11	0.95	-	N13
Station 5	-	13.95	13.95		
	N13	3.91	10.04	N15	
	N15	3.14	6.90	N14	
	N14	5.18	1.72	-	N16
Station 6	-	13.95	13.95		
	N16	9.22	4.73	N17	
	N17	3.50	1.23	-	N18, N19

Station 7	-	13.95	13.95		
	N19	8.99	4.96	N18	
	N18	3.42	1.54	-	N20
Station 8	-	13.95	13.95		
	N20	5.97	7.98	N21	
	N21	4.93	3.04	-	N22
Station 9	-	13.95	13.95		
	N22	11.90	2.05	-	N23
Station 10	-	13.95	13.95		
	N23	11.76	2.19	-	-

The result from RPW method shows identical WEs allocation onto workstations with minor differences in the allocation sequence. For example, in Station 5, N14 is assigned before N15 by LCR method but after N15 by RPW method, yet both WEs are under the same workstation.

Table 5-6 New Workstations time after applying RPW

Work station	WE Time	Transfer Time	Total Time
Station 1	12.75	1	13.75
Station 2	10.82	2	12.82
Station 3	12.10	2	14.10
Station 4	13.00	2	15.00
Station 5	12.23	2	14.23
Station 6	12.72	2	14.72
Station 7	12.41	2	14.41
Station 8	10.91	2	12.91
Station 9	11.90	2	13.90
Station 10	11.76	2	13.76

From both methods, the assembly line can be shown graphically to see how balance it is (Figure 5-4).

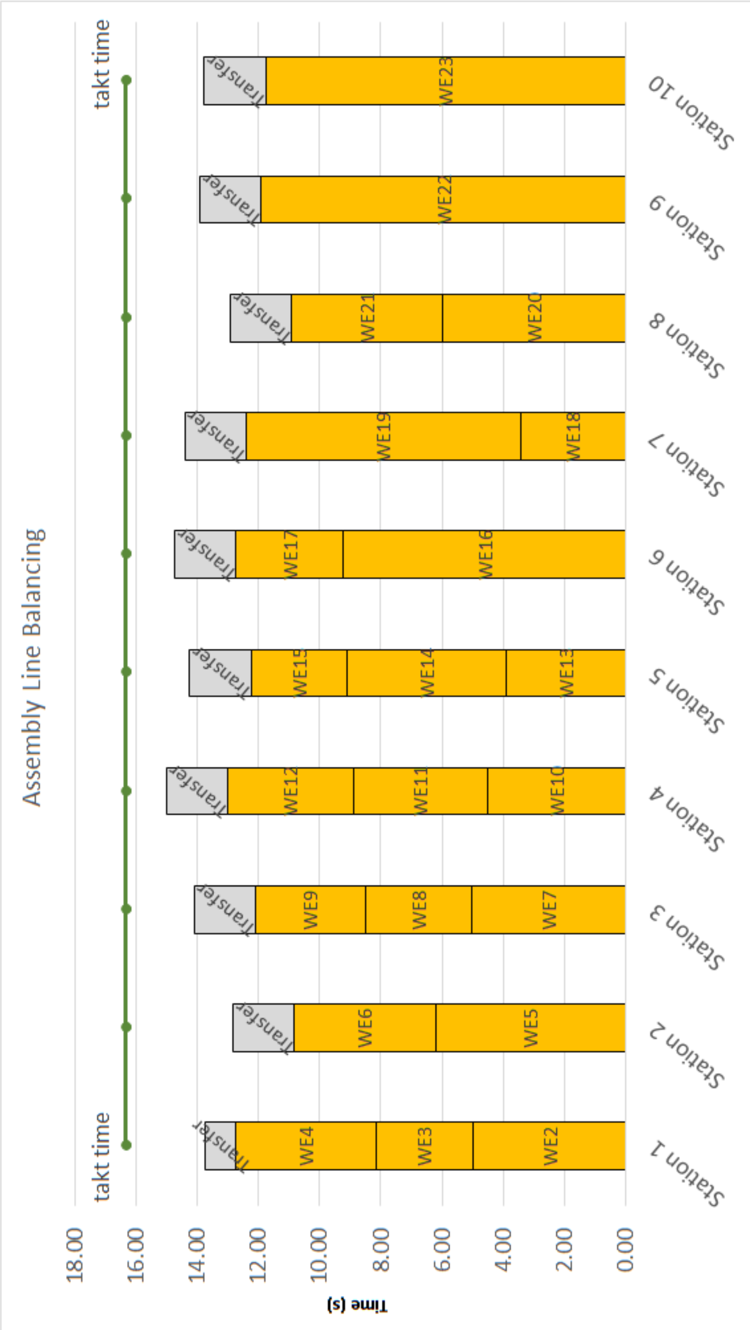


Figure 5-4 Graphical Representation of Assembly Line

Furthermore, the smoothness index can be recalculated to compare with the original value (13.39).

$$SI = \sqrt{\sum_{i=1}^{10}(15.00 - S_i)^2} = 3.91$$

It can be seen that there is a dramatic decrease in the smoothness index. The close the SI is to 0, the smoother the assembly line. Thus, this is a proof of successful implementation of method study and assembly line balancing by distributing equal amount of workloads to workstations.

5.3 Summary of Assembly Line Balancing

This chapter applies two methods of assembly line balancing namely LCR and RPW to assign WEs to individual workstations by means of theoretical work elements allocation according to individual work element's time. A precedence table and diagram are constructed before these two methods are applied. Furthermore, additional constraints are determined such as the similarity in shapes and colours of plug M-088 and M-079 as well as disregarding WE1 in assembly line balancing since it has become the supplying role rather than assembling role due to several reasons as discussed. Afterwards, steps of LCR and RPW are described and surprising reached the same solution in how WEs are assigned to workstations. It should be noted that LCR and RPW methods are different and not every time do they show the same result. However, they exhibit similarities and differences for usage: since RPW is an updated version of LCR, RPW will be more accurate and reliable, yet, LCR is a simpler and faster method. However, both methods incorporate precedence constraints as well as work element's time, but LCR assigns work element according to its time whereas RPW assigns work element according to its RPW value. The result from assembly line balancing gives 10 workstations; therefore, there will be three lines of 10 workstations that work in single straight line. Considering the total amount of workers required for this assembly line will be 32 workers: 30 workers for three assembly lines plus two workers on N1. Compared to the originally planned assembly lines which require 33 workers, this assembly line reduces amount of worker by 1 as well as enhancing the production rate hence the productivity. Moreover, the workloads of workstations are more balanced compared to original assembly line with a dramatic reduction in smoothness index from 13.39 to 3.91.

Chapter 6. Phase IV: Work Measurement

After work elements have been fixed to workstation, the study time per workstation is to be determined. The objective of work measurement within is research to standardise assembly time required to finish a work by a qualify worker by applying time study. For work measurement, stop watch will be used to time the new method in controlled environment; that is the process is performed by skilled, experience and fixed workers. This part will use direct time study whereby timing of worker's performance on standardised method on each workstation. Under time study, performance rating will evaluate the worker's pace relative to standard performance to determine the standard time. Finally, the allowance time will be calculated into basic time to compute the standard time of the workstation as well as work regime.

6.1 Design for Experiment

As time study aims to determine two factors, performance rating and relaxation allowances time, the recording materials will be created separately to suit both purposes.

6.1.1 Performance Rating

The sheet is designed to determine performance rating which is given to assembly line supervisor to rate and record the duration at each workstation. The study will be done in various trials on different time of various days with each trial assembling 10 units for better accuracy in estimating time per unit. Performance rating record sheet is displayed in Appendix E1. The record is used by the assembly supervisor in the front line to record workstation individually, whereas the summary sheet is used by the author to gather all data concerning only the obtained basic time. The final basic time for a workstation is obtained by averaging basic time obtained individually from performance rating.

To quantify the rating accurately, the supervisor and author have come up with a table of rating criteria based on the standard experience his workers are performing and comparison with standardised methods performed in Chapter 4. The rating is separated in score interval of 5; the highest scale is 120 while the lowest scale is 80 by the assuming that anything with scale of 120 is ultimate performance and below 80 is considered intentional and no interest in working.

Scale	Description
120	Exceptionally fast performance is seen with intense effort and concentration to achieved high degree of coordinations. Worker is unlikely to keep this performance for long period of time.
115	Task is performed at extreme fast pace with coordinations above average worker. Worker shows extreme enthusiasm and energy in performance.
110	Worker is extremely active and performs according to standardised method with accuracy and quality. Worker shows high degree of coordinations and dexterity than averaged qualified worker
105	Worker is highly active and performs according to standardised method with accuracy and quality. Movements are faster and smoother than usual and no extra movement is seen
100	Worker is active and performs according to standardised method with accuracy and quality. Movements are smooth and working pace can be achieved by average worker
95	Worker shows steady and unhurried manner in performance while performing according to standard method. Though it looks slow, no extra movement is seen and no time is wasted intentionally on other actions.
90	Worker performs at a pace slower than average worker and shows slight deviation from standard method due to unnecessary actions. The spirit in working is slightly lacking causing coordinations to stumble slightly.
85	Worker lacks spirit and performs at an unusual slow pace. Actions are slightly uncoordinated.
80	Worker shows high deviation from standard method with several unnecessary movements. Coordinations are fumbling due to lack of energy in working.

Figure 6-1 Description in Scale of Rating

6.1.2 Relaxation Allowance Time

The objective of relaxation allowance time is to determine the degree necessary to consider personal activities and fatigue into standard time. There will be two methods in determining the relaxation allowance: ILO's and Williams's methods. For ILO's method, percentage of personal activities and fatigue will be determined experimentally and systematically respectively to obtain relaxation allowance time given by the equation below.

$$Relaxtion\ Allowance\ Time = Personal\ Activites + Fatigue + Variable\ Allowances$$

On the other hand, Williams's method is much simpler by using scoring table for allowance factors to obtain overall relaxation allowance since his method has already taken personal needs into account. Both methods will be scored by three people: production manager, production engineer, and assembly line supervisor. This is to get an overall average value for relaxation allowance.

ILO's Method

1. Personal Activities

   Defining personal needs is obtained by collecting how long personal activities are done during the whole day (8 am until 8 pm) in 5 days period. The data will collected on a designed sheet, Appendix E2, every time they leave the workstation for personal activities. The result will be used to determine the percentage of time needed for personal activities which will be further calculated into basic time to determine standard time. According to the equation below, the denominator represents the total working hour under experimentation.

$$\%\,Personal\ Activities = \frac{Time\ used\ for\ Personal\ Activities}{5\ days \times 11\ hr\ \times 60\ min}$$

2. Fatigue and Variable Allowances

Percentage of fatigue during operation is determined by scoring tables from comparative strain. The method has already been discussed in Chapter 2. The scores for each workstation are obtained by determining the severity of strains imposed on the worker, which further links to point allocation for each type of strains. The designed form for scoring ILO's strains is shown in Appendix E3.

Williams's Method

Williams's method is straightforward and doesn't require much of experimental data collection since fixed and variable allowances are calculated together, not separately as in ILO's method. Thus, only scoring sheet is designed, Appendix E4, for three people to score.

6.2 Data Collection

The data collection is divided into two parts: 1) performance rating 2) allowances time.

6.2.1 Performance Rating Data Collection

Raw data for performance rating for each workstation is shown in Appendix F1. The following assembly time is obtained from incorporating performance rating per trial. The basic time or standard time is then obtained from averaging the result of 20 trials.

Table 6-1 Performance Rating Summary Sheet

Performance Rating Summary Sheet										
Workstation / Trial	1	2	3	4	5	6	7	8	9	10
1	13.86	12.73	14.28	14.73	14.33	15.31	13.88	12.42	13.76	13.07
2	13.53	11.50	14.52	14.56	14.36	14.65	13.83	12.40	13.08	13.24
3	14.10	13.31	13.54	14.47	14.47	14.59	14.22	12.79	13.52	13.09
4	13.70	11.45	13.97	14.95	14.03	14.66	14.66	13.01	13.69	13.34
5	13.72	12.42	13.72	14.32	14.32	15.51	14.15	12.77	13.99	13.99
6	12.81	11.62	13.83	14.79	14.67	15.44	14.67	13.33	14.57	14.10
7	13.66	12.91	13.53	13.92	14.93	14.39	14.50	13.60	13.90	13.65
8	13.61	12.62	13.51	14.35	13.75	14.90	14.42	12.57	13.78	13.94
9	13.88	13.42	13.88	14.85	13.50	14.35	15.02	13.09	13.65	13.77
10	13.69	12.86	14.40	14.56	14.47	13.41	15.20	12.76	13.33	14.54
11	13.72	12.45	14.44	15.24	14.60	15.36	14.35	13.06	14.22	14.42
12	13.29	12.44	14.13	14.58	13.50	13.80	14.29	13.01	14.70	13.49
13	14.08	11.72	13.35	15.00	13.95	14.25	13.50	13.21	14.56	13.90
14	13.74	11.74	13.05	14.68	14.52	14.75	14.18	12.72	13.94	13.34
15	14.05	12.14	13.63	14.86	13.98	14.89	14.41	12.62	13.47	13.50
16	13.39	12.98	13.78	14.30	13.50	13.79	14.49	12.91	12.83	13.56
17	14.68	12.11	14.02	15.23	13.97	15.46	15.02	12.85	13.10	13.69
18	14.24	11.63	13.63	14.69	13.89	14.06	14.07	12.46	13.79	14.12
19	13.33	12.51	13.79	15.99	14.92	14.76	13.27	13.82	13.94	14.12
20	13.37	12.63	13.62	14.69	13.32	14.47	14.47	12.70	13.38	13.87
Total	274.45	247.18	276.62	294.76	282.95	292.80	286.58	258.09	275.19	274.74
Frequency	20	20	20	20	20	20	20	20	20	20
Average	13.72	12.36	13.83	14.74	14.15	14.64	14.33	12.90	13.76	13.74
Basic Time	13.72	12.36	13.83	14.74	14.15	14.64	14.33	12.90	13.76	13.74

6.2.2 Relaxation Allowance Time Data Collection

6.2.2.1 ILO's Method

<u>Personal Activities</u>

Raw data of personal activities within 5 days for each work station is shown in Appendix F2. The following table displays the summary of personal activities percentage compared to working hour. Therefore, personal activities are accounted for approximately 3% of the working hours.

