Investigation of Production Line Balancing for Assembling 12.7mm AAG to Enhance Productivity in Medium Caliber Gafat Armament Industry

By:

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A Thesis Submitted to the department of Mechanical Engineering
School of Mechanical, Chemical and Materials Engineering
Specialization Manufacturing System

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in manufacturing System

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Approval Sheet

I/we, the advisors of the thesis entitled "Investigation of Production Line Balancing for Assembling 12.7mm AAG to Enhance Productivity" and developed by Abebe Minda, hereby certify that the recommendation and suggestions made by the board of examiners were appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by -- Abebe Minda have read and evaluated the thesis entitled "Investigation of Production Line Balancing for Assembling 12.7mm AAG to Enhance Productivity" and examined the candidate during open defense. This was, therefore, to certify that the thesis was accepted for partial fulfillment of the requirement of the degree of Master of Science in manufacturing System.

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Declaration

I hereby declare that the project/thesis entitled "Investigation of Production Line Balancing for Assembling 12.7mm AAG to Enhance Productivity," in Gafat Armament Engineering Industry was submitted for the masters of degree was my original work and the thesis has not formed the basis for the award of any degree, associateship, fellowship or any other similar titles.

______________________	____________________	______________
Name of the student	Signature	Date

Recommendation

In partial fulfillment of the requirements for the Master of Science in Manufacturing Engineering degree, I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Investigation of Production Line Balancing for Assembling 12.7mm AAG to Enhance Productivity," prepared under my/our guidance by Abebe Minda. As a result, I/we advise submitting the thesis to the department in amended form in accordance with the relevant protocols.

______________________	____________	__________
Advisor	Signature	Date

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List of Acronyms, Abbreviation's and Symbols

AAG	Anti-Aircraft Gun
ALB	Assembly Line Balancing
ALBP	Assembly Line balancing problems
BL	Balancing Loss
FFD	First Fit Decreasing
GA	Genetic Algorithm
GAEI	Gafat Armament Engineering Industry
JIT	Just in Time
KWM	Kilbridge and Wester Method
LCR	Largest Candidate Rule
LOB	Line of Balance
MM	Millimeter
MADM	Multiple Attributes Decision Making
N	Workstation
OT	Observed Time
PFD	Personal Fatigue and Delay
QC	Quality Control
RPW	Ranked Position Weighted
SALB	Simple Assembly Line Balance
T	Total Processing Time
Tek	Work Element Time
Ts	Service Time
TQM	Total Quality Management
TQM	Total Quality Management
WIP	Work in Progress

ABSTRACT

The optimization of the assembly line balancing for 12.7mm AAG products in the Gafat Armament Engineering Industry was conducted to improve productivity. The existing production or assembling line was evaluated as the standard to enhance efficiency. In the production process, assembly line balancing was conducted. The problem of existing line balancing was time wastage due to allocating tasks among workstations so that facilities and personnel were insuffently used while the work sequence was upheld.

In this study, the multiproduct assembly line balancing problem (MALBP) for the hybrid system and the Rank positional weight approach for Type I of the Simple Assembly Line Balancing Problem (SALB P) were described. Assigning tasks to work stations so that the number of stations was kept to a minimum for a given production rate and cycle time was a component of both MALBP and SALBP Type I (SALBP-1). In order to sustain and create competitive advantages, to reduce labor overload in order to boost assembly production efficiency and decrease time wastage between workstations.

Therefore, an effective line balanced was suggested in light of the manufacturing areas. Utilizing stopwatch time and data observation, the efficiency was optimized from 74 percent to 103 percent by applying the rank position weighted heuristic approach. In order to organize the work components into the workstation using the line balancing technique, a new work sequence has also been devised.

Keywords:-Assembly line, Line balancing, RPW, Line efficiency ,Smoothness Index, Precedence, System Loss

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

The goal of this thesis study was to increase productivity for assembly line balancing by applying strategies from the assembly line. Line balancing has shown to be a useful strategy in this armaments and weapons manufacturing company for reducing staffing levels while increasing output.

Generally, optimize assembly line was one of the sections of cellular manufacturing which consist of major workers in lean manufacturing. The concept of line balancing itself was everyone was working together in a balance manner where everyone doing the same amount of work, the deference was smoothed, no one was overburden, no one was waiting and the work being done in a well single piece flow

Moreover, rearranging the work stations and distributing the workload evenly among assemblers can help accomplish balancing and ensure that each task takes roughly the same amount of time. Additionally, line balancing decreases the number of workers and workstations, which can save expenses and space requirements for the assembly area. This was only one of the numerous advantages that line balancing offers. Line balancing also has the advantage of being able to pinpoint the bottleneck-causing process and reducing it through operator work standardization. In addition to identifying bottlenecks, line balancing distributed the effort throughout the workforce to prevent any individual from being overworked (Hisham, 2013).

Assembling line balance involves assigning tasks to machines with the goal of decreasing human workflow, cutting down on throughput time and work-in-progress, and ultimately increasing productivity. Division of labor was the practice of assigning multiple persons to a single task. By making sure that each station was worked at roughly the same amount of time, the division of labor should be balanced equally. Every single stage of the product assembly process needs to be thoroughly examined and assigned to stations in a way that balances utilization of the available workstations. After that, every operator completes tasks correctly, and the work flow was coordinated. Short distances between stations, a low volume of work in progress, accurate scheduling of production periods, and a predictable production quantity were all characteristics of a synchronized line in a comprehensive work flow (Islam, Mohiuddin, Mehdi and Sakib, 2014).

Industrial factories must increase their production capability and efficacy to compete with their market rivals in light of the rapidly rising demand for their products. The production process must simultaneously be able to operate at a reduced cost and a higher level of effectiveness. As a result, the approach taken to resolve the manufacturing issue was important. There were a number of approaches to address productivity-related issues, including standard time, quality control (QC), and total quality management (TQM) (Reyneke, 2011).

1.2. Statement of the Problem

In the existing assembling process, determining which station from line 1 and which from line 2 save assembly time at efficient and effective system was challenging. In addition to this; there was scheduling problem for the right part at station to assemble. An extension of single assembly line balancing difficulties with several parallel manufacturing lines was also big challenge. Every lines produces a different good but global cycle time was the same for every line. By merging station loads of nearby lines in the balancing step, which allows one operator to service the lines instead of two, the line efficiency can be increased based on organizing the line in a favorable way. In other words, the ways the lines were arranged affects how each line's balance difficulty was related to the others. Therefore, in order to achieve good line balance in the sector, limiting the number of operators and production time were essential.

1.3. Objectives of the Study

1.3.1. General Objective

The main goal of this thesis was to investigate problem of production line balancing for the assembly of 12.7mm AAG in order to improve productivity in the medium-arms industry by evaluating the existing process.

1.3.2. Specific Objectives

The following were specific objective of the thesis:

1. To investigate assembly line bottleneck of the existing system causing a delay.

2. To analyze the production costs of existing system in order to improve productivity.
3. To calculate the number of workstations that was practical and efficiently divides the workload among employees in order to check the efficiency.
4. To develop a hybrid type of automated and manual assembly to optimize the production line.
5. To reduce the overall idle time and number of operators needed to complete a certain amount of work at a given time on the assembly line.

1.4. Significance of the study

Assembly line balancing was a manufacturing system that was commonly utilized. Assembly line balancing was an issue that involves minimizing the number of workstations, minimizing cycle time, maximizing the smoothness of the workload, and maximizing the relatedness of the task. It was employed to swiftly assemble big quantities of a consistent product. Assembly lines were first created to produce standardized goods in large quantities at a low cost. This was done in order to take advantage of the high worker specialization and related learning effects. On the other hand, assembly line balancing (ALB) allows for the application of modern production tactics like mass customization and makes effective flow-line systems available for low volume assembly-to-order production. Numerous advancements in production systems have occurred since Henry Ford's time, transforming assembly lines from rigid, single-model lines with precise timing to more adaptable systems with buffers in between. The manufacturing process was significantly accelerated by the assembly line. It helped many workers who used to spend up to 10 or 12 hours a day in the factory trying to meet quotas by enabling factories to produce goods at a remarkable rate and by managing to reduce the labor hours necessary to complete a product.

1.5. Scope of study

The investigation of production line balance for the assembly of a 12.7mm AAG assembly line will be the main subject of this study. GAEI created the medium caliber production factory, among other factories. Various kinds of weapons, such as overhauled and newly constructed products, were produced in this factory. RPW techniques will be used to assess the company's data that has been gathered. Furthermore, ongoing enhancement initiatives will be carried out to further enhance the workstation.

1.6. Expected outcome of the Study

Following the study's conclusion, Gafat Armament Engineering Industry will set up an ideal production assembly line balancing for 12.7mm AAG weapons, guaranteeing lower assembly costs and appropriate operator utilization. Overall, this study demonstrates how to assemble 12.7mm AAG for the Gafat Armament Engineering Industry in a method that was both economically feasible and will strengthen Ethiopia's security.

1.7. Relevance of the Project in Light of Current Situation

The corporation will adopt the suggested new balance line design to optimize its assembly line, which was, why this study was important to the organization. The best possible balance between floor area, manufacturing process, and output should be achieved via an assembly line balancing system. It streamlines the production process, cuts down on time, expense, and material handling while enabling simple production flow, operational flexibility, and the efficient use of labor. The following goals can be accomplished with the help of an effective assembly line balancing:

- To guarantee that work moves forward without interruption from one location to another
- Provide adequate space for production.
- Employ labor effectively

1.8. Limitation of the Study

The following were some of the limitations of this study: -

- Lack of proper documentation of the company
- Lack of reliable data source
- Lack of continuity on the customer demand
- Financial problem for transportation and printing
- Power fluctuation.

1.9. Thesis outline

There were five chapters in this thesis research: An overview of the investigation into the assembly line balance of 12.7mm AAG to increase productivity was covered in Chapter 1. The problem statement, importance, scope, aim, anticipated result, and limitations of this thesis were also explained. The concept of assembly line balance, its history, and a thorough literature analysis were all covered in detail in Chapter 2.

The third chapter provides a data collecting methods, tools, and procedures. Chapter 4 includes data computation, analysis, performance evaluation findings, and evaluation-related discussion. In chapter five, the thesis outcome was finally summarized and future study directions were provided along with some closing thoughts.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Assembly line manufacturing is the process of producing goods by moving them between locations where different parts of their assembly were completed by use of an automated conveyor. It's used to assemble large volumes of a reliable product fast. Assembly lines were originally developed to exploit the high labor specialization and ensuing learning effects to produce standardized goods in large quantities at a low cost. However, the implementation of assembly line balance (ALB) made effective flow-line systems available for low volume assembly-to-order manufacturing, hence enabling modern production methods. This suggests that in the near future, meticulous planning and execution of assembly systems and workstations—while optimizing one or more objectives without going against constraints placed on the line—will continue to be extremely relevant practically. In 2ALB situations, several objectives were taken into account. In actual, it was frequently preferable to distribute the burden evenly and, if at all possible, to assign related tasks to the same workstation. To do this, we employed the line balancing technique.

1. Reducing the number of workstations
2. Reducing duration of cycle time
3. Increasing the workload smoothness
4. Increasing work relatedness.

A manufacturing process was known as an assembly line involves adding replaceable pieces to a product one after the other in order to generate the final result. Henry Ford and his engineers employed the assembly line for the first time. Additionally, Ford was the first in constructing factories based on that idea. An optimization issue of great economic significance has been line balancing; the difference in efficiency between an optimal and a sub-optimal assignment can result in annual savings (or waste) of millions of dollars. Lower manufacturing costs made it possible for businesses to compete more successfully and to fully utilize the potential of the market. Assembly line systems can in a variety of forms; among popular variants were the traditional automated intermittent and lean manufacturing methods. A variety of products were frequently made using these assembly line techniques. Certain traits were shared by assembly lines.

Since Henry Ford invented assembly lines, line balancing has been a major industrial optimization problem. Lower manufacturing costs led to more competitive prices for manufactured goods, better market Workstations coupled by material handling devices make up a basic assembly line. A workstation was a location on an assembly line where a specific portion of the job required for assembly was completed. In an assembly line, every workstation was equipped with all the tools, equipment, personnel, and even robotic arms that were required for the various tasks or operations that were allocated to it. An assembly line's fundamental operation starts with the feeding of a part into the first workstation. Following receipt of the parts, the designated operation(s) will be carried out by the first workstation. After the procedure was finished, a material handling device will transfer the part to the following station, where it will be used for the designated operations (Bung Wai Kit, 2018). xploitation, and higher firm competitiveness (Reyneke, 2011).