Table 6-2 Personal Activities Summary Sheet

Personal Activities Summary Sheet within 5 days					
Workstation	Toilet	Water	Miscellaneous	Total	Percentage
1	41.8	16.2	42.99	100.99	3.1%
2	42.63	16.33	43.18	102.14	3.1%
3	42.6	19.96	33.82	96.38	2.9%
4	48.55	13.99	43.53	106.07	3.2%
5	47.63	23.78	28.95	100.36	3.0%
6	45.32	19.46	36.5	101.28	3.1%
7	32	27.61	47.72	107.33	3.3%
8	47.74	21.8	30.42	99.96	3.0%
9	37.79	20.83	34.48	93.1	2.8%
10	48.75	19.06	26.69	94.5	2.9%
Average	43.48	19.90	36.83	100.21	3.0%

<u>Fatigue allowances and Variable Allowances</u>

The percentage of the remaining allowance time is computed by ILO's method. It is obtained by letting production manager, production engineer, and assembly line supervisor to score based on ILO's criteria. The experiment is conducted such that no interaction is made during the scoring session in order to make the data not bias. The following summary is a collected data combined from three score sheets. Individual data is shown in Appendix F3.

Table 6-3 Summary of ILO's Method

Summary of ILO's Method										
Raters	Workstation									
	1	2	3	4	5	6	7	8	9	10
Production Manager	7%	7%	7%	7%	7%	7%	8%	8%	8%	8%
Production Engineer	7%	7%	7%	7%	7%	7%	9%	9%	9%	9%
Assembly Line Supervisor	6%	6%	6%	6%	6%	6%	7%	7%	7%	7%

According to the data collected, fatigue allowance and variable allowance is approximately 6% – 9%; combining with the percentage of personal activities (3%), the relaxation allowance time is 9% - 12%.

6.2.2.2 Williams's Method

Williams's Method is much straightforward and simple to obtain the relaxation allowance time. The following table summarises the relaxation allowance time from three scorers. Raw data is available in Appendix F4.

Table 6-4 Summary of Williams's Method

Summary of William's Method										
Scorer	Workstation									
	1	2	3	4	5	6	7	8	9	10
Production Manager	14%	14%	14%	14%	14%	14%	15%	15%	14%	14%
Production Engineer	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%
Assembly Line Supervisor	16%	16%	16%	16%	16%	16%	16%	16%	17%	17%
Average	15%	15%	15%	15%	15%	15%	16%	16%	16%	16%

6.3 Evaluation

It can be seen from the result that the relaxation time allowance is 15%-16%, which is slightly greater than using ILO's method. The main reason is because Williams's method puts great weight on standard fatigue, which is the fix allowance (personal need and fatigue) of 10%; but typical ILO's method only account fix allowance of 5%. Since this research applies onto cable parts assembly in which there is minimal amount of forces and tedious tasks required, the author and the other factory members believe that ILO's method is more appropriate choice to be used as relaxation allowance time in the range of 9%-11% as obtained from the result.

Once relaxation time is determined, the rest-pause regime for the assembly line. By using 9% - 12% of the relaxation time of the total working hour per day which is 660 minutes, the total rest pause regime will have to be between 59.4 minutes and 79.2 minutes. Therefore, for highest production per day, about 60 minutes of relaxation time is chosen. The finalised rest pause regime is shown below.

Table 6-5 Rest-Pause Regime

Time		Duration (min)	Activity
8:00	10:00	120	Work
10:00	10:10	10	Break
10:10	12:00	110	Work
12:00	13:00	60	Lunch
13:00	15:00	120	Work
15:00	15:10	10	Break
15:10	17:00	110	Work
17:00	17:30	30	Break
17:30	18:40	70	Work
18:40	18:50	10	Break
18:50	20:00	70	Work

6.4 Summary

The purpose of this chapter is to determine the standard time and the relaxation allowance time to compute into rest-pause regime. In determining the standard time, performance rating approach is used whereby each workstation is rated according to the perspective of the assembly line supervisor whether the rate of assembly is the same, above, or below standard in which the standard is scored as 100. Once every workstation performance rating is scored, the basic time is computed giving the result shown below. It can be seen that the maximum standard time is 14.74 seconds (workstation 4) which means that a cable will be produced every 14.74 seconds since it is the bottleneck.

Table 6-6 Workstation Standard Time

Workstation	Basic Time (Standard Time)
1	13.72
2	12.36
3	13.83
4	14.74
5	14.15
6	14.64
7	14.33
8	12.90
9	13.76
10	13.74

The next step is to determine the relaxation allowance time. Two methods have been used to compare the relaxation allowance time: ILO’s method and Williams’s method. Since relaxation allowance is composed of fix allowance (personal needs and fatigue) and variable allowance (environmental issues), it can be broken down into 3 parts: personal needs, fatigue, and variables. ILO’s methods enable the determination of fatigue and variables; therefore, experiment has to be done separately to determine the personal needs. The percentage of personal needs computed is 3% and using ILO’s method, fatigue and variables are 9%, giving the range between 9% and 12%. Conversely, Williams’s method results in relaxation allowance of 15% - 16%, which is greater compared to ILO’s method between Williams’s method places great concern to fatigue recovery (10%).

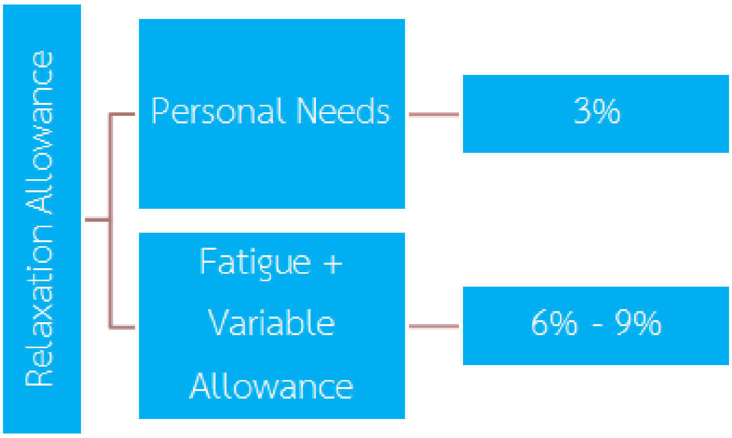


Figure 6-2 Summary of ILO's Method

Figure 6-3 Summary of Williams's Method

The factory chooses ILO’s method at 10% to create a rest-pause regime of 10 minutes break in the morning, 10 minutes in the afternoon, 30 minutes at 17:00 o’clock and 18:40 o’clock during overtime.

Chapter 7. Phase V: Conclusions and Recommendations

The purpose of this research is to establish a new cable assembly because the existing assembly line layout is not capable of producing the expected demand from customer. Two main methods are applied to set up a new cable assembly line: work study and assembly line balancing. Work study consists of two main parts: method study and work measurement. With this framework, this research is divided into four stages: 1) Define Phase, 2) Method study, 3) Assembly Line Balancing, and 4) Work measurement. In define phase, the materials, problems, measurements, and project team are defined. In method study, using the determined materials and problems, the prototype workstations and methods have been reconfigured into more effective and efficient method by reducing number of motions, distance of movements, and eye shift, and using best of both hands, and promoting natural movements. The result is a standardised method as well as associated work elements of the task. In assembly line balancing, utilising the standardised work elements from previous section, workloads are distributed systematically and equally into workstations in order that jobs are not overloaded to any worker. In work measurement, the basic time (standard time) of each work station is determined and work regime is formulated by applying time study. When all phases combined, a standardised assembly line is formed.

7.1 Conclusions

In define phase, after understanding the materials required and the product to be produced, it is found that the problem is old assembly capacity is unable to meet the demand per month, 160,000 cables for 22 days of daily order. With 11 hours of working time (overtime included) per day, this will result in 5.45 seconds required for one cable. Nonetheless, due to the constraint of working location, it is only possible to create 3 identical assembly lines, scoping the research down to one assembly line before duplicating the lines. Hence, the goal of this research is to establish a takt time of 16.35 seconds (5.45 x 3). Furthermore, project team consisting of factory manager, production manager, production engineer, and assembly line supervisor are gathered together to create an assembly line that can achieve 16.35 seconds.

In method study, there are 7 procedures to follow: record, examine, develop, evaluate, define, install, and maintain. In recording, stopwatch and video recorder are used to study micro-motions which are used to establish Simo-Chart. Within each work element, each micro action is recorded. In examine stage, work elements under prototype workstations are studied to determine which actions are ineffective, inefficient in order for them to be eliminated, simplified, rearranged, or combined. After 10 prototyped workstations have been examined, actions between workstation (transferring assembled united either by loading or unloading) are also studied. In develop stage, the improvements of the prototype workstations are divided into process development and micro-motion development. In process development, 23 work elements are formed, increased from 19 work elements; this is due to after analysing and simplifying elements can ease working process. In micro-motion development, actions within work elements are enhanced such that they can be performed at a faster rate. In evaluate stage, the proof shows an average time reduction of 22 seconds, about 17% reductions or time being saved. Not only the does the time of each WE is reduced, the degree of time fluctuation also decreased, so the method is more standardised than before. In defining stage, once the method is proven valid, paperwork is filed as Simo-Chart (Table 4-18) and Process standard (Appendix D2). For install and maintain stage, the actions can be done after an assembly line is formed.

In assembly line balancing, two methods, LCR and RPW, are applied to compare the differences of the result. Before applying these methods, precedence diagram is constructed showing the relationship between WEs including the time of each WE. In addition, several constraints are determined. Firstly, Plug M-088 and Plug M-079 can't be located in the same workstation due to minor difference in appearance. Secondly, N1 (inserting gaskets) is removed from assembly line balancing and will be supplied and done by other assembly line once gaskets are produced. For LCR method, using the algorithm by placing WEs into workstations based on precedence constraints, WE duration, transfer time and takt time, the result is shown below.

Work station	Total Time
Station 1	13.75
Station 2	12.82
Station 3	14.10
Station 4	15.00
Station 5	14.23
Station 6	14.72
Station 7	14.41
Station 8	12.91
Station 9	13.90
Station 10	13.76

Figure 7-1 Workstation Time for LCR Method

For RPW, it is more complicated than LCR method because RPW value has to be determined for each WE before allocating WEs into workstations. Once RPW value is determined, WEs are allocated according to the descending value of RPW. Surprisingly, the result is identical to LCR method. Furthermore, the smoothness index of the assembly line has reduced from 13.39 for prototype assembly line to 3.91 for new assembly line.

After method is standardised and workstations are established, in work measurement, the objective is to determine the standard time and work regime for workstations. Under the method of time study, performance rating will be used to determine standard time while relaxation time will be used to determine the work regime. The performance rating is rated by assembly line supervisor within 20 trials for 10 workstations, shown in Appendix F1, which calculates standard time according to performance rating; the overall standard time based on performance rating is averaged in Table 6-1. The result of performance rating is shown below.

Workstation	Standard Time
1	13.72
2	12.36
3	13.83
4	14.74
5	14.15
6	14.64
7	14.33
8	12.90
9	13.76
10	13.74

Figure 7-2 Workstation Standard Time

Determining the percentage of relaxation time applies ILO's method and Williams's method, which will be rated by production manager, production engineer, and assembly line supervisor. Since relaxation time is divided into 3 parts (personal activities, fatigue, and variable allowances), ILO's allowance conversion table covers only fatigue and variable allowances, so personal activities have to be determined experimentally. Conversely, Williams's method is used to determine relaxation time straightforward. For ILO's method, the percentage of personal activities is 3% of the working hours, and percentage of fatigue, variable allowances ranges from 6% to 9%; thus, the relaxation time for ILO's method is between 9% and 12%. For Williams's method, the percentage of relaxation time is 15%-16%. As evaluated, ILO's method is more appropriate and gives higher productivity, so relaxation time is chosen between 9% - 12% of the working hours (660 minutes) or 59.4 minutes – 79.2 minutes. Hence, 60 minutes is the time available for relaxation, giving the rest-pause regime as 10 minutes, 10 minutes, 30 minutes, and 10 minutes.

Finally, given that 600 minutes is remained as working hours and 60 minutes break and the bottleneck at workstation 4 with 14.74 seconds, an assembly line can achieved 2442 cables per day which is more than required at 2424 cables per day. Comparing to the old method which has a bottleneck is 18.83 seconds; the productivity within the same time frame is 1912 cables. The result is 27.7% increase in productivity.

$$New\ Method: Cables\ per\ day = \frac{600\ minutes\ \times 60\ seconds}{14.74\ seconds\ per\ cable} = 2442\ cables$$

$$Old\ Method: Cables\ per\ day = \frac{600\ minutes\ \times 60\ seconds}{18.83\ seconds\ per\ cable} = 1912\ cables$$

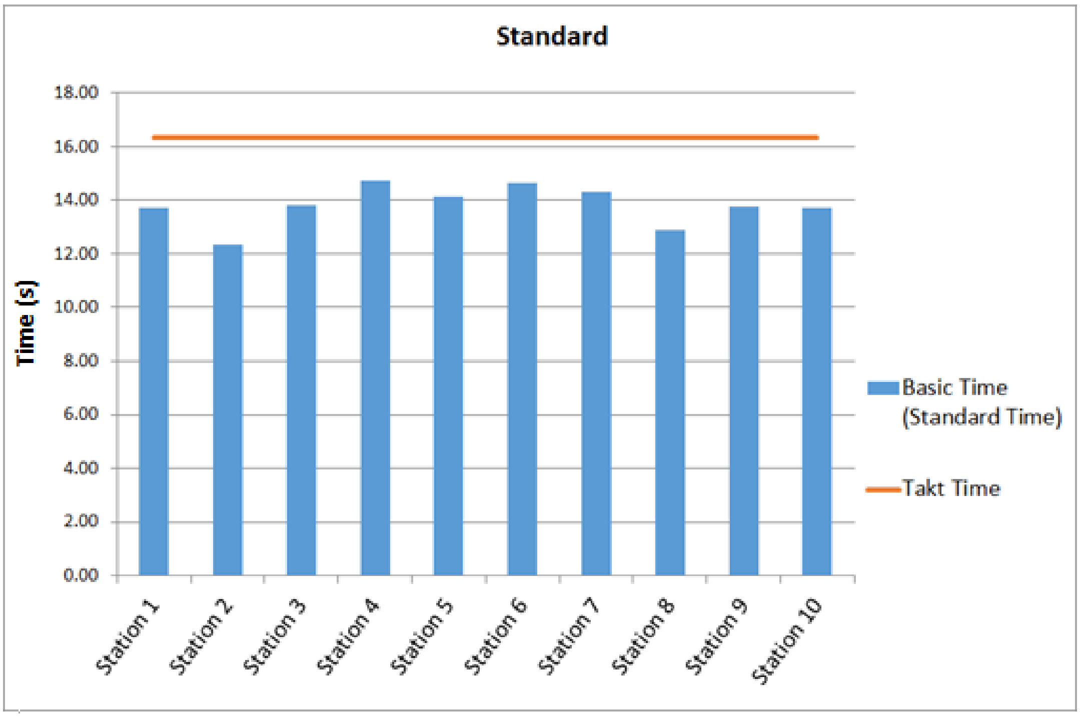


Figure 7-3 Workstation Standard time

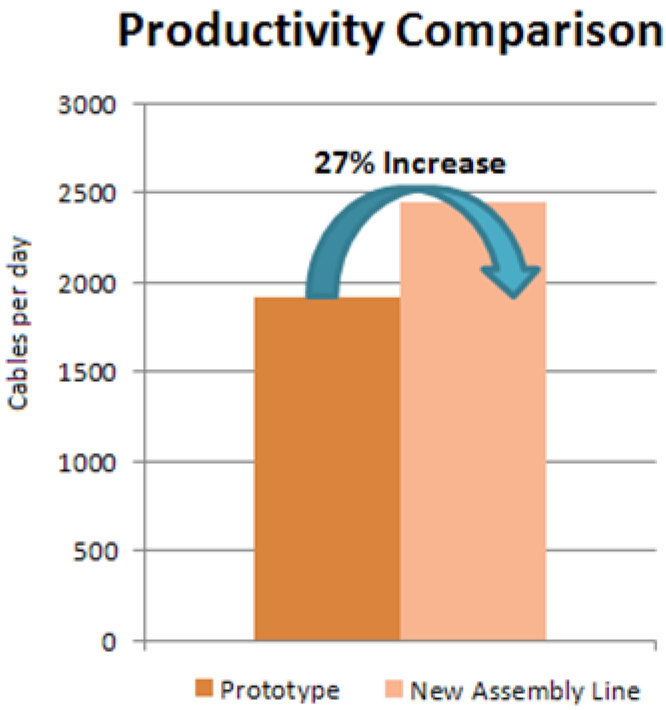


Figure 7-4 Productivity Comparison

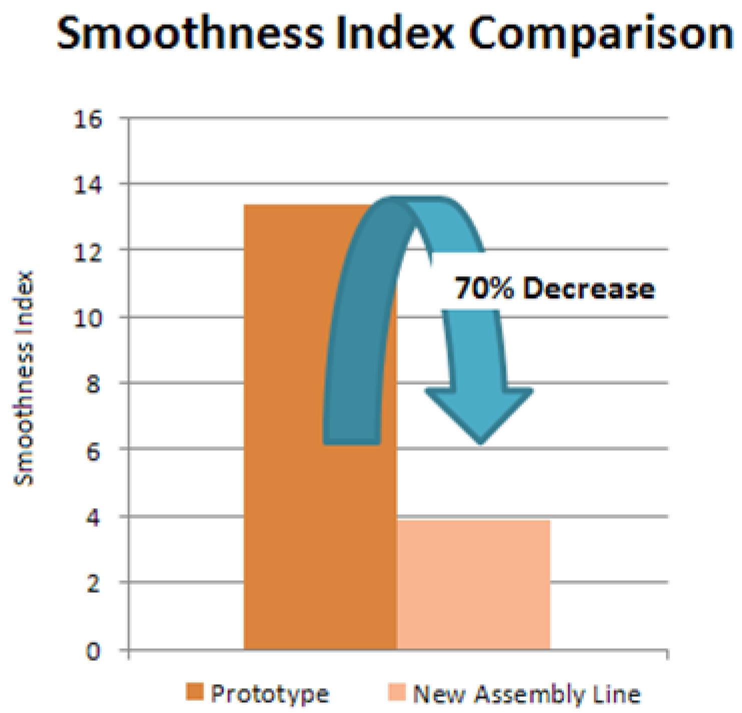


Figure 7-5 Smoothness Index Comparison

7.2 Limitations of Research

Since this research applies only in optimising one assembly line, there might be slight difference in time measurement when tripling the assembly line as planned because there is always difference in human capability even though every chosen worker has 5 years' experience. Furthermore, this research relies heavily on time measurement, so there is always human error in timing when starting and stopping the stopwatch. However, this is minimised by taking trials and calculating the average value.

7.3 Recommendations

This framework is a tedious task because it requires numerous time measurements in every stage. One must always keep in mind what is measured, what is the goal, what tools are used. One way to help keeping tracking of framework progress is a project chart, keeping it updated.

In setting up an assembly line, it is essential to determine who are involved in order to gain the most knowledge and expertise. Furthermore, method study aims to standardised working procedure based on micro-motions study; thus, it is essential for the team to understand tools that will be used in method study including Simo-Chart. In addition, brainstorming is important to drive the development stage of method study by eliminating unnecessary motions or simplifying assembly methods. It should be kept in mind that the objective is to standardise the method, rather than forcing the workers to perform faster or pressuring them, which will consequently have negative working atmosphere. One must be extremely careful when conducting time measurement in aware of the pressure on the worker. This is because in order to gain the most accurate data, worker must work under optimum and natural surrounding as close as possible.

In the next stage, the team must understand techniques and procedures related to LCR and RPW method. Furthermore, precedence diagram must be carefully constructed since it will affect overall line balancing.

In work measurement, this is when the time measurement requires extreme care not to pressure too hard on workers. The workers are realising that at this stage standard time is going to be determine. Workers can prolong the actions hoping to extend standard time; however, performance rating counters the effect. Thus, the scorers of performance rating must be carefully chosen and should be one who really understands how the workers perform at standard pace in normal day.

Lastly, three assembly lines can be studied in other ways. In this research, three assembly lines will operate independently with no crossing-over of materials. However, future study can be done if assembly lines are combined, materials are interchanged, or layouts differ from straight line to U-shape or other possible layouts.

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APPENDICES

Appendix A: Table used to calculate Allowance Time

Appendix A1 – Severity Allocation

Table I. Points allocated for various strains: Summary

Type of strain			Severity		
			Low	Medium	High
A.	*Physical strains resulting from nature of work*				
	1.	Average force exerted	0-85	0-113	0-149
	2.	Posture	0-5	6-11	12-16
	3.	Vibration	0-4	5-10	11-15
	4.	Short cycle	0-3	4-6	7-10
	5.	Restrictive clothing	0-4	5-12	13-20
B.	*Mental strains*				
	1.	Concentration/anxiety	0-4	5-10	11-16
	2.	Monotony	0-2	3-7	8-10
	3.	Eye strain	0-5	6-11	12-20
	4.	Noise	0-2	3-7	8-10
C.	*Physical or mental strains resulting from nature of working conditions*				
	1.	Temperature			
		Low humidity	0-5	6-11	12-16
		Medium humidity	0-5	6-14	15-26
		High humidity	0-6	7-17	18-36
	2.	Ventilation	0-3	4-9	10-15
	3.	Fumes	0-3	4-8	9-12
	4.	Dust	0-3	4-8	9-12
	5.	Dirt	0-2	3-6	7-10
	6.	Wet	0-2	3-6	7-10

Appendix A2 – Physical Strains

1. Average Force

lb.	0	1	2	3	4	5	6	7	8	9
0	0	0	0	0	3	6	7	8	9	10
10	11	12	13	14	14	15	16	16	17	18
20	19	19	20	21	22	22	23	23	24	25
30	26	26	27	27	28	28	29	30	31	31
40	32	32	33	34	34	35	35	36	36	37
50	38	38	39	39	40	41	41	42	42	43
60	43	43	44	44	45	46	46	47	47	48
70	48	49	50	50	50	51	51	52	52	53
80	54	54	54	55	55	56	56	57	58	58
90	58	59	59	60	60	60	61	62	62	63
100	63	63	64	65	65	66	66	66	67	67
110	68	68	68	69	69	70	71	71	71	72
120	72	73	73	73	74	74	75	75	76	76
130	77	77	77	78	78	78	79	80	80	81
140	81	82	82	82	83	83	84	84	84	85

2. Comparative Stain for Posture

	Points
Sitting easily	0
5itting awkwardly, or mixture of sitting and standing	2
5tanding or walking freely	4
Ascending or descending stairs unladen	5
5tanding or walking with a load	6
Climbing up or down ladders, or some bending, lifting, stretching or throwing	8
Awkward lifting, shovelling ballast to container	10
Constant bending, lifting, stretching or throwing	12
Coalmining with pickaxes, lying in a low seam	16

3. Comparative Strain for Vibration

	Points
Shovelling light materials	1
Power sewing-machine Power press or guillotine if operative is holding the material Cross-cut sawing	2
Shovelling ballast Portable power drill operated by one hand	4
Pickaxing	6
Power drill (two hands)	8
Road drill on concrete	15

4. Comparative Strain for Short Cycle

Average cycle time (centiminutes)	*Points*
16-17	1
15	2
13-14	3
12	4
10-11	5
8-9	6
7	7
6	8
5	9
Less than 5	10

5. Comparative Strain for Restrictive Clothing

	Points
Thin rubber (surgeon's) gloves	1
Household rubber gloves Rubber boots	2
Grinder's goggles	3
Industrial rubber or leather gloves	5
Face mask (e.g. for paint-spraying)	8
Asbestos suit or tarpaulin coat	15
Restrictive protective clothing and respirator	20

Appendix A3 – Mental Strain

1. Concentration / Anxiety

Job	Points
Routine simple assembly Shovelling ballast	0
Routine packing, labourer washing vehicles Wheeling trolley down clear gangway	1
Feed press tool; hand clear of press Topping up battery	2
Painting walls	3
Assembling small and simple batches, performed without much thinking Sewing-machine work, automatically guided	4
Assembling warehouse orders by trolley Simple inspection	5
Load/unload press tool, hand feed into machine Spray-painting metalwork	6
Adding up figures Inspecting detailed components	7
Buffing and polishing	8
Guiding work by hand on sewing-machine Packing assorted chocolates, memorizing pattern and selecting accordingly Assembly work too complex to become automatic Welding parts held in jig	10
Driving a motor bus in heavy traffic or fog Marking out in detail with high accuracy	15

2. Monotony

	Points
Two workers on jobbing work	0
Cleaning own shoes for half an hour on one's own	3
Operative on repetitive work Operative working alone on non-repetitive work	5
Routine inspection	6
Adding similar columns of figures	8
One operative working alone on highly repetitive work	11

3. Eye Strain

	Points
Normal factory work	0
Inspection of easily visible faults Sorting distinctively coloured articles by colour Factory work in poor lighting	2
Intermittent inspection for detailed faults Grading apples	4
Reading a newspaper in a motor bus	8
Arc-welding using mask Continuous visual inspection, e.g. cloth from a loom	10
Engraving using an eyeglass	14

4. Noise

	Points
Work in a quiet office, no distracting noise Light assembly factory	0
Work in a city office with continual traffic noise outside	1
Light machine shop Office or assembly shop where noise is a distraction	2
Woodworking machine shop	4
Operating steam hammer in forge	5
Rivetting in a shipyard	9
Road drilling	10

Appendix A4 – Nature of Working Conditions

1. Temperature

Humidity (%)	Temperature		
	20°C - 25°C	25 °C - 30 °C	30 °C - 35 °C
Up to 75	0	1-9	12-16
76-85	1-3	8-12	15-26
Over 85	4.6	12-17	20-36

2. Ventilation

	Points
Offices Factories with "office-type" conditions	0
Workshop with reasonable ventilation but some draught	1
Draughty workshops	3
Working in sewer	14

3. Fumes

	Points
Lathe turning with coolants	0
Emulsion paint Gas cutting Soldering with resin	1
Motor vehicle exhaust in small commercial garage	5
Cellulose painting	6
Moulder procuring metal and filling mould	10

4. Dust

	Points
Office Normal light assembly operations Press shop	0
Grinding or buffing operations with good extraction	1
Sawing wood	2
Emptying ashes	4
Linishing weld	6
Running coke from hoppers into skips or trucks	10
Unloading cement	11
Demolishing building	12

5. Dirt

	Points
Office work Normal assembly operations	0
Office duplicators	1
Refuse collection	2
Stripping internal combustion engine	4
Work under old motor vehicle	5
Unloading bags of cement	7
Coalminer Chimney-sweep with brushes	10

6. Wet

	Points
Normal factory operations	0
Outdoor workers, e.g. letter carrier	1
Working continuously in the damp	2
Rubbing down walls with wet pumice block	4
Continuous handling of wet articles	5
Laundry wash-house, wet work, steamy, floor running with water, hands wet	10

Appendix A5 – Points Conversion Table

Points	2	3	4	5	6	7	8	9	10	11
0	5%	5%	5%	5%	5%	5%	5%	6%	6%	6%
10	6%	6%	6%	6%	6%	7%	7%	7%	7%	7%
20	8%	8%	8%	8%	9%	9%	9%	9%	10%	10%
30	9%	11%	11%	11%	12%	12%	12%	13%	13%	13%
40	14%	14%	15%	15%	16%	16%	17%	17%	18%	18%
50	19%	19%	20%	21%	21%	22%	22%	23%	23%	24%

(Reference from Kanawaty's textbook)

Note: The table differs from Kanawaty since Kanawaty's table accounts for personal needs of 5%. Therefore, since the percentage of personal needs for this research is done experimentally, 5% is deducted from each cell of the table.

Appendix B: Crimped and Un-crimped Wire

The crimped wires are W/B, G, and G/W. The un-crimped wires are R/L and G/Y. The reason for which R/L and G/Y are un-crimped is because during the process of assembly, there will be one station which will be responsible for assembling all wires into Tube 66. Since Tube 66 has an inner diameter of 9 mm, it is impossible to insert all crimped wires into the tube, even considering inserting the Tube one by one. This is because the thickness of the Tube itself is 2 mm and the crimped head is about 4 mm. Therefore, if one wire is inserted, 7 mm is left. For the next wire, 2 mm inserted will leave 5 mm left. Then, if next wire is inserted, 3 mm is left. Unfortunately, 2 wires are left to be inserted. If both wires are crimped, 4 mm will not be enough to insert into 3 mm.

Furthermore, R/L and G/Y are chosen to be un-crimped wires because along with W/B, R/L and G/Y wires will have to pass through Tube 88, which has an inner diameter of 7 mm. Since W/B is crimped due to it is the main body, 5 mm will be left for R/L and G/Y to pass through. I would be difficult to insert both wires through a 5 mm hole if both are crimped. Thus, for ease of assembly, R/L and G/Y are un-crimped.