Putting together One of the most common issues in manufacturing companies is line balance. The manufacturing engineer first creates an assembly work diagram that lists all of the tasks and their order of precedence. Next, the cycle time was chosen based on the demands of manufacturing. The next challenge was to divide the jobs into several stations while ensuring that: (1) the precedence relation was maintained, meaning that no task can be started until all of its earlier work components have been finished; and (2) the process time of each station does not exceed the cycle time. There were two approaches implemented to solve ALB problems: manual and computerized. Small-scale ALB problems (with less than 15 jobs) can be solved manually; large-scale and integrated problems require computer assistance. The computer-aided assembly line balancing techniques need to enable the investigation of number options for assigning responsibilities to the various stations (Manoria, Mishra, and Maheshwar, 2012).

A series of consecutive workstations connected by a material handling system was called an assembly line. Each workstation has a set of tasks that were completed using a predetermined assembly process that defines the following: (a) task time, or the amount of time needed to complete each task; and (b) a set of precedence relationships, or the order in which the tasks were completed.

The goal of line balancing was to reduce the imbalance force between the worker and the machine by regulating the maximum output by using the minimum number of workstations (Plenert, 1997). Many companies use the line balancing (LB) technique to improve the productivity in the line by reducing the number of labors, reducing the ideal time, and producing two products at the same time. Line balancing (LB) was very important for companies in the mass production type, according to (Yulianti, 2018). with the creation of trajectory balance, an optimal production capacity and high level of work efficiency will be achieved.

Maximizing a manufacturing system's productivity was one of its primary objectives. The type and complexity of the product produced, the caliber of the raw materials, the intricacy of the manufacturing process, and the configuration of the workstations that make up the production process were some of the variables that affect this. Certain criteria were fixed and cannot be altered since they were specific to the product; others, on the other hand, were flexible and can be adjusted. One of the factors that significantly affects system performance was the difficulty of figuring out the optimal workstation arrangement (Micieta and Stollmann, 2011).

2.2. History of Assembly Line

The contemporary factory system emerged as a result of the Industrial Revolution, which elevated technology to a prominent position in production processes. The Industrial Revolution, which began in the 18th century and lasted the whole 19th and 20th century, encompasses a number of discoveries and inventions pertaining to energy, transportation, and material processing technologies. These modifications had an effect on society at large in addition to production systems (Pearce, 2015).

2.3. Assembly Line

Assembly line, was the assembly method where the product was going to number of workstations for assembly one piece at a time. The work was divided into each station in order to complete the total work which means each station makes one small assembly. There were two primary methods of assembly in the industry, which were bench assembly, and assembly line. In bench assembly, the work-piece stays stationary on a bench; all required parts and equipment for assembly were brought to the bench and assemblers move around the bench to perform the assembly. Assembly line was an assembly method where work-pieces move through a sequence of stations for assembly pieces by pieces. According to Rajinith (2015), an assembly line was a production system that uses the assembly line method and has assembly stations arranged in a serial layout.

The word "assembly line" refers to a manufacturing process in which workstations were connected by conveyors or a similar material handling system, allowing each product to proceed directly from one operation to the next and so on. An assembly line was made up of a number of workstations that consistently perform specific operations on a work piece in a cycle time. As a result, each product follows the same routing of operations, and at the end of the line, an identical final product was expected. The complexity of a product's production process primarily depends on the number of its components and the assembly levels Mohamed (2013).

2.3.1. Types of Assembly Line

Assembly line systems can have a variety of forms; some popular varieties were the automated, intermittent, classic, and lean manufacturing models. A variety of products were frequently made using these assembly line techniques. Certain traits were shared by assembly lines.

There were numerous varieties of systems used in assembly lines. Lean manufacturing and the traditional automated intermittent modes were two popular variants. A variety of products were frequently made using these assembly line techniques. Three categories were distinguished on the assembly line:

2.3.1.1. Single-Model Assembly Line

A product that has one model was produced on a single model assembly line. Every work component at every station has the same work, and the line's final product was the same. An advanced manufacturing technology that was negotiated in terms of time and money and allows for the automated setup of operations, this type of assembly system was known as a single model line.

2.3.1.2. Mixed Model Assembly Line

The process of constructing multiple different models of a product on the same assembly line without any changeovers and then arranging those models in a way that reduce the demand for upstream components was known as mixed-model production. Even with enormous efforts, highly homogenous manufacturing processes were typically needed to increase the versatility of production systems.

2.3.1.3. Multi Model Assembly Line

When several or one component were sent through a processing line to produce various end items or finished goods, including waste or by-products, multi-product manufacturing helps process manufacturers. Numerous costing and yielding techniques were available, along with serial control for components and finished goods.

The idea of a combined precedence diagram was to integrate several models into a single, equivalent model. The union of the nodes and the precedence relations of the diagrams for each model were used to create the combined diagram. With precedence matrices, the combined diagram was easily constructed. Figure 2.1 provides a straightforward example to show how to create a composite diagram. Tasks were represented by the numbers inside the circles, and the precedence relations were indicated by the arrows that connect the circles.

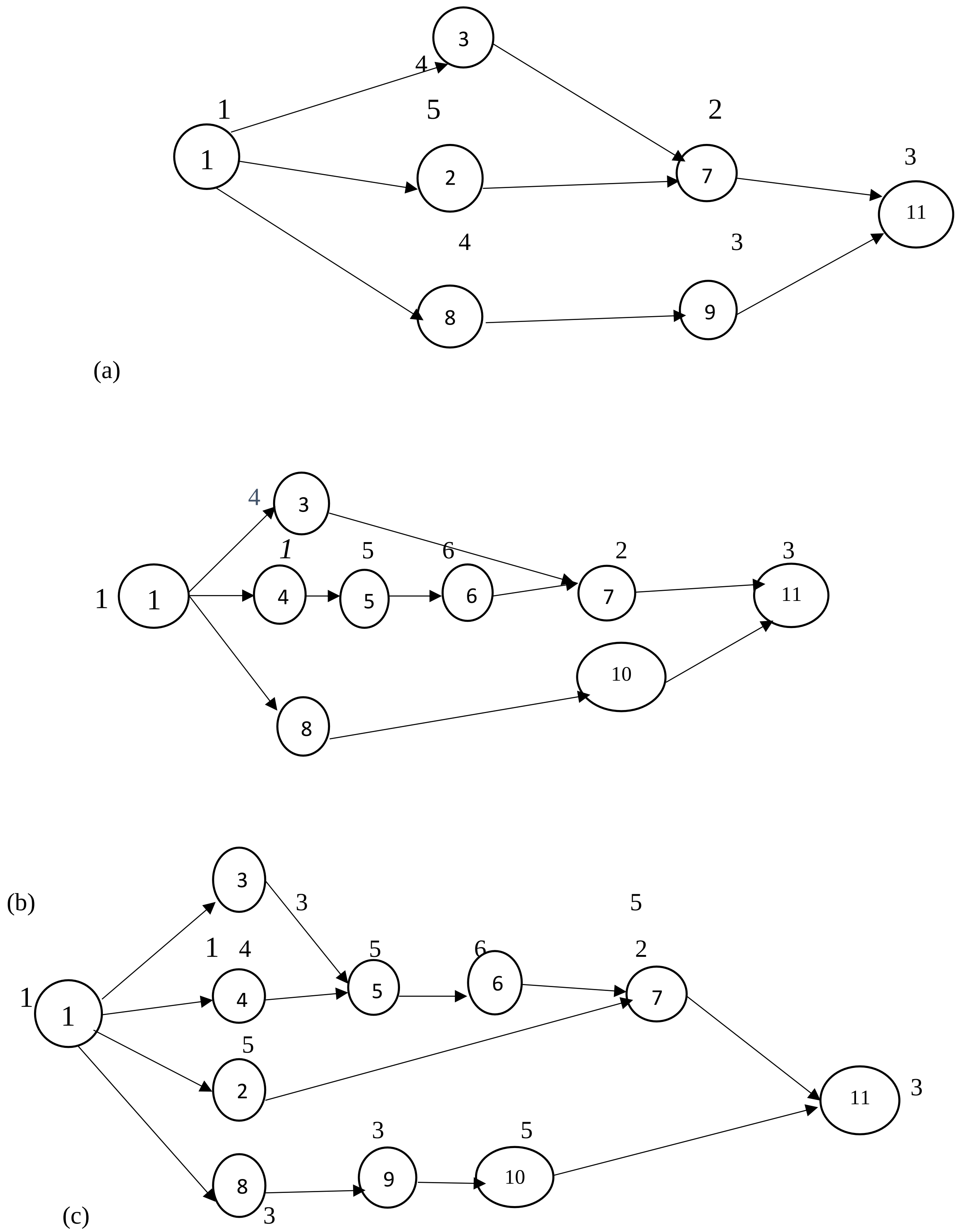


Figure 2.1. a–c. Precedence diagrams of a model A b model B c combined precedence Diagram.

2.4. Assembly Line Balancing

Line balancing was the arranging a production line so that there was an even flow of production from one work station to the next. Line balancing also a successful tool to reduce bottleneck by balancing the task time of each work station so that there were no delays and nobody was overburden with their task (Hisham, 2013).

Optimization of the traditional ALB problem seeks to minimize total idle time by minimizing of the number of stations (or workers) used, given a fixed cycle time. Transformed the mixed-model problem into a single model version by taking the demand averaged time for each task. Line balancing seeks to equalize the work content at a station across all model alternatives, such that the resulting balance was more robust to changes in model demand and production sequencing (Pearce, 2015).

Assembly line balancing was the process of equally distributing tasks to each assembly station in the line such that each workstation receives the same amount of work. The significant thing was to balance the workload of the operator at every station, reducing the operator idle time over the takt time which means the decrease of unused idle station capacity. A well-balanced workstation gives various advantages in reducing wastes, including worker idleness, and need of changing operator, defective product and stocks. It also enables the company to lower the price of their commodity by lowering the unit's production cost (Ranjith, 2015).

Assembly line balancing was one of the important indicators of measuring the level of production process. And the assembly production balance rate was higher, the greater efficiency which production line makes (Yin and Jiang, 2016, June).

2.5. Balancing Terminology for Assembly Lines

Assembly line: - An Assembly was made up of a number of workstations, arranged serially. These stations were linked together by a transportation system that aims to supply materials and move the production item from one station to next one.

Line Balancing: - Line Balancing was leveling the workload across all processes in a cell or value stream to remove bottlenecks and excess capacity. A constraint slows the process down and results if waiting for downstream operations and excess capacity results in waiting and absorption of fixed cost.

Bottleneck - Delay in transmission that slow down the production rate. This can be overcome by balancing the line.

Precedence: - The product can't be move to the next station if it doesn't complete at the previous station. The products flow from one station to the other station. In assembly line the products have to obey this rule. It can be represented by nodes or graph. It establishes the order and priority of actions. The operations in the precedence diagram were divided into parallel and series operations. The parallel operations can be done at same time without disturbing each other, and the series operations were done one after the other with respect to the precedence (Ranjith, 2015).

Smoothness Index: -This was the index to indicate the relative smoothness of a given assembly line balance. Smoothness indeed was zero Indicates perfect balance

Balancing Loss: - The concept of balancing loss was a measurement of an assembly line's efficiency. It was defined as the loss incurred as a result of allocating work elements to workstations. And was given by:

$$\text{Balance loss (BL) (\%)} = \frac{N \times T - \sum_{i=1}^{n} t}{N \times T} \tag{2.1}$$

Where: N- total number of work stations , T- takt time, T_i – station time of station i

The underlying objective was to minimize BL subject to precedence constraints. However, the objective of minimizing BL generally leads to multiple solutions, which may not be equally efficient in the sense of system loss. Our proposed work was a multi-objective one where minimization of balancing loss was to be addressed along with minimization of system loss (Roy, 2011).

System Loss: - In general, it was self-evident that each operator requires a different amount of time to complete the operation; this results in a distribution of assembly time. As a result, these distributions were negative. Handling losses, such as handling the tool, getting materials, or reading the job instructions, were also related to system losses (Ranjith, 2015).

2.6. Time Study

Time study was a technique used to establish a time standard to perform a given assembly operation. It was based on the measuring the work content of the selected assembly, including any personal allowances and unavoidable delays. It was the primary step required to determine the opportunities that improve assembly operations and set production standards. Work measurement techniques, such as stop watch time study, measure standard time data and give more accurate results. Work measurement using a stop watch requires (Yerasi, 2012).

The key objectives of a time study were:

- To increase productivity.
- To balance the work force with available resources.
- To determine the production capacities

Cycle Time: - Cycle time was the Maximum amount of time allowed at each station. This can be found by dividing required units to production time available per day. Generally, stopwatch was used to measure the cycle time. The formula to determine the cycle time was-

$$\textbf{c}\text{ycle time} = \frac{\text{production run time per day}}{\text{total produced parts per day}} \tag{2.2}$$

Lead Time: - Summation of production times along the assembly line or Total time required to manufacture an item or it was the time that elapses between when a process starts and when it was completed.

$$\text{Lead time} = \sum \text{Production time along assembly time}$$

Takt Time: - The rate to which an industry or a company needs to produce the product to satisfy, the customer demands was called as Takt Time (Rashmi Sarmah). The formula for Takt Time was-

$$\text{Takt time} = \frac{\text{available time per day}}{\text{customer demand per day}} \tag{2.3}$$

Idle Time: -Idle time was the time specified as period when system was not in use but was fully functional at desired parameters. The idle time was waiting time, since the operator was idle after performing the all the operations and the work piece was not being moved to the next station. The sum of all idle times for all stations in the line was termed as balance delay time. The idle time can be expressed as,

$$\text{Idle time} = \text{takt time} - \text{cycle time} \qquad (2.4)$$

Tolerance Time: - Tolerance time was defined as the time required for work-piece to complete all operations in the current station and to be delivered to the next station.

Throughput Time: - The throughput time was equal to the total process and waiting times of the assembly line. It was defined as the total time required for a work piece to enter and leave the assembly line as completed product (Ranjith, 2015).

Operation Time: - The time between the start and the end of an operation at a station was known as operation time. The operation time can be measured by time studies either by stopwatch, video or image processing techniques.

2.7. Poka–Yoke

Poke-yoke was a Japanese term which means “mistake proofing” commonly referred to “error proofing”. It delivers a visual or other signal which represent a characteristic state of the work task. It was a manufacturing practice of preventing error by designing the production process, tool and equipment so that the operation cannot be performed inaccurately (Ranjith, 2015).

2.8. Work Stations

A workstation was a section in a production line where were certain amount of work was performed. The workstation was characterized by dimensions and was set up with machines, materials, equipment, tools, fixtures and operators needed to perform the assigned operation. Depending on how the job was done, the workstation might be subdivided into manual or automatic stations. An assembly system may consist of one or several workstations (N) (Pearce, 2015).

$$N = \frac{T(\text{standard total processing time})}{cycle\ time} \qquad (2.5)$$

2.9. Operators

An operator was a person who completes the operation or task in an assembly line. The operator can do their tasks manually, using a hand tool, or semi-manually, using an automatic tool or task-specific equipment (Ranjith, 2015). To perform all tasks in an assembly line by a minimum number of operators required was calculated by:

$$Minimum\ number\ \text{of operators} = \frac{total\ assembly\ time}{takt\ time} \qquad (2.6)$$

2.10. Material Flow

The continual transfer of raw materials, components, and parts to the production system from their source of location, such as a warehouse, supplier, sub-assembly, kitting, and so on, was referred to as material flow. Material flow was a critical part of manufacturing that can have an impact on the entire system if a mistake arises during this phase. Sometimes it may stop the work of whole production system until the necessary part was received (Ranjith, 2015).

2.11. Productivity

It was the ratio of desired output to the input. Productivity depends on several factors such as labors, machines and methodologies used (Rashmi Sarmah).

$$\text{productivity} = \frac{\text{output}}{\text{labour} \times \text{production time per day}} \qquad (2.7)$$

2.12. Problems in Assembly Line Balancing

Assembly line balancing was the problem of assigning various tasks to workstations, while optimizing one or more objectives without violating any restrictions imposed on the line. Assembly line balancing problems were classified into three;

- type I Problems
- type II problems

- type III problems

In type I Problems, with a fixed cycle time, costs may be minimized by reducing the total labor hour (i.e., the number of workers).

In type II problems, with a fixed number of stations, throughput was an output variable that was maximized by minimizing the cycle time. Since this requires a predetermined number of workstations.

In type III problems, draws on the economic motivations of both the Type 1 and Type 2 problems in tandem and Multiple operators. Once a workstation features more than one operator, the workstation's lead time ceases to be a simple sum of durations of all operations assigned to it. This project was focused on type-1-line balancing problem. Relevant data obtained from a GAEI was used to formulate the solution. The objective of this project was to balance the cycle time for various operations and increase productivity (Parvez, Amin and Akter, 2017).

2.13. Heuristic Procedures

The balancing of an assembly line was dependent on a number of dynamic assumptions and considerations. Since there was no definitive solution, the solution was versatile. The heuristic approach was a strategy that does not provide ideal or optimum assurance. However, researchers have used it in a variety of case studies. The goal of line balancing was to balance the whole workload on the assembly line among the workers as evenly as feasible. The requirements in this part were many strategies for solving the line balancing problem utilizing data collection. The following were the three-line balancing algorithms:

2.13.1. Largest Candidate Rule

LCR's basic principle was to assign tasks to workstations based on their processing times. Preparation of a tasks list has to be done before tasks assigning begins. In this method, work elements were arranged in descending order according to their T_{el} (work element) values. LCR considers the cycle time and precedence relationship in line designing. In this method, the work elements were assigned to workstations based on size of elements time, T_{ek} (work elements time) values. The algorithm consists of the following steps:

1. Assign elements to the worker at the first workstation by starting at the top of the list and selecting the first element that satisfies precedence requirements and does not cause the total sum of T_{ek} at that station to exceed the allowable T_s(service time) when an element was selected for assignment to the station, start back at the top of the list for Subsequent assignments;
2. When no more elements can be assigned without exceeding T_s then proceed to the next station;
3. Repeat steps 1 and 2 for the other stations in turn until all elements have been assigned.

2.13.2. Helgeson-Birnie (Ranked Positional Weight) Method

Helgeson and Birnie (1961) introduced the RPW approach. The RPW heuristic's primary concept was to assign the tasks—which consist of lengthy chains of subsequent tasks—first. The number of successor tasks or the total task times of the successor tasks can be used to determine the length of the chain. PW, or the longest path time for the associated task in the precedence diagram, was the sum of the task's processing time and the processing times of all of its successors. The positional weight of the job in the RPW technique was determined by adding the task processing time and the task processing times of the subsequent tasks. The jobs were ordered using positional weights in descending order. This method was selected because it calculates the Tek value for every RPW element and indicates where it falls in the precedence hierarchy. This method was selected because it calculates the Tek value for every RPW element and indicates where it falls in the precedence hierarchy. The assembly line in production was also connected to this strategy. Next, according to their RPW values, the elements are arranged on work stations in general order (Deshpande and Joshi, 2007, January).

Steps: -

1. Draw the precedence diagram
2. For each work element, determine the positional weight.
3. Rank the work elements in descending order of ranked positional weight (RPW).

4. Assign the work element to a station. Choose the highest RPW element. Then, select the next one. Continue till cycle time was not violated. Follow the precedence constraints also.
5. Repeat step 4 till all operations were allotted to one station.

There was no more effective way to assign work items to stations than the RPW methodology. Using the RPW method, you can decide how much cycle time to allot and then figure out how many work stations the manufacturing line needs, or vice versa. This cannot be accomplished with any other kind of line balancing. We calculate the necessary cycle time for each station

Traditionally, heuristic line balancing approaches use an iterative solution procedure to distribute tasks to stations one at a time. Depending on whether iterative process was nested inside the other, the iteration searches both the set of unassigned tasks and the set of stations for a feasible match. This leads to two distinct broad approaches to the structure of the iteration (Pearce, 2015).

A traditional SALB solution heuristic that employs the task-oriented method was RWP (Helgeson and Birnie). It minimizes the number of stations while solving the Type 1 ALB with a fixed cycle time. Let; Pi be the set of all tasks that were predecessors to task i, and Qi be the set of all tasks that were successors to job i. Next, for each activity, the ranking positional weight score (Ri) was determined by

$$\mathrm{R_i} = \mathrm{T_i} + \sum_{\mathrm{J=Q_i}} \mathrm{T_j} \qquad (2.8)$$

i.e. the RPW of a task was its own time plus the sum of all successor task times.

Where; T_i − starting task time

T_j _ finishing task time

R_i − rank position weighted starting

Q_i − total number of task time

2.13.3. Kllbridge and Wester Method

Since in 1961, this method has drawn a lot of attention. It presented a heuristic based on the cumulative performance times, and it appears to have worked well when applied to a number of challenging line balancing problems in the industrial setting. Using a heuristic process, work elements were assigned to stations based on where they were in the precedence diagram. This solves a problem with the largest candidate rule, which allows an element to be chosen regardless of its precedence diagram position if it has a high Te value. Generally speaking, the largest candidate rule was not as good as the line balancing solution offered by the Kilbridge and Wester technique.

It calculates the cumulative performance time of each layer (the sum of the times of the layers it succeeds) as well as the time for each layer (the total of the processing periods of the jobs that belong to a specific layer). It locates the layer that just fills or overfills the station by moving in units of a layer from the left to the right (Rekiek, Dolgui, Delchambre and Bratc,2002).

2.14. Just in Time

The goal of the just-in-time (JIT) manufacturing system was to maximize material and components management by cutting down on waste and non-value-added activities. Just-in-time (JIT) manufacturing was the process of producing components, materials, or finished goods precisely when needed, in the required quantity and quality. By using JIT, the in-process inventory and related costs can be reduced. By enhancing manufacturing flexibility, this strategy also raises customer satisfaction. Different lot sizes have a direct impact on inventory and lead times. Small lot production shortens lead times and lowers inventory. Use small lot size to optimize the assembly line in a 12.7mm AAG production line. That was the batch size was modified to lower lot size in order to shorten the lead time and improve the throughput. This project suggests using a straight-line balance. Straight-line manufacturing and a just-in-time method are used in many production lines. examined how the production system, assembly lines, and the ongoing advancement of both humans and machines were affected by the line balance issue (Pisuchpen and Chansangar, 2014).

2.15. Methods of Line balancing and their effects

The collection of data that was pertinent to and helpful for this endeavor depends on the literature review. In the end, the information and data analysis will offer a deeper comprehension of the issues that now plague the active components assembly area and the ways in which different approaches might be employed to address these issues. The main goal was to combine several assembly line techniques to develop an ideal solution, then use simulation software to save costs and increase assembly area productivity (Wiyaratn and Watanapa, 2010).

Onc u Haz_r. This research aims to identify and address open issues with a broad range of real-world applications. The conclusions presented could be useful in creating decision support systems (DSS) for assembly line planning that was both profitable and economical.

Pachghare. Vrittika. In an effort to reduce manufacturing time, this study evaluates assembly line balancing techniques and looks for the most recent advancements and market trends.

Zhang Wenqiang. A well-known manufacturing optimization problem was the Assembly Line Balancing (ALB) problem, which assigns different jobs to stations in an ordered sequence while optimizing one or more objectives without going against line constraints. Genetic Algorithms (GAs) have been a popular optimization tool in the manufacturing industry, and as a result, their application to ALB problems has grown significantly. A generalized Pareto-based scale-independent fitness function (gp-siffGA) was described in this study for addressing the ALB problem with worker allocation (ALB-wa) in order to simultaneously minimize cycle time, workload variance, and total cost while adhering to precedence relationship constraints.

Becker, Christian. Research on assembly line balancing has typically concentrated on the rather restrictive simple assembly line balancing problem (SALBP).

Lucas. The Assembly Line Balance problem (ALB) was addressed in this study using the Assembly Line Balance Optimization Model (ALBO). At the moment, ALB relies on human specialists. We used an evolutionary approach that was derived from the Ant Colony Optimization method. The ALBO model was tested using the efficiency records of three handbag models that have been running on the production lines for two months. It demonstrates that the model can raise efficiency by around 13.88%. This was a huge improvement since the real production process's efficiency was now 15% less efficient than the industry average, which might result in millions of dollars in profit.