Appendix C: Data Collection for Modelled Assembly Line

Appendix C1 – Time Measurement for Modelled Assembly Line

Work Station	Work Element	Trial									
		1	2	3	4	5	6	7	8	9	10
1	1,2,3	17.68	16.55	16.29	17.32	16.42	16.28	16.61	16.82	16.77	16.62
2	4,5	16.83	15.66	15.78	16.12	15.04	16.92	15.33	16.12	16.34	15.40
3	6,7,8	17.43	16.88	17.21	16.34	16.59	16.01	16.20	16.38	17.12	16.48
4	9,10	14.78	13.78	12.63	12.91	14.89	12.50	12.00	13.24	14.22	12.58
5	11,12	16.39	17.55	17.01	16.25	17.88	17.91	16.51	17.13	17.35	16.77
6	13	15.10	15.88	16.01	14.43	14.79	16.32	14.52	15.67	15.34	14.87
7	14,15	15.46	16.12	15.01	15.04	16.23	16.00	15.65	15.89	15.66	15.40
8	16	19.10	17.88	17.50	19.10	18.55	19.66	19.98	18.60	18.55	19.34
9	17	18.40	17.37	17.45	16.78	17.57	18.55	18.88	17.40	17.85	18.33
10	18	17.33	16.56	16.20	17.91	16.02	16.45	17.15	16.79	17.22	16.38
11	19	9.45	8.67	8.56	8.24	9.21	9.41	7.88	8.78	8.34	9.20

Continue...

Work Station	Work Element	Trial										Average
		11	12	13	14	15	16	17	18	19	20	
1	1,2,3	17.72	16.81	16.01	17.22	16.68	15.95	16.78	16.93	17.02	16.29	16.74
2	4,5	16.86	15.91	15.51	16.03	15.28	16.58	15.48	16.23	16.59	15.09	15.96
3	6,7,8	17.46	17.15	16.92	16.25	16.86	15.69	16.36	16.49	17.38	16.15	16.67
4	9,10	14.81	14.00	12.42	12.84	15.13	12.25	12.12	13.33	14.43	12.33	13.36
5	11,12	16.42	17.83	16.72	16.16	18.17	17.55	16.68	17.24	17.61	16.43	17.08
6	13	15.13	16.13	15.74	14.35	15.03	15.99	14.67	15.77	15.57	14.57	15.29
7	14,15	15.49	16.38	14.75	14.96	16.49	15.68	15.81	16.00	15.89	15.09	15.65
8	16	19.14	18.17	17.20	18.99	18.85	19.27	20.18	18.72	18.83	18.95	18.83
9	17	18.44	17.65	17.15	16.69	17.85	18.18	19.07	17.52	18.12	17.96	17.86
10	18	17.36	16.82	15.92	17.81	16.28	16.12	17.32	16.90	17.48	16.05	16.80
11	19	9.47	8.81	8.41	8.19	9.36	9.22	7.96	8.84	8.47	9.02	8.77

Appendix C2 – Time Measurement for Original Work Elements

Old Work Element	Time for 10 Units									
	Trial									
	1	2	3	4	5	6	7	8	9	10
WE1	59.80	61.01	60.69	58.72	58.79	61.38	61.72	59.90	61.21	60.22
WE2	31.20	34.34	32.09	30.12	32.40	32.78	33.12	33.30	33.22	31.62
WE3	64.82	65.30	62.40	65.14	61.42	61.71	64.32	63.09	63.55	65.35
WE4	67.02	68.17	68.24	66.27	66.34	68.71	68.66	67.45	68.41	65.79
WE5	73.10	72.32	72.11	73.04	71.78	72.67	73.55	72.09	71.48	71.25
WE6	57.44	58.30	56.34	57.33	57.89	56.46	57.24	56.40	56.38	57.70
WE7	49.01	47.77	48.21	49.30	49.71	48.88	49.75	50.11	49.52	48.30
WE8	36.67	34.38	36.10	35.78	38.96	35.53	35.53	36.67	34.89	36.88
WE9	43.19	43.50	44.65	47.41	43.19	46.71	44.40	47.41	46.00	46.71
WE10	64.70	66.81	64.70	65.45	67.34	64.70	62.59	64.17	63.12	63.65
WE11	108.55	107.70	109.85	105.14	110.23	108.42	106.50	105.55	109.13	106.27
WE12	42.19	40.72	41.76	41.10	41.66	43.30	42.07	40.24	42.76	41.84
WE13	131.11	129.31	128.84	130.54	130.63	128.39	131.44	130.21	131.80	130.64
WE14	77.43	69.66	71.30	70.24	70.55	72.36	70.40	73.65	70.89	68.79
WE15	47.61	51.78	47.57	47.51	49.20	50.54	48.73	51.08	51.00	49.13
WE16	168.25	166.19	165.66	167.60	167.70	165.14	168.62	167.22	169.03	167.71
WE17	148.02	150.40	151.67	147.42	151.41	149.90	152.45	150.70	148.74	151.95
WE18	150.00	146.42	152.20	150.34	147.51	151.15	147.53	148.76	147.92	150.55
WE19	70.02	70.20	68.33	68.31	65.84	67.77	69.49	67.82	67.67	69.87

Continue…

Old Work Element	Time for 10 Units										Average	Time per 1 unit
	Trial											
	11	12	13	14	15	16	17	18	19	20		
WE1	58.68	60.53	61.82	59.54	59.45	61.04	60.63	59.06	62.41	60.33	60.35	6.03
WE2	30.06	33.83	33.25	30.96	33.10	32.43	32.01	32.41	34.46	31.74	32.42	3.24
WE3	63.58	64.77	63.59	66.07	62.12	61.36	63.17	62.19	64.82	65.47	63.71	6.37
WE4	65.94	67.70	69.34	67.07	66.98	68.38	67.61	66.63	69.57	65.90	67.51	6.75
WE5	71.14	71.49	74.05	74.51	72.94	72.08	71.70	70.63	73.51	71.44	72.34	7.23
WE6	56.29	57.80	57.47	58.19	58.58	56.12	56.16	55.55	57.56	57.82	57.15	5.72
WE7	47.81	47.27	49.39	50.20	50.44	48.52	48.61	49.19	50.79	48.42	49.06	4.91
WE8	35.52	33.91	37.24	36.63	39.68	35.19	34.47	35.80	36.06	37.00	36.14	3.61
WE9	41.83	42.92	46.04	48.50	44.01	46.28	43.10	46.32	47.49	46.85	45.32	4.53
WE10	63.65	66.34	65.75	66.25	68.00	64.38	61.64	63.39	64.19	63.75	64.73	6.47
WE11	107.10	107.09	111.33	106.18	111.12	107.98	105.17	104.51	110.67	106.41	107.74	10.77
WE12	40.27	39.91	43.68	42.53	42.81	42.72	40.26	38.83	44.79	42.03	41.77	4.18
WE13	127.95	127.98	131.96	132.90	132.52	127.46	128.46	127.85	135.13	130.96	130.30	13.03
WE14	67.42	68.80	73.35	71.76	71.77	71.74	68.49	72.08	73.03	68.99	71.14	7.11
WE15	46.46	51.25	48.72	48.37	49.91	50.18	47.63	50.16	52.28	49.25	49.42	4.94
WE16	164.64	164.68	169.21	170.29	169.85	164.08	165.23	164.53	172.83	168.07	167.33	16.73
WE17	144.70	148.97	155.06	149.90	153.44	148.89	149.25	148.17	152.24	152.29	150.28	15.03
WE18	146.56	144.99	155.68	152.93	149.54	150.11	144.34	146.20	151.48	150.90	149.26	14.93
WE19	68.14	69.40	70.17	69.69	66.92	67.22	67.73	66.44	69.60	70.06	68.53	6.85

Appendix C3 – Action between workstations

Action	Work Station	Trial																				Average
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Putting on Rack	1	0.97	0.98	0.99	0.97	0.97	1.00	0.98	1.00	0.96	0.97	1.01	1.01	0.98	0.98	0.98	0.98	0.98	0.99	0.96	0.96	0.98
	7	2.24	2.21	2.33	2.35	2.22	2.20	2.24	2.15	2.17	2.18	2.25	2.36	2.34	2.30	2.26	2.27	2.32	2.13	2.14	2.16	2.24
Pulling Toward	2	1.40	1.42	1.43	1.41	1.40	1.44	1.41	1.44	1.39	1.39	1.46	1.46	1.42	1.42	1.41	1.41	1.42	1.43	1.38	1.38	1.42
	3	1.33	1.36	1.37	1.33	1.32	1.30	1.32	1.34	1.34	1.38	1.36	1.35	1.32	1.31	1.32	1.36	1.34	1.34	1.31	1.37	1.34
	4	0.88	0.89	0.91	0.92	0.93	0.86	0.84	0.84	0.85	0.91	0.90	0.92	0.91	0.92	0.87	0.90	0.89	0.91	0.85	0.84	0.89
	5	0.93	0.94	0.96	0.98	0.98	0.91	0.88	0.89	0.90	0.96	0.95	0.97	0.96	0.97	0.92	0.95	0.94	0.96	0.90	0.89	0.94
	6	0.99	1.02	1.03	1.04	0.98	0.97	0.99	0.95	0.96	0.97	0.99	1.04	1.03	1.01	1.00	1.00	1.02	0.94	0.95	0.96	0.99
	7	1.22	1.26	1.27	1.28	1.21	1.20	1.22	1.17	1.18	1.19	1.23	1.29	1.27	1.25	1.23	1.24	1.26	1.16	1.17	1.18	1.22
	8	0.87	0.88	0.90	0.91	0.92	0.85	0.83	0.83	0.84	0.90	0.89	0.91	0.90	0.90	0.86	0.89	0.88	0.90	0.84	0.84	0.88
	9	1.38	1.42	1.44	1.45	1.37	1.35	1.38	1.32	1.34	1.35	1.39	1.46	1.44	1.41	1.39	1.40	1.43	1.31	1.32	1.33	1.38
	10	1.44	1.48	1.50	1.51	1.43	1.41	1.44	1.38	1.40	1.40	1.45	1.52	1.50	1.48	1.45	1.46	1.49	1.37	1.38	1.39	1.44
	11	1.47	1.48	1.51	1.54	1.55	1.43	1.40	1.40	1.43	1.52	1.51	1.54	1.52	1.53	1.46	1.50	1.48	1.51	1.42	1.41	1.48
Pushing Forward	2	1.37	1.41	1.42	1.44	1.36	1.34	1.37	1.32	1.33	1.34	1.38	1.45	1.43	1.40	1.38	1.39	1.42	1.30	1.31	1.32	1.37
	3	1.38	1.42	1.44	1.45	1.37	1.35	1.38	1.32	1.34	1.35	1.39	1.46	1.44	1.41	1.39	1.40	1.43	1.31	1.32	1.33	1.38
	4	0.84	0.85	0.87	0.88	0.89	0.82	0.80	0.80	0.81	0.87	0.86	0.88	0.87	0.87	0.83	0.86	0.85	0.87	0.81	0.81	0.85
	5	0.92	0.95	0.96	0.97	0.91	0.90	0.92	0.88	0.89	0.90	0.92	0.97	0.96	0.94	0.93	0.93	0.95	0.87	0.88	0.89	0.92
	6	1.29	1.30	1.33	1.35	1.36	1.26	1.23	1.23	1.25	1.34	1.32	1.35	1.34	1.34	1.28	1.32	1.30	1.33	1.24	1.24	1.30
	8	1.34	1.35	1.38	1.41	1.41	1.31	1.27	1.28	1.30	1.39	1.37	1.40	1.39	1.39	1.33	1.37	1.35	1.38	1.29	1.29	1.35
	9	0.96	0.99	1.00	1.01	0.95	0.94	0.96	0.92	0.93	0.94	0.96	1.01	1.00	0.98	0.97	0.97	0.99	0.91	0.92	0.93	0.96
	10	1.27	1.28	1.31	1.33	1.34	1.24	1.21	1.21	1.23	1.31	1.30	1.33	1.31	1.32	1.26	1.30	1.28	1.31	1.23	1.22	1.28
	11	1.28	1.29	1.32	1.34	1.35	1.25	1.22	1.22	1.24	1.32	1.31	1.34	1.32	1.33	1.27	1.31	1.29	1.32	1.24	1.23	1.29

Appendix D: Method Study Data Collection

Appendix D1 – Time Measurement for New Work Elements

New Work Element	Time for 10 Units									
	Trial									
	1	2	3	4	5	6	7	8	9	10
WE1	58.90	59.49	59.79	60.68	59.77	59.18	58.88	58.70	58.82	59.17
WE2	49.7	49.98	49.70	50.03	50.87	50.99	50.13	49.57	49.13	48.96
WE3	32.2	32.52	32.68	33.17	32.68	32.35	32.19	32.09	32.16	32.35
WE4	45.9	46.13	45.90	46.17	46.87	46.96	46.26	45.79	45.43	45.29
WE5	62.2	62.32	62.57	62.01	62.26	61.70	63.13	61.89	62.51	61.33
WE6	46.3	46.76	47.00	47.70	46.99	46.52	46.28	46.14	46.24	46.51
WE7	50.2	50.45	50.20	50.50	51.26	51.36	50.59	50.08	49.68	49.53
WE8	35	35.07	35.21	34.90	35.04	34.72	35.53	34.83	35.18	34.51
WE9	36	36.07	36.22	35.89	36.04	35.71	36.54	35.82	36.18	35.50
WE10	45.3	45.75	45.98	46.67	45.97	45.51	45.28	45.15	45.24	45.51
WE11	43.9	44.14	43.90	44.19	44.93	45.03	44.28	43.79	43.40	43.25
WE12	41.2	41.28	41.45	41.08	41.24	40.87	41.82	40.99	41.41	40.62
WE13	39.2	39.40	39.20	39.43	40.03	40.11	39.50	39.11	38.80	38.68
WE14	51.9	52.02	52.25	51.73	51.96	51.44	52.77	51.61	52.19	51.09
WE15	31.6	31.98	32.17	32.74	32.16	31.78	31.59	31.47	31.55	31.77
WE16	92.3	92.76	92.30	92.85	94.24	94.43	93.02	92.09	91.35	91.08
WE17	35.1	35.16	35.29	35.01	35.13	34.85	35.57	34.94	35.26	34.66
WE18	34.2	34.36	34.20	34.39	34.86	34.92	34.44	34.13	33.88	33.79
WE19	90.1	88.81	90.95	89.84	90.19	89.40	91.41	89.66	90.54	88.87
WE21	60	60.60	60.90	61.82	60.89	60.28	59.98	59.80	59.92	60.28
WE20	49.4	49.50	49.70	49.25	49.45	49.00	50.14	49.15	49.65	48.71
WE22	119.2	119.43	119.89	118.85	119.32	118.28	120.93	118.62	119.78	117.59
WE23	117.8	118.37	117.80	118.48	120.20	120.43	118.68	117.54	116.63	116.29