Jaturanonda Chorkaew. This paper offers a heuristic process for allocating assembly tasks to workstations that simultaneously takes ergonomics and productivity concerns into account. The process minimizes the assembly line's balancing delay by using Kilbridge and Wester's algorithm to determine the initial task-workstation assignment solution. Using a job reassignment algorithm, assembly tasks that reduce worker postural strain were switched between workstations to improve the original solution.

Sivasankaran, P. An attempt was made to provide a thorough analysis of the assembly line balancing literature in this study. Three factors determine the eight varieties of assembly line balance problems: the number of models (single- and multi-model), the type of assembly line (straight-type and U-type), and the nature of job times (deterministic and probabilistic).

Boysen, Nils. In this work, assembly lines were specialized flow-line production systems that were crucial to the industrial manufacturing of standardized goods in large quantities. Assembly lines have even become more significant recently in mass-customization, or low volume manufacture of bespoke goods.

Li Yang, 2019. The study was titled "Optimization for Assembly Line Systems Using Simulation." Based on the Discrete Event Simulation (DES) technique, this analysis examines the optimization for an assembly system in an industrial scenario. The objective of the simulation system was to generate multiple configurations of the intended production system and, specifically, to provide a resolution that would lower labor demand and address bottlenecks in the system.

Stadnicka, G. Bruno, and Antonelli (2017). The purpose of this study was to minimize machine and operator idle time by allocating line balancing responsibilities among employees and work stations. There were two approaches to address the issue of worker job assignment: a work-sharing system or a fixed assignment system. The assignment policy in a fixed assignment was developed using the workers' pre-existing knowledge. Under the job-sharing concept, employees must be cross-trained and dynamically moved from one station to another in order to balance the workload. The analysis's findings indicate that the optimal option was to hire nine operators who use a one-piece flow manufacturing technology to finish the production process. This will lead to the production of the necessary quantity of goods using the best laborers, workstations, and a well-balanced workload.

Helgeson and Birnie (1961) used a ranking positional weight technique to tackle the assembly line balancing problem. A multi-attribute-based method was used by Kabir and Tabucanon (1995) to tackle the batch model assembly line (two or more products) problem. Monden (1993) was interested in assembly line sequencing that would take into account the stability of part utilization rates. A heuristic approach was presented by Miltenburg (1989) to decrease "lumpiness" in raw material utilization and quantify the stability of components usage rates. Shortest-route formulation was utilized by Erel and Gokcen (1999) to optimize task time for various models while taking precedence constraints into account. A binary integer formulation for the mixed-model assembly line balancing problem was created by Erel and Gokcen (1998). Another study by Erel and Gocken (1997) employed a combined precedence diagram—a technique first introduced by Thomopoulos (1967)—to create a goal programming approach. Vilarinho and Simaria (2002) devised a two-stage heuristic method for balancing mixed-model assembly lines.

Assembly lines were designed for a sequential organization of workers, tools or machines, and parts; worker motion was minimized to the greatest extent possible (Micieta and Stollmann). The development of the assembly line revolutionized manufacturing and contributed to the higher level of the Industrial Revolution.

Kumar Naveen. In order to reduce the overall cost of equipment and the number of workstations, this paper evaluates several works in the field of assembly line balance and looks for the most recent advancements and industry trends.

Table 2.1. A summary of a few chosen ALB-related publications released between 2000 and 2018

Authors	Line type	Type of modeling	No. objectives	Solution method
(Sabuncuoglu, Erel andTanyer,2000)	Single-model ALBP	------	One	Genetic algorithm
(Ağpak and Gökçen, 2005)	SALBP	zero-one integer programming	One	GAMS-CPLEX
(Baykasoglu, 2006)	straight and U-type ALBP	------	Two	Simulated annealing algorithm
(Baykasoğlu and Özbakır, 2007)	Stochastic UALBP	------	One	Genetic algorithm
(Wu and Hu, 2008)	2S-ALBP	zero-one integer programming	Two	Branch and bound algorithm
oksari, Işleyen, Güner and Baykoç, 2008)	SALBP & UALBP	------	One	Learning effect
(Lin, Che, Chiang, Che, and Chiang, 2009)	ASP^2	Binary linear programming	Two	Particle swarm optimization & Genetic algorithm
(Kilincci, 2010)	SALBP-type2	------	One	Petri net-based heuristic algorithm
(Kilincci, 2011)	SALBP-type1	------	One	Petri net & Firing sequence backward
(Wei & Chao, 2011)	SALBP-type E	Binary linear programming	One	Excel
(Tavakkoli Moghadda, Gholipour-Kanani and Cheraghalizadeh, 2012)	mixed-model ALBP	Binary linear programming	Two	Genetic & Memetic algorithm
(Zheng, Li, Li, and Tang, 2012)	SALBP-type1	------	One	Ant colony optimization
(Ağpak, Yegül, and Gökçen, 2012)	2S U-type ALBP	zero-one integer programming	Two	GAMS-CPLEX
(Manavizadeh, Hosseini, Rabbani and Jolai, 2013)	UALBP	Mathematical model	Two	Simulated annealing algorithm
(Kucukkoc and Yaman, 2013)	mixed-model ALBP	zero-one integer programming	One	Hybrid genetic algorithm
(Zacharia, Tsirkas, Kabouridis and Giannopoulos, 2015)	SALBP-type 2	-----	One	Genetic algorithm

(Ritt, Costa and Miralles, 2016)	ALWABP[3]	Mixed Integer programming	One	Local search algorithm
(Ogan and Azizoglu, 2015)	UALBP	zero-one linear programming	One	Branch and bound algorithm
(Pape, 2015)	SALBP-type1	-----	One	Dynamic programming & a tabu search
(Sikora, Lopes, Lopes and Magatão, 2015)	SALBP-type2	-----	One	Genetic algorithm
(Esmaeilbeigi, Naderi, and Charkhgard, 2015)	SALBP-type E	mixed integer linear programming	One	CPLEX
Delice, Aydoğan and Ozcan, 2016)	2S U-type ALBP	-----	One	Genetic algorithm
(Mukund Nilakantan and Ponnambalam, 2016)	Robotic UALBP	zero-one linear programming	One	Particle swarm optimization algorithm
(Pitakaso and Sethanan, 2016)	SALBP-type1	zero-one linear programming	One	Differential evolution algorithm
(Kalayci, Polat and Gupta, 2016)	DLBP[4]	mixed integer programming	four	Genetic algorithm with a variable neighborhood search
Zhang, Yan, Liu and Jiang, 2016)	SALBP-type2	mathematical model	One	differential evolution algorithm
Corominas, García-Villoria and Pastor,2016)	SALBP-type E	mixed integer linear programming	One	Heuristics derived from IP[5] andEIP[6]
(Delice, Aydoğan, Özcan, and İlkay, 2017)	2S U-type ALBP	-----	Two	Particle swarm optimization algorithm
(De Albuquerque, Filho, Neto and De Oliveira , 2017)	SALBP-type1	-----	One	Fish School Search algorithm
(Zhong and Ai, 2017)	single-model ALBP	Mathematical model	Three	Modified ant colony optimization algorithm
(Li, Kucukkoc and Tang, 2017)	UALBP	mixed integer linear programming	One	Ant colony optimization algorithm
(Kellegöz, 2017)	multi-manned stations ALBP	mixed integer program	Two	Simulated annealing algorithm
(Roshani and Giglio, 2017)	multi-manned ALBP	mixed integer program	One	Simulated annealing algorithm
(Han-ye Zhang, 2017)	SALBP-type1	zero-one linear programming	Two	An improved immune algorithm
Belassiria, Mazouzi, El Fezazi and El Maskaoui, 2017)	SALBP-type E	mixed integer programming	Two	Hybrid genetic algorithm
(Dong, Zhang and Xiao, 2018)	Stochastic ALBP	chance-constrained	Two	Hybrid Particle swarm algorithm optimization

		mixed 0–1 programming		and Simulated annealing algorithm
(Polat, Mutlu and Özgormus, 2018)	SALBP-type2	Mathematical model	Two	Goal programming
(Kamarudin and Rashid, 2018)	SALBP-type1	Mathematical model	Three	-----
(Li, Kucukkoc and Zhang, 2018)	UALBP	-----	One	Branch, bound and remember algorithm

2 Assembly sequence planning

3 Assembly line worker assignment and balancing problem

4 Disassembly line balancing problem

5 Iterated procedure

6 Enhanced Iterative Procedure

2.16. Research Gap

The majority of the previously studied literatures focused on minimizing expenses, streamlining processes, and removing obstacles to achieve the best possible balance between product quality and efficiency. Research gaps were found in the area of assembly line balance for 12.7mm AAG utilizing ranked positional weighted methods after a thorough analysis of the current literature studies. Of these, the majority of study has been done by various researchers on the evolution of line balancing problems and the impact of process parameters; however, very little research has been done on the investigation of the ideal process parameter for assembly line balancing for 12.7mm AAG. This thesis study was aimed to fill the research gap.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Introduction

The 12.7mm AAG machine gun and assembly line have a straightforward construction and dependable performance. It was an automatic weapon that was mostly employed against hostile air targets, armored vehicles, and soldiers concealed in light clothing. It was a type of automatic firearm with two functions. It can fire at paratroopers and low-flying jets for anti-aircraft purposes. It may demolish or neutralize enemy fire stations, light armored vehicles, and vessels, as well as obstruct important commerce routes, when used on land or in water. The rifle it has based on gas operated automatic principles. Its features include a decent design, light weight, fast firing speed, good accuracy, and ease of maintenance. Figure 3.1. shows 12.7mm AAG assembled weapon

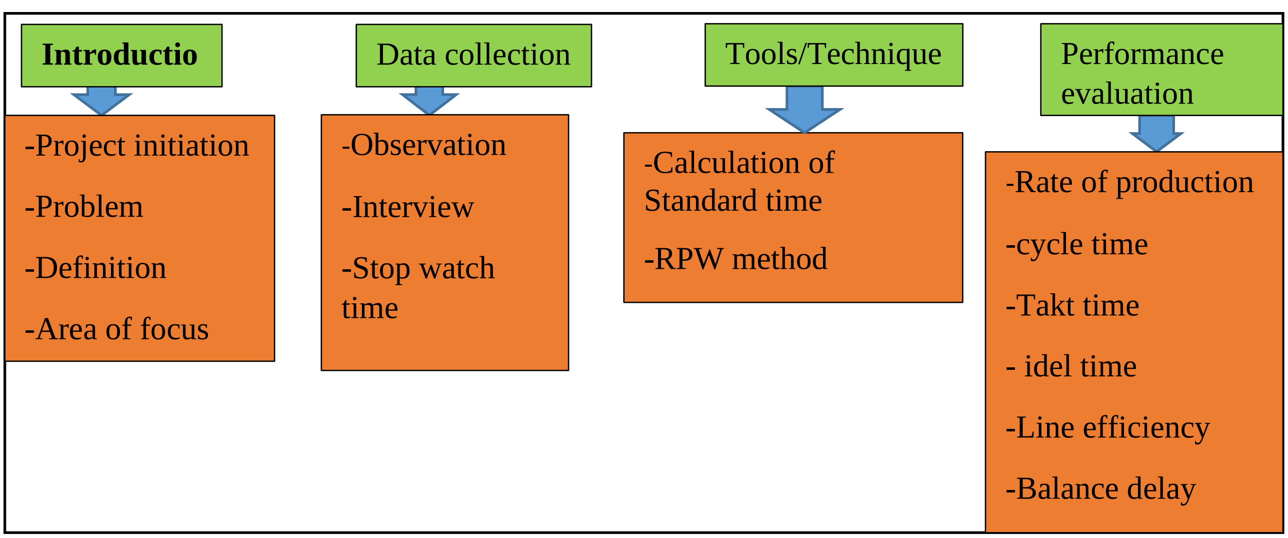
Figure 3.1. 12.7mm AAG assembled weapon (source; HRM)

The materials utilized in the investigations to produce the results will be covered in this chapter. The acquired data will be gathered and examined in accordance with the right guidelines and methodology. The study framework, data collection techniques, research instruments, and measurement tools for data analysis were some of the factors to take into account in this situation. The project's objectives of adjusting and balancing an existing assembly line require a set of required procedures to be followed in order to produce reliable results. The balance losses of the current line should be assessed as the following stage in order to identify the causes of these losses. Once these variables have been ruled out, the assembly process was finally adjusted to meet the required parameters. There were seven (7) work stations in this factory, each with a distinct capacity. Different capacity lead to different line balance issues. The activities causing a bottleneck and the improperly paced accessories and equipment needed to assemble the 12.7mm AAG were the problems. An extended cycle time was caused by the bottleneck. Three subassemblies—the receiver cover, the receiver body and the trigger mechanism subassembly—were the source of the bottleneck in this study. Line balancing delays the completion of the product. In order to accomplish the project's goal, an identical subassembly line—consisting of just three stations for receiver cover, receiver body and trigger mechanism subassembly—was chosen as the initial assignment in order to examine and identify any issues with 12.7mm AAG assembly lines.