Continue…

New Work Element	Time for 10 Units										Average	Time per 1 unit
	Trial											
	11	12	13	14	15	16	17	18	19	20		
WE1	58.70	57.88	57.24	57.70	58.33	57.98	58.04	58.45	57.63	56.88	58.61	5.86
WE2	49.51	49.95	50.57	50.63	50.00	49.22	48.45	48.83	48.50	47.79	49.63	4.96
WE3	32.09	31.64	31.29	31.54	31.89	31.70	31.73	31.95	31.51	31.10	32.04	3.20
WE4	45.74	46.11	46.62	46.66	46.15	45.50	44.87	45.18	44.91	44.33	45.84	4.58
WE5	61.27	61.58	62.88	61.83	62.70	62.64	61.39	61.52	62.82	61.33	62.09	6.21
WE6	46.14	45.50	45.00	45.36	45.85	45.58	45.63	45.94	45.30	44.71	46.07	4.61
WE7	50.03	50.43	50.98	51.04	50.47	49.77	49.07	49.41	49.12	48.48	50.13	5.01
WE8	34.48	34.65	35.39	34.79	35.28	35.25	34.55	34.62	35.35	34.51	34.94	3.49
WE9	35.46	35.64	36.40	35.78	36.29	36.25	35.53	35.60	36.36	35.50	35.94	3.59
WE10	45.15	44.51	44.02	44.38	44.86	44.60	44.64	44.95	44.32	43.75	45.08	4.51
WE11	43.73	44.12	44.66	44.71	44.17	43.48	42.80	43.13	42.85	42.22	43.83	4.38
WE12	40.58	40.79	41.65	40.95	41.53	41.49	40.66	40.75	41.61	40.62	41.13	4.11
WE13	39.07	39.38	39.81	39.85	39.41	38.86	38.32	38.59	38.35	37.86	39.15	3.91
WE14	51.03	51.32	52.54	51.55	52.36	52.31	51.15	51.26	52.48	51.09	51.80	5.18
WE15	31.47	30.95	30.54	30.83	31.24	31.02	31.05	31.31	30.79	30.31	31.42	3.14
WE16	91.99	92.72	93.74	93.84	92.80	91.50	90.22	90.85	90.31	89.14	92.18	9.22
WE17	34.63	34.79	35.44	34.91	35.35	35.32	34.70	34.76	35.41	34.66	35.05	3.50
WE18	34.09	34.34	34.69	34.72	34.37	33.93	33.50	33.71	33.53	33.13	34.16	3.42
WE19	88.79	89.22	91.06	89.67	90.80	90.71	88.74	89.14	90.98	88.87	89.89	8.99
WE21	59.80	58.96	58.31	58.78	59.42	59.07	59.13	59.54	58.71	58.72	59.74	5.97
WE20	48.66	48.91	49.94	49.10	49.80	49.75	48.76	48.86	49.89	48.71	49.32	4.93
WE22	117.47	118.05	120.47	118.51	120.12	120.01	117.70	117.93	120.35	117.59	119.00	11.90
WE23	117.41	118.32	119.58	119.69	118.42	116.82	115.24	116.02	115.35	113.90	117.65	11.76

Appendix D2 – Process Standard

PROCESS STANDARD

Page : 1 / 11

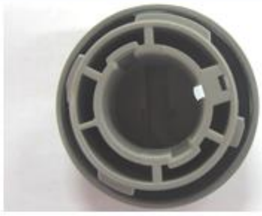
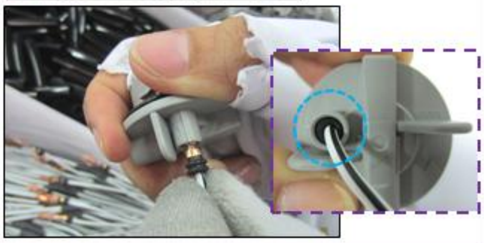
Model : N-RLC	Part No. :		Engineering Dept.			Production Dept.	
Part Name : Cable Assembly	Section :	Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ							

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
1	Socket Plug M-088 Gr ประกอบ Gasket R-087 Supply จาก AS4		
2	ประกอบสายไฟชุด Joint W/B เข้ากับ Tube 7x8 (B) ความยาว 85 $^{+3}_{-0}$ mm	A,B	
3	ประกอบสายไฟชุด Joint W/B จากข้อ 1.1 เข้ากับ Tube 8x9 (B) ความยาว 40 $^{+3}_{-0}$ mm		
4	ประกอบสายไฟชุด Joint W/B จากข้อ 1.1 และ และข้อ 1.2 เข้ากับ Socket Plug M-088 Gr		

Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							S = มีระดับค่า severity (sev) ช่วง 9-10
							= มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

Page : 2 / 11

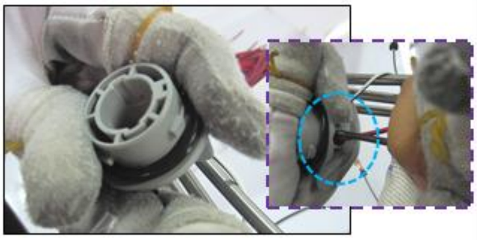
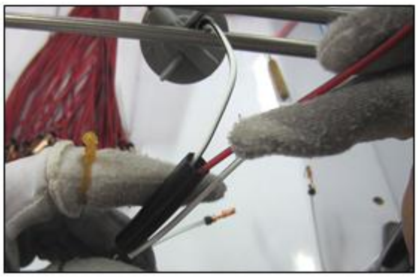
Model : N-RLC	Part No. :	Engineering Dept.			Production Dept.	
Part Name : Cable Assembly	Section : Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ						

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
5	ประกอบสายไฟ AV0.5 R/L ความยาว 348±2 เข้ากับ Socket Plug M-088 Gr และกดยางให้แน่นเสมอกันไม่เอียง	A,B	
6	6.1 นำสายไฟ AV0.5 R/L จากข้อ 2.1 สอดเข้ากับ Tube 8x9 (B) ความยาว 40 $^{+3}_{-0}$ mm		
	6.2 นำสายไฟ AV0.5 R/L จากข้อ 2.1 และข้อ 2.2 สอดเข้ากับ Tube 8x9 (B) ความยาว 85 $^{+3}_{-0}$ mm		

Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							S = มีระดับค่า severity (sev) ช่วง 9-10
							= มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

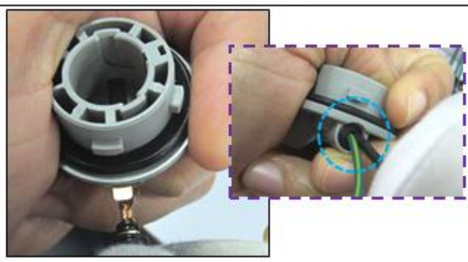
		Engineering Dept.			Production Dept.	
Model : N-RLC	Part No. :					
Part Name : Cable Assembly	Section : Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ						

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
	Socket Plug M-079 Gr ประกอบ Gasket R-087 Supply จาก AS4		
7	ประกอบสายไฟ AV0.5 G/Y ความยาว 323 ±2 เข้ากับ Socket Plug M-079 Gr และกดยางให้แน่นเสมอกันไม่เอียง	A,B	
8	ประกอบสายไฟชุด Joint W/B เข้ากับ Socket Plug M-079 Gr		
9	นำสายไฟ AV0.5 G/Y จากข้อ 3.1 สอดเข้ากับ Tube 7x8 (B) ความยาว 85 $^{+3}_{-0}$ mm		

Training Record

วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
						A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
						B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
						C = รูปร่างภายนอกสมบูรณ์ (Appearance)
						▽= มีระดับค่า severity (sev) ช่วง 9-10
						▽= มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

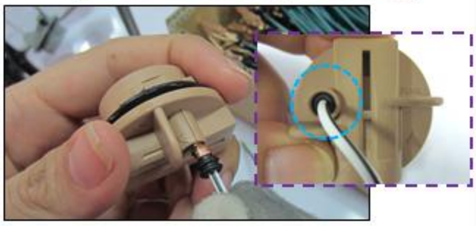
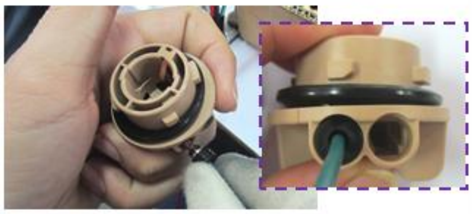
Model : N-RLC	Part No. :	Engineering Dept.			Production Dept.	
Part Name : Cable Assembly	Section : Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ						

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
	Socket Plug M-086 Br ประกอบ Gasket R-087 Supply จาก AS4		
10	ประกอบสายไฟชุด Joint W/B เข้ากับ Tube 8x9 (B) ความยาว 40 $^{+3}_{-0}$ mm	A,B	
11	ประกอบสายไฟชุด Joint W/B จากข้อ 4.1 เข้ากับ Socket Plug M-086 Br		
12	ประกอบสายไฟ AV0.5 G เข้ากับ Socket Plug M-086 Br		

Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							S = มีระดับค่า severity (sev) ช่วง 9-10
							▽ = มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

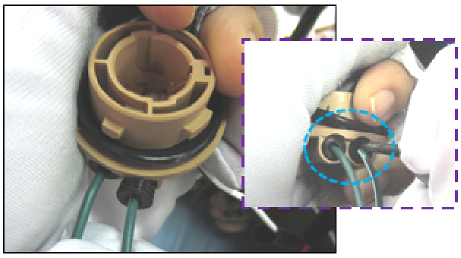
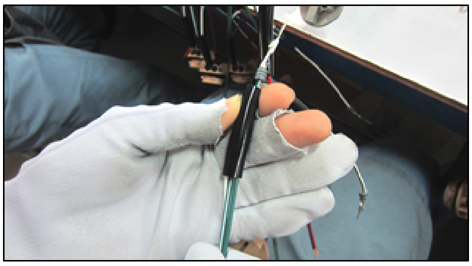
Model : N-RLC	Part No. :	Engineering Dept.			Production Dept.	
Part Name : Cable Assembly	Section : Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ						

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special Characteristic	รูปภาพประกอบ
13	ประกอบสายไฟ AV0.5 G/W เข้ากับ Socket Plug M-086 Br และกดยางให้แน่นเสมอกันไม่เอียง ทั้งสองเส้น	A,B	
14	ขยาย Terminal ใน Socket Plug ทุกอัน		
15	5.2 ประกอบสายไฟ AV0.5 G,G/W เข้ากับ Tube 8x9 (B) ความยาว 40 $^{+3}_{-0}$ mm		

Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							S = มีระดับค่า severity (sev) ช่วง 9-10
							= มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

Model : N-RLC	Part No. :		Engineering Dept.			Production Dept.	
Part Name : Cable Assembly	Section :	Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ							

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
16	ประกอบสายไฟ AV0.5 W/B,G/W, G ,G/Y และ R/L ประกอบเข้ากับ Tube 9x10 (B) ความยาว 66^{+3}_{-0} mm	B,C	
17	ประกอบ Bushing R-089 เข้ากับสายไฟ AV0.5 R/L		
18	ประกอบ Bushing R-089 เข้ากับสายไฟ AV0.5 G/Y		

Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							S = มีระดับค่า severity (sev) ช่วง 9-10
							= มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

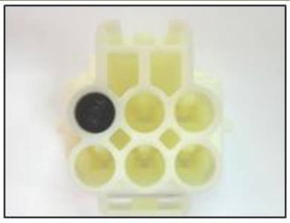
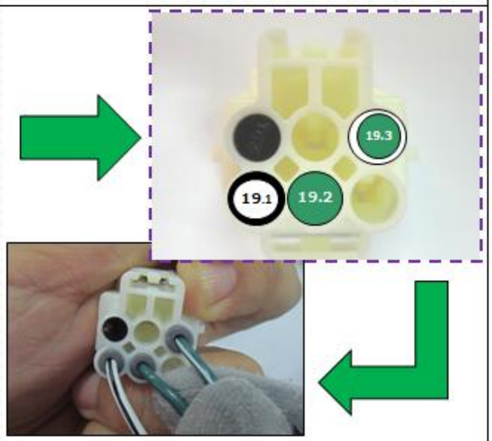
Model : N-RLC	Part No. :	Engineering Dept.			Production Dept.	
Part Name : Cable Assembly	Section : Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ						

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
	Connector (W) No. 96900-03694 ประกอบ Bushing R-023 Supply จาก AS4		
19	ประกอบสายไฟ AV0.5 เข้ากับ Connector No.96900-03694 ตำแหน่งตามภาพ 19.1 เสียบสายไป AV0.5 W/B 19.2 เสียบสายไป AV0.5 G 19.3 เสียบสายไป AV0.5 G/W	A,C	
20	ทำการย้ำ Terminal ที่สายไฟ AV0.5 R/L , G/Y		

Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							S = มีระดับค่า severity (sev) ช่วง 9-10
							= มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

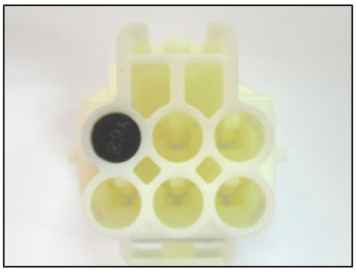
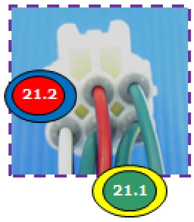
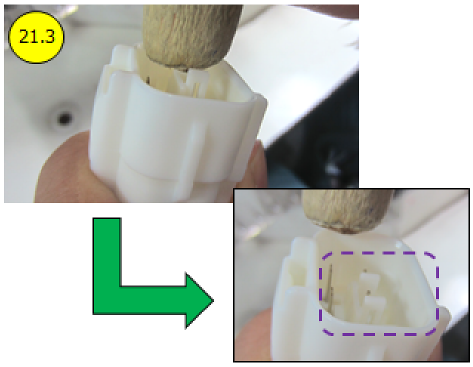
Model : N-RLC	Part No. :	Engineering Dept.			Production Dept.	
Part Name : Cable Assembly	Section : Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ						

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
21	21.1 ประกอบสายไฟ AV0.5 G/Y เข้ากับ Connector ตำแหน่งตามภาพ 21.2 ประกอบสายไฟ AV0.5 R/L เข้ากับ Connector ตำแหน่งตามภาพ 21.3 กดล็อคที่ Connector	A,C	  

Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							S = มีระดับค่า severity (sev) ช่วง 9-10
							C = มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