3.2. Methodology of the Research

The techniques utilized in the research projects was to produce findings will be covered in this topic. The study framework, data collection techniques, research instruments, and measurement tools for data analysis were some of the factors to take into account in this situation (De Carlo, Arleo, Borgia, and Tucci, 2013).

Table 3.1. visualization of methodology



3.2.1. Data Collection

A portion of the data was gathered through book research, and another portion involved gathering empirical data through observations, time measurements, and document analyses. The data useful for the studies were gathered in this section. Various techniques for gathering data were covered in these studies, including

- Observation: -using the time measurement
- Measurements of time
- conversation

Observation

Observation was the most important way that people in daily life gather information about the world. This occurs mostly at random, based on expectations, needs, and experiences. However, observation was also a scientific method of data collection when it was carried out methodically. When gathering knowledge on behavior and occurrences in real-world settings, observations were the most helpful (Patel and Davidson, 2011). An assembly line that was currently in use was observed in order to examine work assignments for this thesis.

Two observations were made in order to respond to the study questions. The first observation was made in an unstructured manner with the aim of gathering an overview of the case company assembly procedure. Unstructured observations were frequently employed in research to get as much data as possible regarding a particular issue (Patel & Davidson, 2011).

One of the assembly lines of the case firm was the site of the second observation. It was intended to be a supplement to the document research and to determine whether the job tasks carried out on the assembly line in real life matched the work descriptions that were viewed.

The following variables were part of the data gathering and can affect or be used to gauge how well the manufacturing process was performing (Singh, G., 2019).

- Processing times of each task;
- Priorities between processes;
- Number of workers for each task;

- Assembly line:
- Working hours;
- Production output.

Time measurements

Quantitative research was defined as the process of measuring a phenomenon of interest. To validate the measurements, the data collected was analyzed in order to identify trends or relationships among the data. The process of taking measurements was always fraught with error, which can come from a variety of sources and was typically classified into two categories: systematic and random errors. Systematic errors were the result of a fundamental flaw in the system, while random errors, such as human error, appear by chance (Watson, 2015). To prevent quality flaws in quantitative studies, the research should be constructed using sound theories, high-quality instruments, and precision when taking measurements (Patel and Davidson, 2011).

The time measurements of labor tasks in a single manufacturing line were included in this study. One observer using one clock conducted the time studies over a three-week period. Every job task on the assembly line was timed ten times, with a precision of two decimals in each time. When the operator started the task and stopped it when it was completed, the clock began to run. Ten measurements from a single labor job were taken consecutively, however occasionally during the time study, the operator was changed.

Data analysis

The process of compiling and analyzing collected data was known as data analysis. The study's foundation was built on gathered empirical data that was compared to the theoretical framework. Pattern matching was the term used by Yin (2007) to describe the process of comparing empirical data to a theoretical hypothesis (Yin, 2014). The goal of the study was consistently followed to make sure that the hypotheses and data gathered were pertinent to the investigation and to offset any misalignment.

Theory of Constraints (Bottlenecks): - The widely read business novel the Goal, written in the 1980s by Dr. Eliyahu, Goldratt, and Jeff Cox, introduced the Theory of Constraints (TOC), an improvement technique. According to Goldratt and Cox, a system was made up of interdependent functions and processes. The maximum performance of a given system depends on its internal constraints (Sproull, 2019). Throughout this thesis work, a bottleneck will occasionally be used to refer to a system limitation.

The component of the system that prevents increased performance was known as the bottleneck. As a result, in order to strengthen the system, the bottleneck must be located and removed through improvement efforts. Once the required adjustments have been made, a new bottleneck will emerge. To make changes to other processes will not result in any stronger output from the system, since the bottleneck was the limiting factor (Sproull, 2019).

Sproull (2019) goes on to outline the following five measures for resolving bottlenecks:

1. Determine the bottleneck
2. Select an exploitative strategy for the bottleneck.
3. Delegate all other tasks to the bottleneck.
4. If required, raise the bottleneck.
5. Stop inertia from turning into the next bottleneck. Go back to Step 1 now.

How does one break through the bottleneck after it has been identified? Sproull (2019) states that this can be accomplished by taking steps including transferring work activities from the bottleneck to other areas of the system, cutting waste, altering the bottleneck's environment, and monitoring workstations.

3.2.2. Tools and Techniques

There were different kinds of tools and procedures for line balancing. Among them the following methods were some of line balancing; -

1. Ranked Positional Weight method
2. Largest candidate rule
3. Kilbridge and western’s method

3.2.2.1. Rank-Based Positional Weight Helgeson-Birnie Method

A traditional SALB solution heuristic that employs the task-oriented method was RWP (Helgeson and Birnie). By using a set cycle time to solve Type 1 Assembly Line Balancing (ALB), it reduces the number of stations.

The Helgeson-Birnie approach was also known as the Ranked Positioned Weight (RPW) method. In 1961, Helgeson and Birnie at General Electric devised this technique. Every operation determines the ranked positional weight's value. The operations were assigned to workstations by the implementation of procedures (Eryuruk et al., 2008). While (Basuki, Aprilyanti, and Junaidi, 2019) claim that production line design can reduce the amount of idle time that employees have to complete tasks, (Ekoanindiyo and Helmy, 2017) assert that the Ranked Positional Weight method can swiftly and effectively solve production line imbalance problems.

The procedures involved in this approach were;

- creating a precedence diagram and figuring out the standard time
- Starting from the final operation and computing the weight of each operation, one can ascertain the weight of the operations on the precedence diagram.

In addition to accounting for cycle time constraints and the guidelines for the sequence of operations in the precedence diagram, the grouping was done based on the RPW's order of priority (weight), starting with the largest. The task approach was carried out until one of the following conditions was meet:

a. All the operations were already charged to the stations
b. There were no operations having uncharged time constraints

It blends the western technique with the largest candidate rule and Kilbridge. For every element, an RPW was determined. The element's "Te" value and its placement in the precedence diagram were taken into consideration when calculating the RPW value. Subsequently, the elements were arranged on the work station according to their RPW values.

Let; P_i be the set of all tasks that come before task i , and Q_i be the set of all tasks that come after task i. Next, each task's ranked positional weight score (R_i) was determined using the formula below: ranking positional weight score (R_i) for each task was then determined using the method below;

$$R_i = T_i + \sum_{j \epsilon Q_i} T_j \qquad (3.1)$$

i.e. the RPW of a task was its own time plus the sum of all successor task times.

Where; T_i - starting task time , T_j - finishing task time, R_i - rank position weighted starting and Q_i - total number of task time

Then the elements were assigned to work station in the general order of their RPW values **(**Deshpande and Joshi, 2007, January).

Steps:

1. Draw the precedence diagram
2. For each work element, determine the positional weight. It is the total time on the longest path from the beginning of operation to the last operation of the network.
3. Rank the work elements in descending order of ranked positional weight (RPW).
4. Assign the work element to a station. Choose the highest RPW element. Then, select the next one. Continue till cycle time was not violated. Follow the precedence constraints also.
5. Repeat step 4 till all operations were allotted to one station.

3.2.2.2. Assessment of Performance

To assess and contrast various solutions, a number of quality metrics have been developed. These seven were listed in the following order.

Rate of production: - The rate at which a product was created was known as the rate of production.

$$\text{Rate of production} = \frac{\text{total productivity per day}}{\text{total running hour per day}} \tag{3.2}$$

$$\text{Cycle time} = \frac{\text{production run time}}{\text{total produced parts}} \tag{3.3}$$

$$\text{Idle time} = \text{total production time} \times \text{efficiency} \tag{3.4}$$

Line efficiency: - was the degree to which the resources of the assembly line including human and capital resources were wisely and effectively used.

$$Line\ efficiency(E) = \frac{\text{sum of task time}}{actual\ N^{o}.\ \text{of work station} \times \text{largest cycle time}} \times 100\% \qquad (3.5)$$

$$Minimum\ \ N^{o}.\,\text{of}\, workstatios = \frac{\sum_{i}^{n} time\ \text{for tasks}}{cycle\ time} \qquad (3.6)$$

$$Balance\ delay\ = \frac{N^{o}.\text{of}\, workstatios \times cycle\ time - total\ work\ content}{N^{o}.\text{of}\, workstatios \times cycle\ time} \times 100\% \qquad (3.7)$$

Or Balance delay (%) was the amount by which the line falls short of 100%

$$\text{Balance delay } = 100\% - \text{ calculated efficiency} \qquad (3.8)$$

CHAPTER FOURE

DATA ANALYSIS AND COLLECTION

4.1. Data Analysis

The primary and secondary data gathered from observation and interviews with GAEI on the medium caliber production factory of 12.7mm AAG weapon assembly shop floor was presented in this chapter. Primary data were gathered by time studies, observations, and interviews with managers and operators of the 12.7mm AAG assembly line. The product model, the 12.7mm AAG assembly line, the number of operators and workstations, the processing time for each task, and the present line balance circumstances were all provided. The following were the techniques used to collect data: Using the prepared instruments, time measurement was the process of observing and documenting each element's or cycle's working hours. Stopwatch time Study, a way of measuring time, was used to record observations.

Based on information obtained from observations and interviews, the company was deficient in the following areas:

- One of the issues with an assembly shop's low productivity and delayed product deliveries was bottlenecks. The data indicates that idle time was increased and that there was a sizable amount of bottleneck.
- The factory needs to concentrate on task balancing between operators in order to divide equitable workloads according to operating time, based on the principles of line balancing.
- The most significant issue found in the training and development section was the lack of training for shop floor employees. There was no way to determine whether training was necessary or not with the current system.
- In addition, a deficiency in operator skill and product part quality were three more bottlenecks in the assembly shop.
- There was currently no set time for each product; instead, the arrangement was based on experience and educated guessing.

- This leads to an uneven distribution of labor among operators. Because of this, while taking into account the requested volume of product in the industry, standard time was preferred for common items.
- It was necessary to set up each station with the appropriate jigs, fixtures, equipment, and facilities. The operation carried out at each station was verified by the quality assurance department after being signed off on by the technician, quality circle member, quality assurance specialist, and team leader.
- trigger subassembly, receiver body and receiver subassembly were the three bottlenecks in the current setup, as determined by watching the assembly line and speaking with the operators.
- Optimal line balancing was necessary to arrange equipment, permit the movement of items, and create a secure and comfortable work environment in an assembly shop.

4.2. The 12.7mm AAG Assembly Line (Existing)

The purpose of gathering data for this study was to understand the 12.7 mm AAG production process as it currently exists and to pinpoint the issues that lower output. In order to pinpoint time-consuming, non-value-added processes along the process and track the areas that require development in order to cut down on idle production time. Managing, concentrating, and optimizing the new manufacturing line was a necessary precondition for this project. The weapon design determined the similarity of the 12.7mm AAG assembly lines.