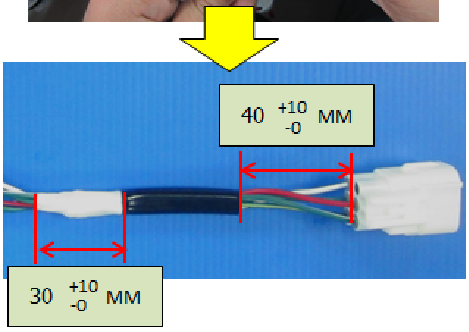
		Engineering Dept.			Production Dept.	
Model : N-RLC	Part No. :					
Part Name : Cable Assembly	Section : Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ						

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
22	พัน Tape (w) ให้ได้ค่า ตามภาพ	B	 

Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							S = มีระดับค่า severity (sev) ช่วง 9-10
							= มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

Model : N-RLC	**Part No. :**	**Engineering Dept.**			**Production Dept.**	
Part Name : Cable Assembly	**Section :** Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ						

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

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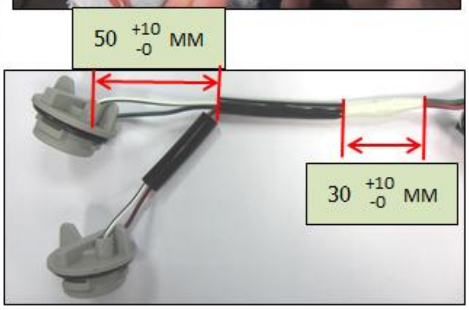
ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
23	พัน Tape (w) ให้ได้ค่า ตามภาพ	B	



Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเดินสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							S = มีระดับค่า severity (sev) ช่วง 9-10
							C = มีระดับค่า severity (sev) ช่วง 7-8

PROCESS STANDARD

Model : N-RLC	Part No. :	Engineering Dept.			Production Dept.	
Part Name : Cable Assembly	Section : Rev.d	Issued	Checked	Approved	Asst.FM	Fatory Mgr.
Subject : ขั้นตอนการกอบชุดสายไฟ						

เครื่องมืออุปกรณ์ที่ใช้ : ไขควง, ถุงมือผ้า, ดินสอสีเพื่อใช้ทำสัญลักษณ์, ไม้บรรทัด, Sticker

เอกสารที่ใช้ : -

วิธีการทำงานเริ่มต้นที่ : หผ.เตรียมตัวอย่างชิ้นงานสำเร็จรูป และตรวจสอบความถูกต้องของรายการวัตถุดิบที่จะใช้ในการประกอบชิ้นงานทุกครั้งก่อนการปฏิบัติงาน

ขั้นตอนการประกอบ (ดูรูปภาพ)

No.	การประกอบ	Special haracteristi	รูปภาพประกอบ
11	ชิ้นงานสำเร็จรูป		

Training Record	วันที่	ผู้ฝึกสอน	พนง.	วันที่	ผู้ฝึกสอน	พนง.	คุณลักษณะพิเศษ (Special Characteristic)
							A = การเสียบสายไฟถูกต้อง (Assembly),ไม่ใช้สารต้องห้าม (No use of soc)
							B = ขนาดความยาว (Dimension) และแรงดึงได้ตามมาตราฐาน (Tension stress)
							C = รูปร่างภายนอกสมบูรณ์ (Appearance)
							▽= มีระดับค่า severity (sev) ช่วง 9-10
							▽= มีระดับค่า severity (sev) ช่วง 7-8

Appendix D3 – Kanawaty Standard practice sheet

Standard practice sheet

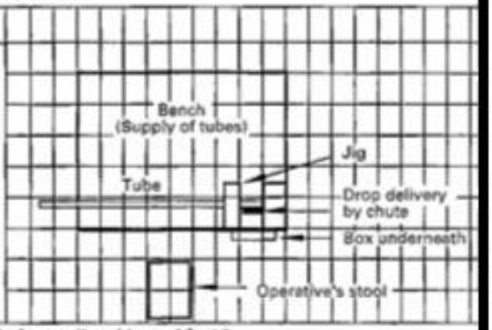
Product: *3 mm diam. glass tube, supplied in 1 metre lengths*

Operation: *File and break to lengths of 1.5 cm*

Working conditions: *Light good*

Equipment

Jig No. 231
Half-round 15 cm



Location: *Fitting shop* | **Ref. studies Nos.** *12, 13*

Operative: | **Clock No.** *54* | **Charted by:** | **Date:**

Approved by: | **Date:**

EL	Left hand	Right hand	EL
1	*Take tube between thumb and first two fingers: push forward to stop*	*Hold file: wait for L.H.*	1
2	*Rotate tube between thumb and fingers*	*Notch tube all round with edge of file hard up against face of jig*	2
3	*Hold tube*	*Tap notched end of tube sharply with file so that it falls into chute*	3

Appendix D4 – Maintain Form

Performance Maintainance Form							
Month				Week			
Workstation	Takt Time	Experiment Time	Number of Cables	Avg Assembly Time	Standard Process	Remark	Suggestion
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Appendix E: Work Measurement Documents

Appendix E1 – Performance Rating Record Sheet

<table>
<tr><td colspan="7">Performance Rating Record Sheet</td></tr>
<tr><td colspan="2">Product</td><td colspan="5">640A-RCL</td></tr>
<tr><td colspan="2">Workstation</td><td colspan="5"></td></tr>
<tr><td colspan="2">Rated By</td><td colspan="5"></td></tr>
<tr><td colspan="2">Instruction</td><td colspan="5">Please rate the performance of the worker based on your opinion with respect to standard performance of 100.
ie. 110 = faster than usual, 95 = slower than usual</td></tr>
<tr><td rowspan="2">Trial</td><td rowspan="2">Date</td><td rowspan="2">Time</td><td rowspan="2">Rating</td><td colspan="2">OT</td><td rowspan="2">BT</td></tr>
<tr><td>10 units</td><td>1 unit</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>8</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>9</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>10</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>11</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>13</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>14</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>15</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>16</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>17</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>18</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>19</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>20</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Average</td><td></td><td></td></tr>
<tr><td colspan="3">OT: Observed Time</td><td colspan="4">BT: Basic Time</td></tr>
</table>

Appendix E2 – Personal Activities Record Sheet

Personal Activities Record Sheet					
Workstation					
Day	Description	min	Note	total	%
Day 1					
Day 2					
Day 3					
Day 4					
Day 5					

Appendix E3 – Fatigue Allowance Scoring Sheet (ILO's Method)

Scorer:		Relaxation Allowances: ILO's Method																			
Stress/ Strain	Types	Workstation																			
		1		2		3		4		5		6		7		8		9		10	
		Stress	Pts.	Stress	Pts.	Stress	Pts.	Stress	Pts.	Stress	Pts.	Stress	Pts.	Stress	Pts.	Stress	Pts.	Stress	Pts.	Stress	Pts.
Physical Strains	Average Force																				
	Posture																				
	Vibration																				
	Short Cycle																				
	Restrictive Clothing																				
Mental Strains	Concentration																				
	Monotomy																				
	Eye Strain																				
	Noise																				
Working Condition	Temperature																				
	Ventilation																				
	Fumes																				
	Dust																				
	Dirt																				
	Wet																				
Sum																					
Conversion to Relaxation																					

Appendix E4 – Relaxation Scoring Sheet (Williams's Method)

Williams's Method										
Scorer:	Workstation									
Allowance Factors	1	2	3	4	5	6	7	8	9	10
Standard Fatigue										
Energy demand										
Posture and Motions										
Restrictive Clothing										
Discipline										
Monotony										
Concentration										
Thermal and Atmospheric Conditions										
Physical Environment										
Visual										
Vibration and Instability										
Total										

Appendix F: Work Measurement Data Collection

Appendix F1 – Performance Rating of 10 Workstations

Workstation 1

Performance Rating Record Sheet						
Product		640A-RCL				
Workstation		1				
Rated By						
Instruction		Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual				
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	27/7/2015	9:00	95	145.9	14.59	13.86
2	27/7/2015	11:00	105	128.9	12.89	13.53
3	27/7/2015	13:40	100	141	14.10	14.10
4	27/7/2015	15:35	105	130.5	13.05	13.70
5	28/7/2015	9:50	100	137.2	13.72	13.72
6	28/7/2015	13:30	90	142.3	14.23	12.81
7	28/7/2015	15:25	110	124.2	12.42	13.66
8	28/7/2015	16:15	95	143.3	14.33	13.61
9	29/7/2015	8:30	90	154.2	15.42	13.88
10	29/7/2015	10:00	100	136.9	13.69	13.69
11	29/7/2015	13:15	95	144.4	14.44	13.72
12	29/7/2015	16:10	95	139.9	13.99	13.29
13	30/7/2015	8:45	100	140.8	14.08	14.08
14	30/7/2015	9:50	100	137.4	13.74	13.74
15	30/7/2015	11:30	105	133.8	13.38	14.05
16	30/7/2015	13:40	90	148.8	14.88	13.39
17	31/7/2015	9:05	95	154.5	15.45	14.68
18	31/7/2015	11:20	100	142.4	14.24	14.24
19	31/7/2015	13:50	95	140.3	14.03	13.33
20	31/7/2015	15:30	100	133.7	13.37	13.37
Average						13.72
OT: Observed Time			BT: Basic Time			

Workstation 2

Performance Rating Record Sheet						
Product		640A-RCL				
Workstation		2				
Rated By						
Instruction		Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual				
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	27/7/2015	9:10	100	127.3	12.73	12.73
2	27/7/2015	11:10	100	115	11.50	11.50
3	27/7/2015	13:50	110	121	12.10	13.31
4	27/7/2015	15:45	100	114.5	11.45	11.45
5	28/7/2015	10:00	100	124.2	12.42	12.42
6	28/7/2015	13:45	95	122.3	12.23	11.62
7	28/7/2015	15:30	95	135.9	13.59	12.91
8	28/7/2015	16:30	90	140.2	14.02	12.62
9	29/7/2015	8:45	100	134.2	13.42	13.42
10	29/7/2015	10:15	110	116.9	11.69	12.86
11	29/7/2015	13:30	95	131.1	13.11	12.45
12	29/7/2015	16:20	100	124.4	12.44	12.44
13	30/7/2015	9:00	90	130.2	13.02	11.72
14	30/7/2015	10:00	100	117.4	11.74	11.74
15	30/7/2015	11:40	100	121.4	12.14	12.14
16	30/7/2015	13:50	95	136.6	13.66	12.98
17	31/7/2015	9:20	90	134.5	13.45	12.11
18	31/7/2015	11:30	95	122.4	12.24	11.63
19	31/7/2015	14:00	110	113.7	11.37	12.51
20	31/7/2015	15:45	105	120.3	12.03	12.63
Average						12.36
OT: Observed Time			BT: Basic Time			

Workstation 3

Performance Rating Record Sheet						
Product	640A-RCL					
Workstation	3					
Rated By						
Instruction	Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual					
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	3/8/2015	9:15	95	150.3	15.03	14.28
2	3/8/2015	11:15	100	145.2	14.52	14.52
3	3/8/2015	14:00	100	135.4	13.54	13.54
4	3/8/2015	15:40	105	133	13.30	13.97
5	4/8/2015	10:15	100	137.2	13.72	13.72
6	4/8/2015	13:50	95	145.6	14.56	13.83
7	4/8/2015	15:40	105	128.9	12.89	13.53
8	4/8/2015	16:40	95	142.2	14.22	13.51
9	5/8/2015	9:00	90	154.2	15.42	13.88
10	5/8/2015	10:20	100	144	14.40	14.40
11	5/8/2015	13:40	100	144.4	14.44	14.44
12	5/8/2015	16:30	95	148.7	14.87	14.13
13	6/8/2015	9:15	100	133.5	13.35	13.35
14	6/8/2015	10:10	95	137.4	13.74	13.05
15	6/8/2015	11:45	100	136.3	13.63	13.63
16	6/8/2015	14:00	95	145.1	14.51	13.78
17	7/8/2015	9:30	100	140.2	14.02	14.02
18	7/8/2015	11:35	95	143.5	14.35	13.63
19	7/8/2015	14:15	100	137.9	13.79	13.79
20	7/8/2015	15:55	100	136.2	13.62	13.62
Average						13.83
OT: Observed Time			BT: Basic Time			

Workstation 4

Performance Rating Record Sheet						
Product		640A-RCL				
Workstation		4				
Rated By						
Instruction		Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual				
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	3/8/2015	9:25	100	147.3	14.73	14.73
2	3/8/2015	11:30	95	153.3	15.33	14.56
3	3/8/2015	14:20	95	152.3	15.23	14.47
4	3/8/2015	15:50	100	149.5	14.95	14.95
5	4/8/2015	10:30	100	143.2	14.32	14.32
6	4/8/2015	14:00	95	155.7	15.57	14.79
7	4/8/2015	15:55	110	126.5	12.65	13.92
8	4/8/2015	16:45	95	151.1	15.11	14.35
9	5/8/2015	9:10	95	156.3	15.63	14.85
10	5/8/2015	10:25	105	138.7	13.87	14.56
11	5/8/2015	13:50	105	145.1	14.51	15.24
12	5/8/2015	16:40	95	153.5	15.35	14.58
13	6/8/2015	9:25	95	157.9	15.79	15.00
14	6/8/2015	10:20	100	146.8	14.68	14.68
15	6/8/2015	11:50	105	141.5	14.15	14.86
16	6/8/2015	14:10	100	143	14.30	14.30
17	7/8/2015	9:45	100	152.3	15.23	15.23
18	7/8/2015	11:40	95	154.6	15.46	14.69
19	7/8/2015	14:20	110	145.4	14.54	15.99
20	7/8/2015	16:05	95	154.6	15.46	14.69
Average						14.74
OT: Observed Time			BT: Basic Time			

Workstation 5

Performance Rating Record Sheet						
Product		640A-RCL				
Workstation		5				
Rated By						
Instruction		Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual				
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	3/8/2015	9:25	100	143.3	14.33	14.33
2	3/8/2015	11:30	95	151.2	15.12	14.36
3	3/8/2015	14:20	95	152.3	15.23	14.47
4	3/8/2015	15:50	100	140.3	14.03	14.03
5	4/8/2015	10:30	100	143.2	14.32	14.32
6	4/8/2015	14:00	95	154.4	15.44	14.67
7	4/8/2015	15:55	110	135.7	13.57	14.93
8	4/8/2015	16:45	95	144.7	14.47	13.75
9	5/8/2015	9:10	95	142.1	14.21	13.50
10	5/8/2015	10:25	105	137.8	13.78	14.47
11	5/8/2015	13:50	105	139	13.90	14.60
12	5/8/2015	16:40	95	142.1	14.21	13.50
13	6/8/2015	9:25	95	146.8	14.68	13.95
14	6/8/2015	10:20	100	145.2	14.52	14.52
15	6/8/2015	11:50	105	133.1	13.31	13.98
16	6/8/2015	14:10	100	135	13.50	13.50
17	7/8/2015	9:45	100	139.7	13.97	13.97
18	7/8/2015	11:40	95	146.2	14.62	13.89
19	7/8/2015	14:20	110	135.6	13.56	14.92
20	7/8/2015	16:05	95	140.2	14.02	13.32
Average						14.15
OT: Observed Time			BT: Basic Time			