Current information

- Production schedule was 700-unit weapon per year.
- Annual working day 250 days.
- The required demand was 2.8 weapon per day
- One running shift
- Time Available to Complete the Task was known
- Cycle times of all operations were known.
- Available time = 480 mints per day or eight hours per day
- Tea break = 30 mints per day

Table 4.1. Current Information on Worker Count and Time Required for 12.7mm AAG Assembly Line

Work stations	Descriptions	Assembly time taken (in minutes)	Number of operators
01	Barrel subassembly	140	03
02	Receiver body subassembly	270	03
03	Receiver cover subassembly	420	03
04	Bolt body subassembly	120	03
05	Trigger mechanism subassembly	370	03
06	Shoulder rest subassembly	60	03
07	General assembly	90	03
Total		1470	21

Empirical computation using the available data

- Annual demand = 700 units of weapon
- Annual working day = 250 days
- Daily available time = 480 mints
- Tea break per day time = 15min + 15min = 30min (before lunch and after lunch)
- Wastage time per day =30 mints
- Wastage time per year = 30 times 250 =7500 mints
- One day = twelve hour
- One working day = 8 hour =480 mints
- One hour =sixty (60) mints
- 250 days per year =120000 mints per year = working time per year

$$\text{Networking time during per day} = \text{Daily available time} - \text{Tea break per day time}$$

$$\text{Networking time during per day} = (480\text{min} - 30\text{min}) = 450 \text{ mints}$$

$$\text{Networking time per year } = \text{working time per year } - \text{Wastage time per year}$$

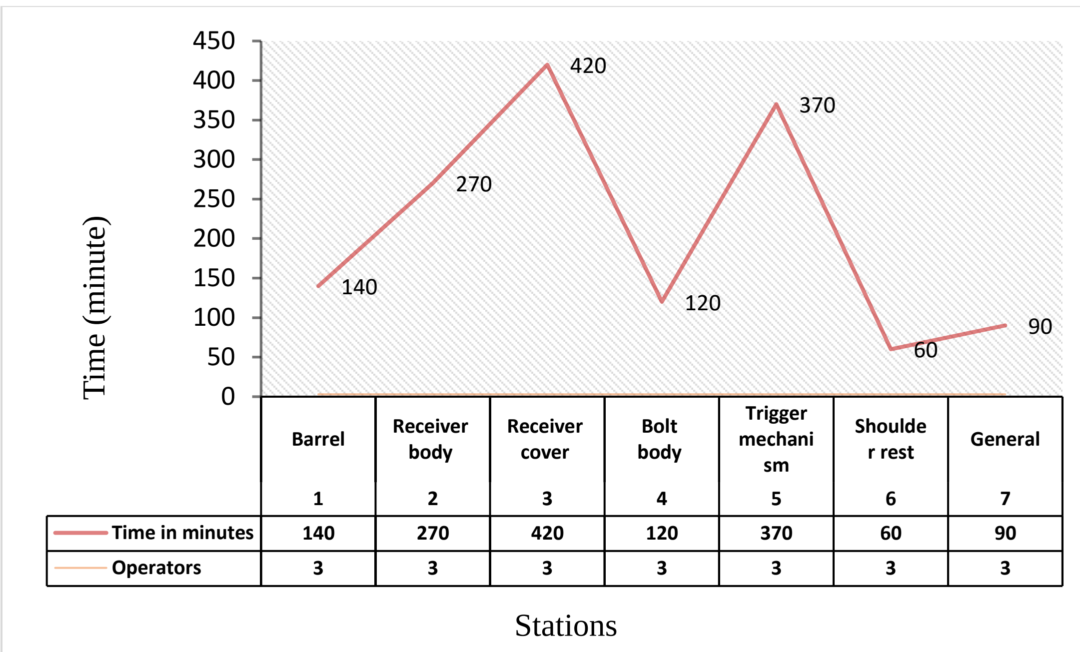
$$\text{Networking time per year} = 120{,}000 \text{ mints per year} - 7{,}500 \text{ mints per year}$$

$$\text{Networking time per year} = 112{,}500 \text{ mints or}$$

$$\text{Annual Networking time} = 112{,}500 \text{ mints}$$

$$\text{Efficiency} = \frac{\text{product target} * \text{time taken}}{\text{working hour} * \text{worker required}} \tag{4.1}$$

$$\text{Efficiency} = \frac{700 * 1470}{112500 * 21} = \frac{1{,}029{,}000}{2{,}362{,}500} = 0.4356 = 43.56\%$$



	Barrel 1	Receiver body 2	Receiver cover 3	Bolt body 4	Trigger mechanism 5	Shoulder rest 6	General 7
Time in minutes	140	270	420	120	370	60	90
Operators	3	3	3	3	3	3	3

Figure 4.1. Line graph of current 12.7 mm AAG Assembly

There were currently seven workstations on the assembly line. The subassemblies in question were the following: trigger subassembly, barrel subassembly, receiver body subassembly, receiver cover subassembly, bolt subassembly, shoulder rest subassembly, and general sub. It makes the number of workstations and operators more evident. Provide input data such as the number of operators, the workstation names, and the processing time. The Figure 4.2 shows the current workstation configurations.

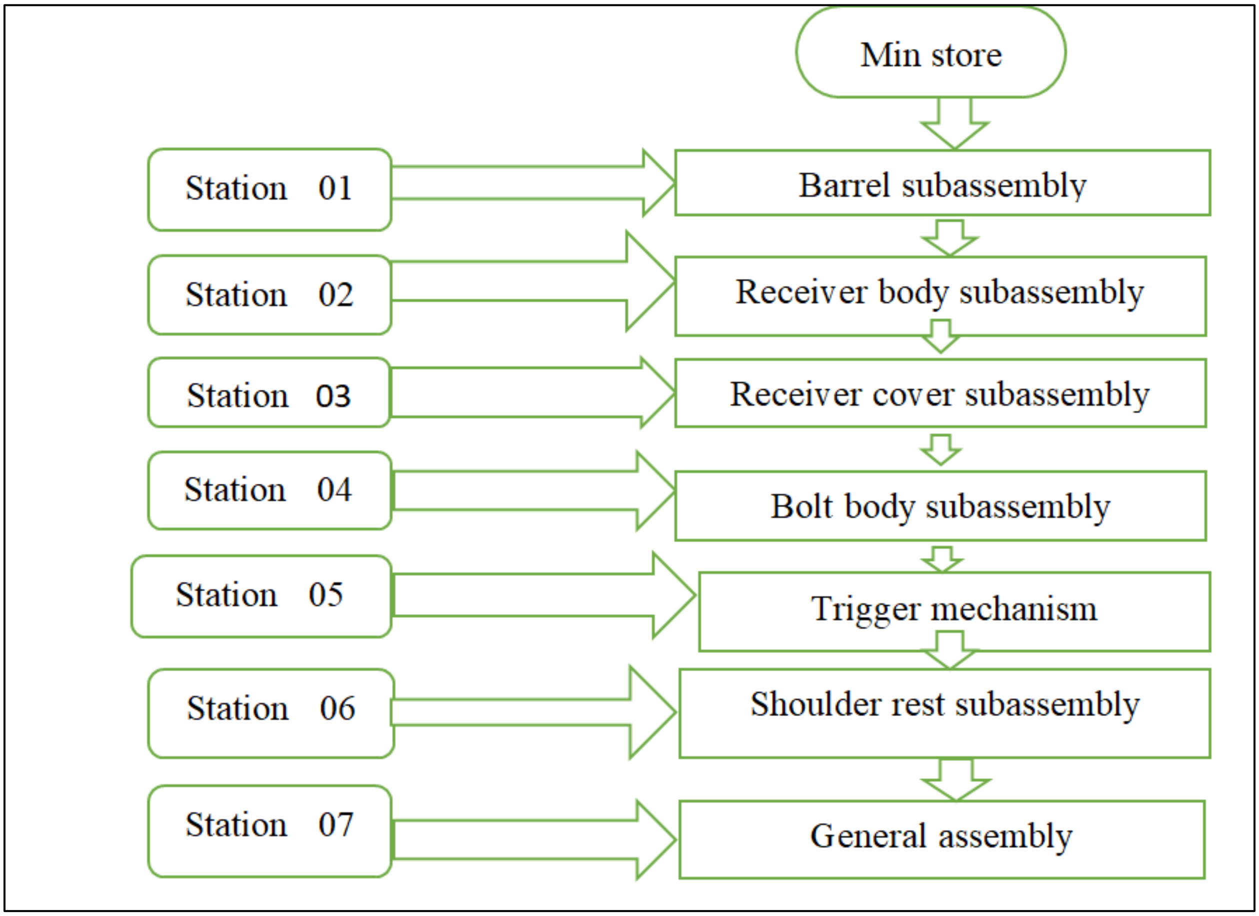


Figure 4.2. Diagram showing the current 12.7 mm AAG assembly line flow.

4.3. Methods and instruments for gathering data

Tools and methods for gathering data were essential since they were employed in analysis. With the following tools, data gathering for the 12.7mm AAG manufacturing process was completed.

- Stopwatch time study: this method involves having team members record the actual timings of the 12.7mm AAG assembly line while visually inspecting the results.
- Gathering data through dialogue with the supervisor and other team members.

There were seven (7) subassemblies needed for the 12.7mm AAG machine gun's final assembly: the barrel subassembly, the trigger mechanism subassembly, the shoulder rest subassembly, the receiver body subassembly, the receiver covers subassembly, the bolt subassembly, and the general assembly. There were restrictions on the assembly of 12.7mm AAG operators. Three operators were needed for each and total of 21 operators (including the assistance) in order to finish the assembly with seven (7) workstations. An assembly line observation revealed the first bottleneck element.

4.4. Standard Time

Information provided by standards was essential to the success of a company. Standard time was the amount of time, accounting for personal time, fatigue, and delays, that an average operator working at a regular pace needs to finish a task using a specified method. Time research was the study of a particular process to ascertain the components of work necessary to finish it, the sequence in which these components occur, and the amount of time needed to execute it correctly. Time study was the most efficient method for establishing standards for highly repeated processes with short cycle times. Every operation needs deviations from the standard to accommodate labor shortages, fatigue, and delays. In most cases, the personal fatigue and delay (PFD) allowance was expressed as a percentage of the standard time and was added to the total amount of time allocated to complete the task at hand.

4.4.1. Calculated Standard Time

One method for determining the average time to complete a single or multi-element process was the time study. The standard was a common denominator used to evaluate productivity since it should give the operator adequate time to finish the task at hand. The standard time to be determined will differ from the expected time. Standard time was the amount of time required for a work to be completed by an average skilled operator at a usual speed while adhering to a specified process. The normal time work was multiplied by a factor that takes pre-set allowances into account in order to calculate standard time. The confidence level of a study was a typical term used to describe its correctness. When it comes to confidence levels, a 95% confidence level indicates that only 95% of the population was represented by the sample, meaning that 5% of the population was unrepresented. By taking the mean of ten observations, we can find the observed time (OT) of a particular element. Next, the sample size, n, were computed to demonstrate its adequacy. Table 4.2 shows samples of ten observation.

Table 4.2. Ten Observation Sample (AAG assembly of 12.7 mm)

Observation	Record stopwatch time(minutes) (X_i)	Mean of sample observation (μ)	X_i - μ	$(X_i - \mu)^2$
1	836.7	828.81	7.89	62.2521
2	818.6	828.81	-10.21	104.2441
3	836.7	828.81	7.89	62.2521
4	818.6	828.81	-10.21	104.2441
5	836.5	828.81	7.69	59.1361
6	836.5	828.81	7.69	59.1361
7	836.7	828.81	7.89	62.2521
8	836.7	828.81	7.89	62.2521
9	835.8	828.81	6.99	48.8601
10	835.9	828.81	7.09	50.2681

The variance and standard deviation were the statistics that were most frequently utilized to get a sense of the data's variability.

$$\mu = \frac{\sum_i^{10} x_i}{n} = \frac{828.81 + \cdots + 828.81}{\text{n}} = \frac{8288.1}{10} = 828.81$$

$$\Sigma(x_i - \mu)^2 = 674.897$$

$$\text{Standard deviation}(S) = \sqrt{\Sigma\frac{(x_i - \mu)\ 2}{n-1}} = \sqrt{74.988556} = 8.65956$$

Number of observations, $N = \left(\frac{ZS}{h\mu}\right)2 = \left(\frac{2*8.65956}{0.05*828.81}\right)2 = 0.84 \approx 1$ cycle times(observation)

Were standard deviations, $S = 8.65956$, mean(μ) = 828.81, for 95% confidence level, z = 2 and error, h = 0.05

One (1) observation was sufficient for an acceptable error of 5% with a 95% confidence level, according to the computation. This was a result of a slight variation in the observation's results. However, ten (10) observations were made in order to increase the efficiency of the observed time. Multiplying the observed time by the average rating yields normal time (NT).