Workstation 6

Performance Rating Record Sheet						
Product		640A-RCL				
Workstation		6				
Rated By						
Instruction		Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual				
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	3/8/2015	9:15	105	145.8	14.58	15.31
2	3/8/2015	11:15	95	154.2	15.42	14.65
3	3/8/2015	14:00	95	153.6	15.36	14.59
4	3/8/2015	15:40	100	146.6	14.66	14.66
5	4/8/2015	10:15	105	147.7	14.77	15.51
6	4/8/2015	13:50	100	154.4	15.44	15.44
7	4/8/2015	15:40	105	137	13.70	14.39
8	4/8/2015	16:40	100	149	14.90	14.90
9	5/8/2015	9:00	95	151.1	15.11	14.35
10	5/8/2015	10:20	95	141.2	14.12	13.41
11	5/8/2015	13:40	110	139.6	13.96	15.36
12	5/8/2015	16:30	90	153.3	15.33	13.80
13	6/8/2015	9:15	95	150	15.00	14.25
14	6/8/2015	10:10	100	147.5	14.75	14.75
15	6/8/2015	11:45	105	141.8	14.18	14.89
16	6/8/2015	14:00	95	145.2	14.52	13.79
17	7/8/2015	9:30	105	147.2	14.72	15.46
18	7/8/2015	11:35	95	148	14.80	14.06
19	7/8/2015	14:15	105	140.6	14.06	14.76
20	7/8/2015	15:55	95	152.3	15.23	14.47
Average						14.64
OT: Observed Time			BT: Basic Time			

Workstation 7

Performance Rating Record Sheet						
Product	640A-RCL					
Workstation	7					
Rated By						
Instruction	Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual					
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	3/8/2015	9:00	90	154.2	15.42	13.88
2	3/8/2015	11:00	95	145.6	14.56	13.83
3	3/8/2015	13:40	100	142.2	14.22	14.22
4	3/8/2015	15:35	100	146.6	14.66	14.66
5	4/8/2015	9:50	100	141.5	14.15	14.15
6	4/8/2015	13:30	95	154.4	15.44	14.67
7	4/8/2015	15:25	105	138.1	13.81	14.50
8	4/8/2015	16:15	105	137.3	13.73	14.42
9	5/8/2015	8:30	110	136.5	13.65	15.02
10	5/8/2015	10:00	110	138.2	13.82	15.20
11	5/8/2015	13:15	100	143.5	14.35	14.35
12	5/8/2015	16:10	95	150.4	15.04	14.29
13	6/8/2015	8:45	90	150	15.00	13.50
14	6/8/2015	9:50	95	149.3	14.93	14.18
15	6/8/2015	11:30	100	144.1	14.41	14.41
16	6/8/2015	13:40	100	144.9	14.49	14.49
17	7/8/2015	9:05	105	143	14.30	15.02
18	7/8/2015	11:20	100	140.7	14.07	14.07
19	7/8/2015	13:50	90	147.4	14.74	13.27
20	7/8/2015	15:30	95	152.3	15.23	14.47
Average						14.33
OT: Observed Time			BT: Basic Time			

Workstation 8

Performance Rating Record Sheet						
Product		640A-RCL				
Workstation		8				
Rated By						
Instruction		Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual				
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	3/8/2015	9:10	100	124.2	12.42	12.42
2	3/8/2015	11:10	95	130.5	13.05	12.40
3	3/8/2015	13:50	95	134.6	13.46	12.79
4	3/8/2015	15:45	100	130.1	13.01	13.01
5	4/8/2015	10:00	100	127.7	12.77	12.77
6	4/8/2015	13:45	95	140.3	14.03	13.33
7	4/8/2015	15:30	110	123.6	12.36	13.60
8	4/8/2015	16:30	95	132.3	13.23	12.57
9	5/8/2015	8:45	95	137.8	13.78	13.09
10	5/8/2015	10:15	105	121.5	12.15	12.76
11	5/8/2015	13:30	105	124.4	12.44	13.06
12	5/8/2015	16:20	95	136.9	13.69	13.01
13	6/8/2015	9:00	95	139.1	13.91	13.21
14	6/8/2015	10:00	100	127.2	12.72	12.72
15	6/8/2015	11:40	105	120.2	12.02	12.62
16	6/8/2015	13:50	100	129.1	12.91	12.91
17	7/8/2015	9:20	100	128.5	12.85	12.85
18	7/8/2015	11:30	95	131.2	13.12	12.46
19	7/8/2015	14:00	110	125.6	12.56	13.82
20	7/8/2015	15:45	95	133.7	13.37	12.70
Average						12.90
OT: Observed Time			BT: Basic Time			

Workstation 9

Performance Rating Record Sheet						
Product		640A-RCL				
Workstation		9				
Rated By						
Instruction		Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual				
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	3/8/2015	9:30	100	137.6	13.76	13.76
2	3/8/2015	11:35	90	145.3	14.53	13.08
3	3/8/2015	14:25	95	142.3	14.23	13.52
4	3/8/2015	15:55	95	144.1	14.41	13.69
5	4/8/2015	10:35	105	133.2	13.32	13.99
6	4/8/2015	14:05	105	138.8	13.88	14.57
7	4/8/2015	16:00	100	139	13.90	13.90
8	4/8/2015	16:50	100	137.8	13.78	13.78
9	5/8/2015	9:15	100	136.5	13.65	13.65
10	5/8/2015	10:30	95	140.3	14.03	13.33
11	5/8/2015	13:55	105	135.4	13.54	14.22
12	5/8/2015	16:45	105	140	14.00	14.70
13	6/8/2015	9:30	110	132.4	13.24	14.56
14	6/8/2015	10:25	100	139.4	13.94	13.94
15	6/8/2015	11:55	95	141.8	14.18	13.47
16	6/8/2015	14:15	90	142.5	14.25	12.83
17	7/8/2015	9:50	90	145.6	14.56	13.10
18	7/8/2015	11:45	100	137.9	13.79	13.79
19	7/8/2015	14:25	100	139.4	13.94	13.94
20	7/8/2015	16:10	95	140.8	14.08	13.38
Average						13.76
OT: Observed Time			BT: Basic Time			

Workstation 10

Performance Rating Record Sheet						
Product	640A-RCL					
Workstation	10					
Rated By						
Instruction	Please rate the performance of the worker based on your opinion with respect to standard performance of 100. ie. 110 = faster than usual, 95 = slower than usual					
Trial	Date	Time	Rating	OT		BT
				10 units	1 unit	
1	3/8/2015	9:35	95	137.6	13.76	13.07
2	3/8/2015	11:40	95	139.4	13.94	13.24
3	3/8/2015	14:30	90	145.4	14.54	13.09
4	3/8/2015	16:00	95	140.4	14.04	13.34
5	4/8/2015	10:40	105	133.2	13.32	13.99
6	4/8/2015	14:10	105	134.3	13.43	14.10
7	4/8/2015	16:05	100	136.5	13.65	13.65
8	4/8/2015	17:00	100	139.4	13.94	13.94
9	5/8/2015	9:20	100	137.7	13.77	13.77
10	5/8/2015	10:40	110	132.2	13.22	14.54
11	5/8/2015	14:10	110	131.1	13.11	14.42
12	5/8/2015	17:10	95	142	14.20	13.49
13	6/8/2015	9:35	100	139	13.90	13.90
14	6/8/2015	10:35	95	140.4	14.04	13.34
15	6/8/2015	13:10	95	142.1	14.21	13.50
16	6/8/2015	16:30	100	135.6	13.56	13.56
17	7/8/2015	10:00	100	136.9	13.69	13.69
18	7/8/2015	11:55	100	141.2	14.12	14.12
19	7/8/2015	14:45	105	134.5	13.45	14.12
20	7/8/2015	17:15	105	132.1	13.21	13.87
Average						13.74
OT: Observed Time			BT: Basic Time			

Appendix F2 – Personal Activities Record Sheet of 10 Workstations

Workstation 1

Personal Activities Record Sheet					
Workstation 1					
Day	Description	min	Note	total	%
Day 1	Toilet	2.48		19.81	3.0%
	Toilet	2.33			
	Water	0.78			
	Miscellaneous	3.42	talk with supervisor		
	Miscellaneous	2.28	talk with workers		
	Toilet	3.41			
	Water	1.23			
	Miscellaneous	2.22	talk with supervisor		
	Toilet	1.08			
	Water	0.58			
Day 2	Toilet	2.31		19.56	3.0%
	Water	1.35			
	Toilet	4.2			
	Miscellaneous	5.12	talk with supervisor		
	Miscellaneous	2.89	Phone call		
	Toilet	2.51			
	Water	1.18			
Day 3	Miscellaneous	4.12	talk with workers	21.31	3.2%
	Water	1.15			
	Toilet	3.19			
	Toilet	3.57			
	Miscellaneous	4.55	talk with supervisor		
	Water	1.31			
	Water	1.26			
	Toilet	2.16			
Day 4	Water	0.78		22.82	3.5%
	Toilet	1.06			
	Water	1.23			
	Miscellaneous	3.11	talk with supervisor		
	Toilet	3.37			
	Miscellaneous	5.3	Phone call		
	Water	1.51			
	Miscellaneous	4.71	talk with supervisor		
	Toilet	1.07			
	Water	0.68			
Day 5	Miscellaneous	1.49	talk with workers	17.49	2.7%
	Toilet	2.68			
	Toilet	4.1			
	Water	2.1			
	Water	1.06			
	Miscellaneous	3.78	talk with workers		
	Toilet	2.28			

Workstation 2

Personal Activities Record Sheet					
Workstation 2					
Day	Description	min	Note	total	%
Day 1	Toilet	1.38		16.22	2.5%
	Miscellaneous	3.41	talk with supervisor		
	Water	1.34			
	Toilet	3.56			
	Miscellaneous	2.33	talk with workers		
	Toilet	3.41			
	Water	0.79			
Day 2	Miscellaneous	4.21	Phone call	18.97	2.9%
	Water	1.52			
	Toilet	3.14			
	Toilet	1.64			
	Miscellaneous	4.54	talk with supervisor		
	Toilet	2.47			
	Water	1.45			
Day 3	Water	1.35		21.81	3.3%
	Miscellaneous	3.67	talk with workers		
	Toilet	3.54			
	Miscellaneous	5.12	talk with supervisor		
	Water	1.33			
	Toilet	1.05			
	Water	2.31			
	Toilet	3.44			
Day 4	Water	1.8		27.25	4.1%
	Toilet	2.3			
	Miscellaneous	2.78	talk with workers		
	Miscellaneous	4.21	Phone call		
	Toilet	3.56			
	Miscellaneous	3.12	Phone call		
	Water	1.2			
	Miscellaneous	4.12	talk with supervisor		
	Toilet	3.41			
	Water	0.75			
Day 5	Miscellaneous	3.12	Phone call	17.89	2.7%
	Toilet	2.53			
	Water	1.41			
	Water	1.08			
	Toilet	4.11			
	Toilet	3.09			
	Miscellaneous	2.55	talk with workers		

Workstation 3

Personal Activities Record Sheet					
Workstation 3					
Day	Description	min	Note	total	%
Day 1	Water	1.71		18.21	2.8%
	Miscellaneous	2.45	talk with supervisor		
	Toilet	3.42			
	Water	1.03			
	Toilet	5.12			
	Toilet	2.04			
	Miscellaneous	2.44	Phone call		
Day 2	Water	0.79		24.68	3.7%
	Miscellaneous	4.01	talk with workers		
	Toilet	2.71			
	Miscellaneous	3.02	Phone call		
	Water	1.52			
	Toilet	2.22			
	Toilet	5.3			
	Miscellaneous	2.1	talk with supervisor		
	Toilet	3.01			
Day 3	Toilet	2.21		15.54	2.4%
	Water	1.58			
	Miscellaneous	2.77	talk with workers		
	Water	1.2			
	Miscellaneous	2.34	talk with supervisor		
	Miscellaneous	3.12	Phone call		
	Toilet	2.5			
	Water	2.03			
Day 4	Miscellaneous	2.45	talk with workers	17.69	2.7%
	Water	1.23			
	Toilet	2.3			
	Water	2.78			
	Miscellaneous	3.52	Phone call		
	Toilet	3.41			
	Toilet	3.11			
	Water	1.34			
Day 5	Water	0.78		14.82	2.2%
	Miscellaneous	3.21	Phone call		
	Toilet	1.25			
	Water	0.68			
	Water	3.29			
	Toilet	4			
	Miscellaneous	2.39	talk with workers		

Workstation 4

Personal Activities Record Sheet					
Workstation 4					
Day	Description	min	Note	total	%
Day 1	Toilet	1.09		23.05	3.5%
	Water	1.77			
	Toilet	4.44			
	Toilet	2.31			
	Miscellaneous	3.31	talk with workers		
	Toilet	2.04			
	Miscellaneous	5.1	talk with workers		
	Toilet	2.3			
	Water	0.69			
Day 2	Miscellaneous	4.12	Phone call	16.08	2.4%
	Water	0.94			
	Miscellaneous	1.12	Phone call		
	Toilet	3.76			
	Miscellaneous	2.12	talk with supervisor		
	Toilet	2.57			
	Water	1.45			
Day 3	Water	1.03		18.11	2.7%
	Miscellaneous	3.15	talk with workers		
	Toilet	2.59			
	Miscellaneous	2.33	talk with supervisor		
	Water	1.05			
	Toilet	3.33			
	Water	1.41			
	Miscellaneous	3.22	talk with workers		
Day 4	Water	0.79		23.23	3.5%
	Toilet	4.34			
	Miscellaneous	3.51	talk with workers		
	Miscellaneous	1.23	Phone call		
	Toilet	2.5			
	Miscellaneous	4.33	Phone call		
	Water	1.13			
	Water	0.77			
	Toilet	3.61			
	Water	1.02			
Day 5	Toilet	4.45		25.6	3.9%
	Toilet	3.41			
	Miscellaneous	2.11	Phone call		
	Miscellaneous	4.5	Phone call		
	Toilet	2.31			
	Water	0.69			
	Toilet	3.5			
	Water	1.25			
	Miscellaneous	3.38	talk with workers		