$\text{Normal time (NT)} = \text{Observed time(OT)} \times \text{Average rating}$. The rating used here is 95% = 0.95 and $\text{Standard time} = \text{Normal time(NT)} \times (1 + \text{Allowances})$

Allowances for this study were: - Personal needs 5%, Unavoidable delay 1%, Basic Fatigue 4% and Noise level (Intermittent – loud) 2%, Total = 12% in appendix II

$\text{Normal time (NT)} = \text{Total Observed time(OT)} \times \text{Average rating factor} = 828.81 * 0.95 = 787.3695 \text{ mints}$.

$$\text{Standard time} = \text{Normal time(NT)} \times (1 + \text{Allowances})$$

$$\text{Standard time} = 787.3695 * 1.12 = 881.85384 = 881.854 \text{ mints}$$

4.5. Time study Results

Table 4.3 shows Observed assembly line of 12.7mm AAG tasks precedence with duration.

Table 4.3 Barrel Subassembly Line Activity Precedence with Duration

Work stations	Work descriptions	Sequence no	Work sequence	Average time taken (minutes)	Man power
01	Barrel subassembly	1	Barrel	3.0	03
		2	Front sight base	10.9	
		3	Front sight base pin	25.8	
		4	Flash eliminator (muzzle break)	21.2	
		5	Flash eliminator lock pin	11.0	
		6	Front sight bolt	5.9	
		7	Front sight nut	4.8	
		8	Front sight mount	6.3	
		9	Front sight mount pin	4.0	
		10	Gas regulator	3.0	
		11	Gas regulator nut	2.9	
		12	Gas tube	3.3	
		13	Barrel lock assembly parts	27.5	
Total				128.6	

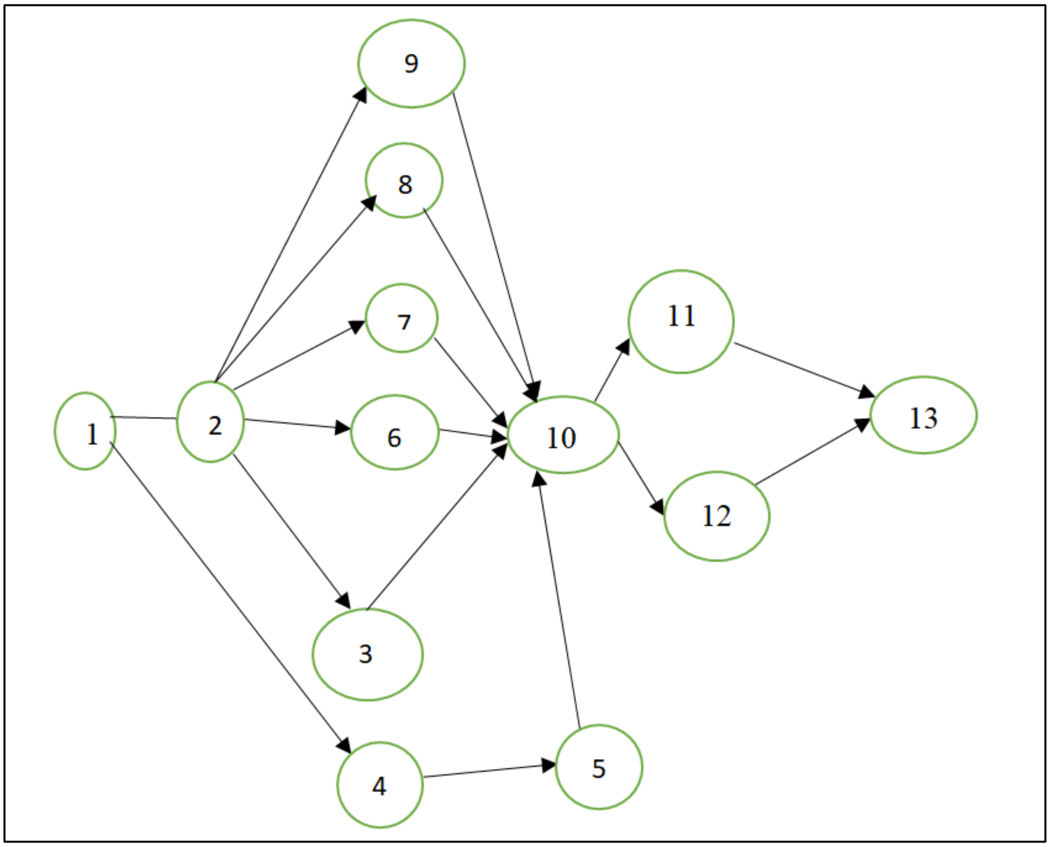


Figure 4.3. Subassembly of Barrel Precedence Diagram

Table 4.4. Receiver Body Subassembly Line Activity Precedence with Duration

Work stations	Work descriptions	Sequence no	Work sequence	Average time taken (minutes)	Man power
02	Receiver body subassembly	1	Receiver body	3.1	03
		2	Rear sight base	45.8	
		3	Rear sight base rivet (pin)	45.7	
		4	Rear sight base spring	11.0	
		5	Rear sight base cup	37.4	
		6	Rivet for base	37.6	

		7	Link puller	5.2	
		8	Link puller side plate	6.7	
		9	Link puller spring	6.6	
		10	Link puller pin	9.2	
		11	Link puller screw	6.6	
		12	Dust protector	8.7	
		13	Dust protector pin	11.0	
		14	Gas piston	8. 1	
		15	Rear sight assembly parts	6.4	
		16	Rear sight pin	5.4	
Total				254.5	

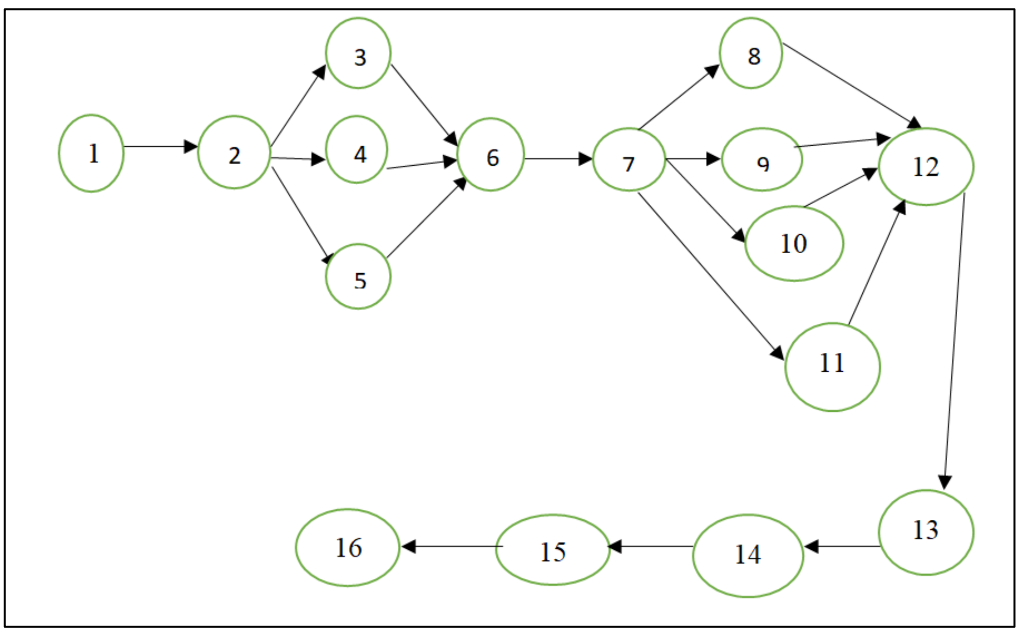


Figure 4.4. Subassembly of Receiver Body Precedence Diagram

Table 4.5. Subassembly of Receiver Cover Activity Precedence with Duration

Work stations	Work descriptions	Sequence no	Work sequence	Average time taken (minutes)	Man power
03	Receiver cover subassembly	1	Receiver cover body	4.0	03
		2	Upper pawl base	6.0	
		3	Upper pawl base guide pin	7.7	
		4	Upper pawl base plate	6.8	
		5	Upper pawl base plate pin	9.0	
		6	Upper pawl right	19.4	
		7	Upper pawl left	19.5	
		8	Upper pawl spring	13.0	
		9	Upper pawl spring pin	12.0	
		10	Feed pawl	20.1	
		11	Feed pawl spring	21.2	
		12	Feed pawl spring pin	21.9	
		13	Feed pawl base	21.7	
		14	Feed pawl base guide pin	20.0	
		15	Feed lever	10.3	
		16	Feed lever spring washer	6.4	
		17	Receiver cover locker	6.1	
		18	Receiver cover locker handle	15.0	
		19	Receiver cover locker spring	5.0	
		20	Receiver cover locker pin	5.9	
		21	Feed lever limiter bracket	9.1	
		22	Feed lever limiter pin	7.8	
		23	Feed lever limiter pin spring	7.0	
		24	Plunger	6.1	
		25	Feed lever plunger pin	7.7	
		26	Feed lever plunger bolt	7.0	
		27	Feed lever lock washer left	9.0	
		28	Feed lever lock washer right	8.8	
		29	Receiver cover lock bracket	7.0	
		30	Receiver cover plate spring	6.1	
		31	Bolt motion	5.3	
Total				331.9	

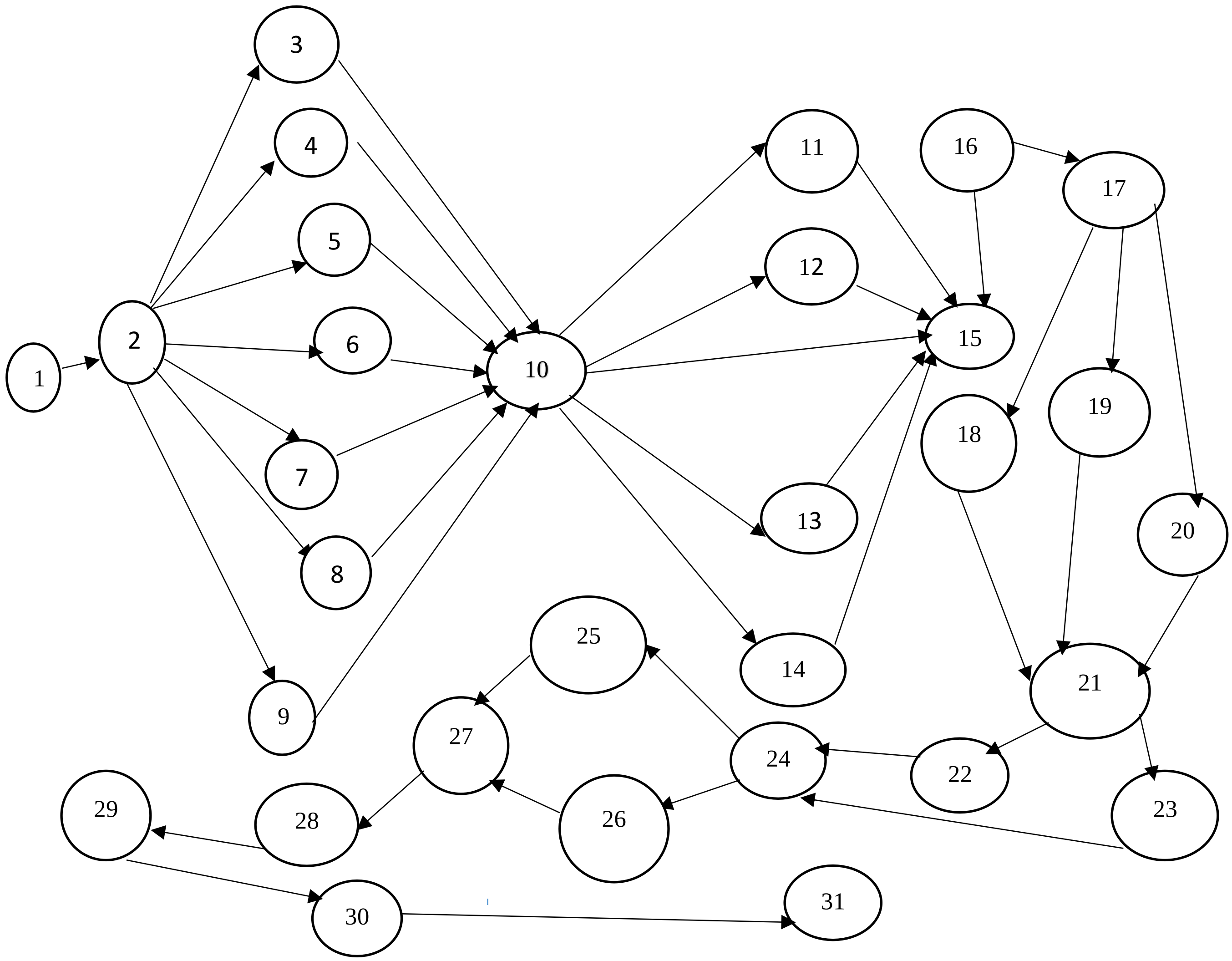


Figure 4.5. Subassembly of Receiver Cover Precedence Diagram

Table 4.6. Subassembly of Bolt Body Activity Precedence with Duration

Work stations	Work descriptions	Sequence no	Work sequence	Average time taken (minutes)	Man power
	Bolt body subassembly	1	Bolt head	11.0	
		2	Bolt right side	11.0	
		3	Bolt left side	7.2	
		4	Extractor	5.8	