Workstation 5

Personal Activities Record Sheet					
Workstation 5					
Day	Description	min	Note	total	%
Day 1	Toilet	1.51		25.72	3.9%
	Toilet	4.12			
	Miscellaneous	2.44	talk with workers		
	Water	2.34			
	Toilet	4			
	Toilet	0.78			
	Water	3.2			
	Miscellaneous	3.67	talk with supervisor		
	Toilet	2.78			
	Water	0.88			
Day 2	Toilet	3.46		20.53	3.1%
	Water	1.24			
	Toilet	2.11			
	Miscellaneous	4.21	talk with supervisor		
	Miscellaneous	1.56	Phone call		
	Water	0.87			
	Miscellaneous	3.25	Phone call		
	Toilet	2.5			
	Water	1.33			
Day 3	Water	2.14		18.66	2.8%
	Water	1.54			
	Toilet	3.78			
	Toilet	2.88			
	Miscellaneous	5.14	talk with supervisor		
	Water	1.19			
	Water	0.94			
	Toilet	1.05			
Day 4	Water	1.01		19.14	2.9%
	Toilet	3.4			
	Toilet	2.5			
	Miscellaneous	4.16	Phone call		
	Toilet	3			
	Toilet	1.13			
	Water	2.12			
	Water	0.8			
	Toilet	1.02			
Day 5	Water	2.12		16.31	2.5%
	Miscellaneous	2.33	talk with workers		
	Toilet	3.2			
	Water	1.04			
	Water	1.02			
	Toilet	4.41			
	Miscellaneous	2.19	Phone call		

Workstation 6

Personal Activities Record Sheet					
Workstation 6					
Day	Description	min	Note	total	%
Day 1	Toilet	2.3		19.98	3.0%
	Miscellaneous	4.23	talk with workers		
	Water	2.01			
	Toilet	2.22			
	Miscellaneous	3.12	talk with workers		
	Toilet	3.5			
	Water	2.6			
Day 2	Miscellaneous	3.2	Phone call	19.57	3.0%
	Water	1.77			
	Toilet	3.67			
	Toilet	3.66			
	Miscellaneous	5.3	talk with supervisor		
	Toilet	1.2			
	Water	0.77			
Day 3	Water	1.3		23.69	3.6%
	Toilet	1.09			
	Toilet	1.79			
	Miscellaneous	3.66	talk with workers		
	Toilet	4.5			
	Miscellaneous	2.34	Phone call		
	Water	1.55			
	Toilet	2.31			
	Water	1.99			
	Toilet	3.16			
Day 4	Water	1.34		19.17	2.9%
	Toilet	2.55			
	Miscellaneous	3.12	talk with supervisor		
	Miscellaneous	4.1	Phone call		
	Water	1.22			
	Water	0.98			
	Miscellaneous	2.45	talk with supervisor		
	Toilet	2.3			
	Water	1.11			
Day 5	Miscellaneous	3.48	Phone call	18.87	2.9%
	Toilet	4.33			
	Water	1.04			
	Water	1.78			
	Toilet	2.52			
	Toilet	4.22			
	Miscellaneous	1.5	talk with workers		

Workstation 7

Personal Activities Record Sheet					
Workstation 7					
Day	Description	min	Note	total	%
Day 1	Water	1.53		17.57	2.7%
	Miscellaneous	5.23	talk with supervisor		
	Toilet	2.44			
	Water	1.25			
	Toilet	1.71			
	Toilet	3.31			
	Miscellaneous	2.1	Phone call		
Day 2	Water	2.31		25.69	3.9%
	Miscellaneous	3.13	talk with workers		
	Toilet	2.7			
	Miscellaneous	4.14	Phone call		
	Water	1.4			
	Toilet	1.22			
	Toilet	1.09			
	Water	2.34			
	Water	1.15			
	Miscellaneous	3.81	talk with supervisor		
	Toilet	2.4			
Day 3	Toilet	3.4		22.27	3.4%
	Water	2.13			
	Miscellaneous	3.41	talk with workers		
	Water	1.52			
	Miscellaneous	4.2	talk with supervisor		
	Miscellaneous	3.71	Phone call		
	Toilet	3.13			
	Water	0.77			
Day 4	Miscellaneous	4.33	talk with workers	18.01	2.7%
	Water	1.44			
	Water	1.24			
	Miscellaneous	5.3	Phone call		
	Toilet	1.65			
	Toilet	1.85			
	Water	2.2			
Day 5	Water	2.65		23.79	3.6%
	Miscellaneous	4.55	Phone call		
	Toilet	4.19			
	Water	3.85			
	Water	1.83			
	Toilet	2.91			
	Miscellaneous	3.81	talk with workers		

Workstation 8

Personal Activities Record Sheet					
Workstation 8					
Day	Description	min	Note	total	%
Day 1	Toilet	2.82		22.02	3.3%
	Water	2.71			
	Toilet	4.91			
	Toilet	1.2			
	Miscellaneous	3.1	Phone call		
	Toilet	2.93			
	Miscellaneous	1.2	talk with workers		
	Toilet	2.11			
	Water	1.04			
Day 2	Miscellaneous	3.94	talk with supervisor	18.3	2.8%
	Water	1.92			
	Miscellaneous	1.34	Phone call		
	Toilet	3.11			
	Miscellaneous	3	talk with supervisor		
	Toilet	1.67			
	Water	1.43			
	Toilet	1.11			
	Water	0.78			
Day 3	Water	1.75		19.11	2.9%
	Miscellaneous	4.01	talk with workers		
	Toilet	3.61			
	Miscellaneous	2.98	talk with supervisor		
	Water	1.35			
	Toilet	2.44			
	Water	1.2			
	Miscellaneous	1.77	talk with workers		
Day 4	Water	1.17		22.57	3.4%
	Toilet	3.3			
	Miscellaneous	4.1	Phone call		
	Toilet	2.3			
	Miscellaneous	1.58	Phone call		
	Water	1.9			
	Water	1.09			
	Toilet	5.1			
	Water	2.03			
Day 5	Toilet	3.48		17.96	2.7%
	Toilet	1.73			
	Water	0.94			
	Miscellaneous	3.4	Phone call		
	Toilet	1.5			
	Water	1.41			
	Toilet	2.27			
	Toilet	2.15			
	Water	1.08			

Workstation 9

Personal Activities Record Sheet					
Workstation 9					
Day	Description	min	Note	total	%
Day 1	Toilet	2.34		16.9	2.6%
	Toilet	1.89			
	Water	1.31			
	Miscellaneous	4.23	talk with supervisor		
	Miscellaneous	1.48	talk with supervisor		
	Water	1.78			
	Miscellaneous	3.87	Phone call		
Day 2	Water	1.3		24.34	3.7%
	Water	1.21			
	Toilet	3.15			
	Miscellaneous	3.52	Phone call		
	Water	1.5			
	Miscellaneous	3.77	talk with workers		
	Toilet	1.9			
	Water	1.38			
	Water	0.78			
	Miscellaneous	3.73	talk with supervisor		
	Toilet	2.1			
Day 3	Water	1.89		17.95	2.7%
	Toilet	2.7			
	Toilet	2.81			
	Water	1.16			
	Miscellaneous	3.38	talk with workers		
	Miscellaneous	2.78	talk with supervisor		
	Toilet	1.77			
	Water	1.46			
Day 4	Water	1.41		15.77	2.4%
	Toilet	2.45			
	Miscellaneous	4.01	Phone call		
	Toilet	1.09			
	Toilet	3.47			
	Water	1.89			
	Water	1.45			
Day 5	Water	1.22		18.14	2.7%
	Toilet	3.57			
	Toilet	4.8			
	Toilet	1.2			
	Miscellaneous	3.71	talk with workers		
	Water	1.09			
	Toilet	2.55			

Workstation 10

Personal Activities Record Sheet					
Workstation 10					
Day	Description	min	Note	total	%
Day 1	Toilet	3.35		18.66	2.8%
	Water	1.6			
	Water	1.39			
	Water	2			
	Toilet	4.12			
	Toilet	3.1			
	Miscellaneous	3.1	talk with supervisor		
Day 2	Miscellaneous	2.89	talk with supervisor	18.91	2.9%
	Miscellaneous	4	talk with supervisor		
	Toilet	4.12			
	Water	1.09			
	Water	1.32			
	Toilet	2.4			
	Toilet	3.09			
Day 3	Toilet	4.71		22.19	3.4%
	Toilet	3.1			
	Water	1.48			
	Miscellaneous	3.27	talk with workers		
	Miscellaneous	2.77	talk with supervisor		
	Water	1.58			
	Water	1.44			
	Toilet	3.84			
Day 4	Water	1.74		16.78	2.5%
	Water	2.18			
	Toilet	3.87			
	Toilet	1.8			
	Toilet	1.03			
	Miscellaneous	3.32	Phone call		
	Miscellaneous	2.84	Phone call		
Day 5	Water	2.14		17.96	2.7%
	Toilet	3.72			
	Miscellaneous	2	Phone call		
	Miscellaneous	2.5	talk with supervisor		
	Toilet	2.3			
	Toilet	4.2			
	Water	1.1			

Appendix F3 – ILO's Method Fatigue Allowance Scoring Sheet

Scorer:	Production Manager	Relaxation Allowances: ILO's Method																			
Stress/ Strain	Types	Workstation																			
		1		2		3		4		5		6		7		8		9		10	
		Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.
Physical Strains	Average Force	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	L	2	L	2
	Posture	L	0	L	0	L	0	L	0	L	0	L	0	L	0	L	0	L	0	L	0
	Vibration	-	-	-	-	-	-	-	-	-	-	-	-	-	-	L	1	-	-	-	-
	Short Cycle	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1
	Restrictive Clothing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mental Strains	Concentration	L	1	L	1	L	1	L	1	L	1	L	1	L	4	L	4	L	4	L	4
	Monotomy	H	11	H	11	H	11	H	11	H	11	H	11	H	11	H	11	H	11	H	11
	Eye Strain	-	-	-	-	-	-	-	-	-	-	-	-	L	2	L	2	L	2	L	2
	Noise	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Working Condition	Temperature	L	2	L	2	L	2	L	2	L	2	L	2	L	2	L	2	L	2	L	2
	Ventilation	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1
	Fumes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dust	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dirt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Wet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sum			16		16		16		16		16		16		21		22		23		23
Conversion to Relaxation		7%		7%		7%		7%		7%		7%		8%		8%		8%		8%	

Continue...

Scorer:	Production Engineer	Relaxation Allowances: ILO's Method																			
Stress/ Strain	Types	Workstation																			
		1		2		3		4		5		6		7		8		9		10	
		Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.
Physical Strains	Average Force	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	L	2	L	2
	Posture	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1
	Vibration	-	-	-	-	-	-	-	-	-	-	-	-	-	-	L	2	-	-	-	-
	Short Cycle	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1
	Restrictive Clothing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mental Strains	Concentration	L	2	L	2	L	2	L	2	L	2	L	2	L	3	L	3	L	3	L	3
	Monotomy	H	8	H	8	H	8	H	8	H	8	H	8	H	8	H	8	H	8	H	8
	Eye Strain	L	1	L	1	L	1	L	1	L	1	L	1	L	2	L	2	L	2	L	2
	Noise	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Working Condition	Temperature	L	2	L	2	L	2	L	2	L	2	L	2	L	2	L	2	L	2	L	2
	Ventilation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Fumes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dust	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dirt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Wet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sum			15		15		15		15		15		15		17		19		19		19
Conversion to Relaxation		7%		7%		7%		7%		7%		7%		7%		7%		7%		7%	

Continue...

Scorer:	A.L. Supervisor	Relaxation Allowances: ILO's Method																			
Stress/ Strain	Types	Workstation																			
		1		2		3		4		5		6		7		8		9		10	
		Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.	Str	Pts.
Physical Strains	Average Force	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Posture	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1
	Vibration	-	-	-	-	-	-	-	-	-	-	-	-	-	-	L	1	-	-	-	-
	Short Cycle	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1
	Restrictive Clothing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mental Strains	Concentration	L	2	L	2	L	2	L	2	L	2	L	2	L	2	L	2	L	2	L	2
	Monotomy	H	8	H	8	H	8	H	8	H	8	H	8	H	8	H	8	H	8	H	8
	Eye Strain	-	-	-	-	-	-	-	-	-	-	-	-	L	2	L	2	L	2	L	2
	Noise	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Working Condition	Temperature	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1
	Ventilation	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1	L	1
	Fumes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dust	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dirt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Wet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sum			14		14		14		14		14		14		16		17		16		16
Conversion to Relaxation		6%		6%		6%		6%		6%		6%		7%		7%		7%		7%	

Appendix F4 – Williams's Method Relaxation Allowance Scoring Sheet

Williams's Method										
Scorer: Production Manager	Workstation									
Allowance Factors	1	2	3	4	5	6	7	8	9	10
Standard Fatigue	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Energy demand	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Posture and Motions	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Restrictive Clothing	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Discipline	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Monotony	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Concentration	1%	1%	1%	1%	1%	1%	2%	2%	1%	1%
Thermal and Atmospheric Conditions	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Physical Environment	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Visual	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Vibration and Instability	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	14%	14%	14%	14%	14%	14%	15%	15%	14%	14%

Williams's Method										
Scorer: Production Engineer	Workstation									
Allowance Factors	1	2	3	4	5	6	7	8	9	10
Standard Fatigue	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Energy demand	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Posture and Motions	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Restrictive Clothing	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Discipline	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Monotony	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Concentration	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Thermal and Atmospheric Conditions	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Physical Environment	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Visual	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Vibration and Instability	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%

Williams's Method										
Scorer: Assembly Line Supervisor	Workstation									
Allowance Factors	1	2	3	4	5	6	7	8	9	10
Standard Fatigue	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Energy demand	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%
Posture and Motions	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Restrictive Clothing	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Discipline	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Monotony	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Concentration	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Thermal and Atmospheric Conditions	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Physical Environment	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Visual	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Vibration and Instability	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	16%	16%	16%	16%	16%	16%	16%	16%	17%	17%

VITA

Mr. Tanic Huangteerakul was born on 20th April, 1990 in Bangkok, Thailand. After completing his high school from Ruamrudee International School in 2008, he pursued his bachelor degree in Nano-Engineering at International School of Engineering (ISE), Chulalongkorn University, in 2008. He completed his bachelor degree in 2012 and was employed at Pacific Pipe Limited Company as a process planning engineer. After one year of working career, he undertook his post-graduate dual degree programme in Engineering Management offered by Regional Centre for Manufacturing System Engineering (RCMSE), Chulalongkorn University and Engineering Business Management, jointly Warwick Manufacturing Group (WMG), University of Warwick.