04		5	Extractor pin	6.1	03
		6	Extractor spring	9.2	
		7	Firing pin	6.0	
		8	Firing lock pin	5.9	
		9	Ejector	5.8	
		10	Ejector pin	8.5	
		11	Bolt head body	4.0	
		12	Buffer spring rod	4.1	
		13	Buffer spring	6.0	
		14	Buffer spring pad	6.3	
		15	Buffer spring pin	26.5	
Total				123.4	

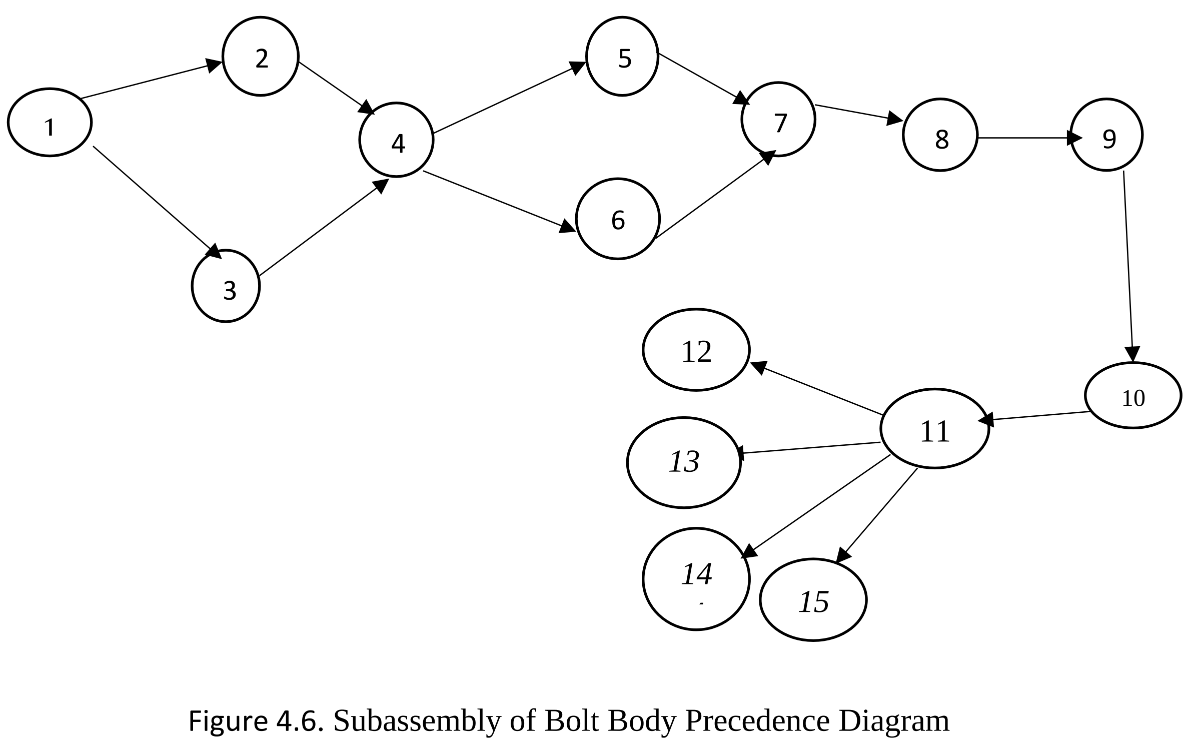


Figure 4.6. Subassembly of Bolt Body Precedence Diagram

Table 4.7. Trigger Mechanism Subassembly Line Activity Precedence with Duration

Work stations	Work descriptions	Sequence no	Work sequence	Average time taken (minutes)	Man power
05	Trigger mechanism subassembly	1	Trigger body	13.8	03
		2	Safety spring	14.9	
		3	Safety spring rivet 3x5	15.2	
		4	Release handle shaft	12. 1	
		5	Release handle rivet	11.0	
		6	Release handle washer	13.8	
		7	Release handle shaft spring	9.5	
		8	Percussion rod	8.6	
		9	Percussion spring	7.4	
		10	Percussion push pin	8.5	
		11	Percussion push pin spring	12.0	
		12	Percussion push plate	15.0	
		13	Percussion push pin	16.3	
		14	Safety lock rivet	17.2	
		15	Safety lock	19.3	
		16	Sear	16.5	
		17	Sear disconnecting rod spring	26.8	
		18	Sear disconnecting rod spring pin	15.4	
		19	Plastic handle	22.1	
Total				275.4	

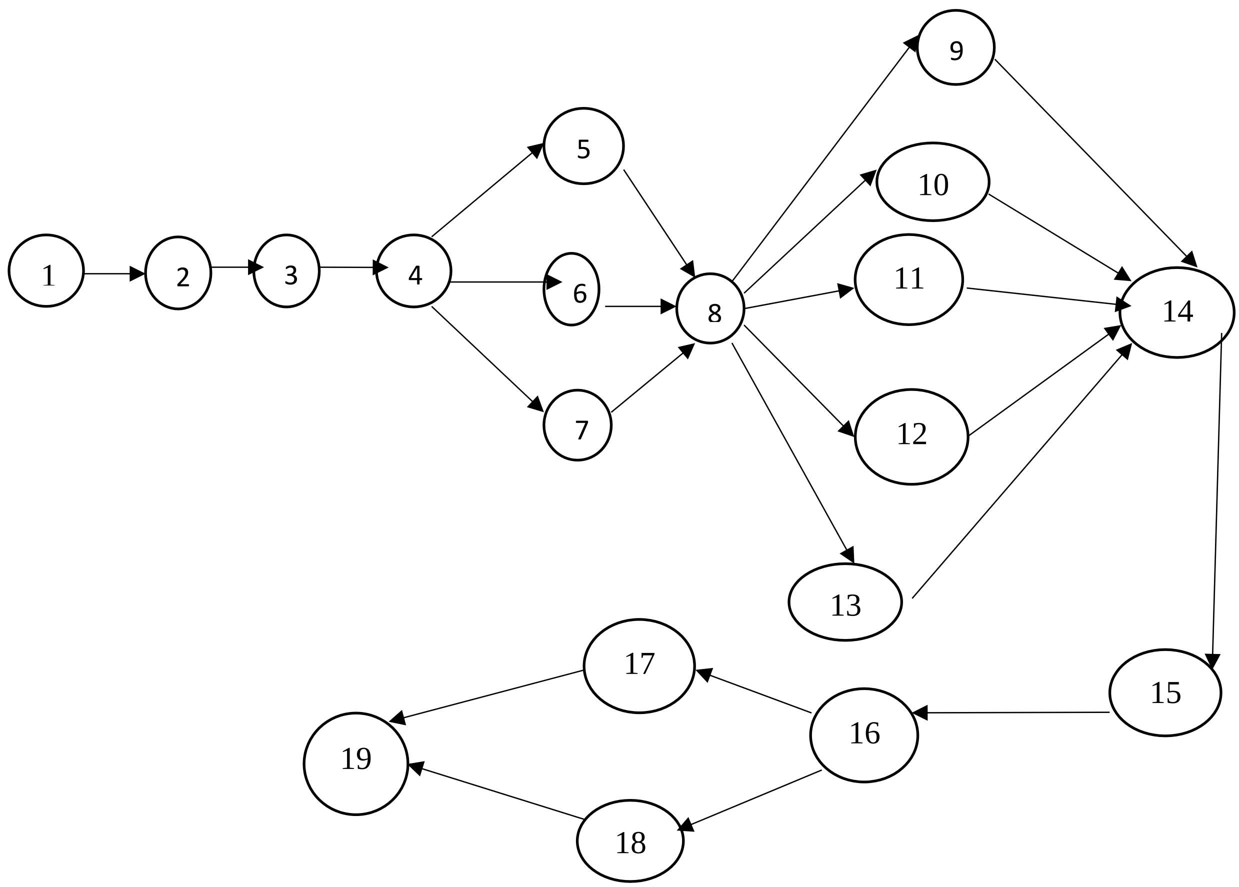


Figure 4.7. Subassembly of Trigger Mechanism Precedence Diagram

Table 4.8. Shoulder Rest Subassembly Line Activity Precedence with Duration

Work stations	Work descriptions	Sequence no	Work sequence	Average time taken (minutes)	Man power
06	Shoulder rest subassembly	1	Back plate	2.6	03
		2	Shoulder rest	3.6	
		3	Shoulder rest rod	2.0	
		4	Shoulder rest spring	3.0	
		5	Shoulder rest tube	4.1	
		6	Shoulder rest pin	3.1	
		7	Shoulder rest connecting pin	3.1	
		8	Back plate lock	3.2	
		9	Back plate lock spring	2.7	
		10	Back plate lock pin	4.1	
		11	Pusher	3.1	
		12	Pusher spring	5.9	

		13	Pusher screw	5.0	
Total				45.5	

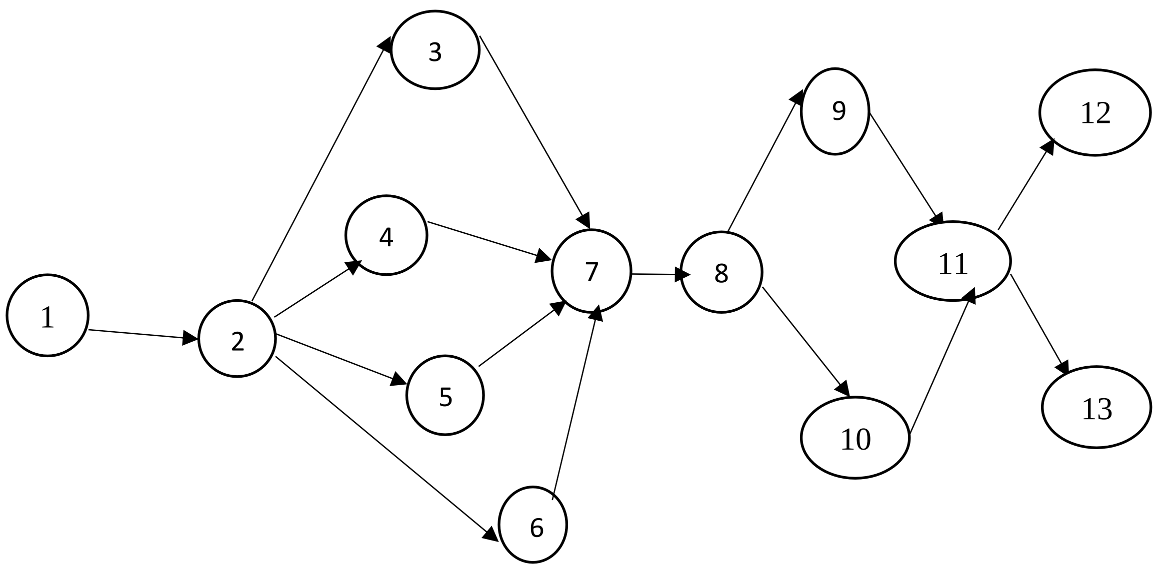


Figure 4.8. Subassembly of Shoulder Rest Precedence Diagram

Table 4.9. General Subassembly Line Activity Precedence with Duration

Work stations	Work descriptions	Sequence no	Work sequence	Average Time taken (minutes)	Man power
07	General subassembly	1	Barrel subassembly	9.1	03
		2	Receiver body subassembly	11.1	
		3	Receiver cover subassembly	15.6	
		4	Bolt subassembly	6.0	
		5	Trigger mechanism subassembly	11.2	
		6	Shoulder rest subassembly	6.6	
Total				59.6	

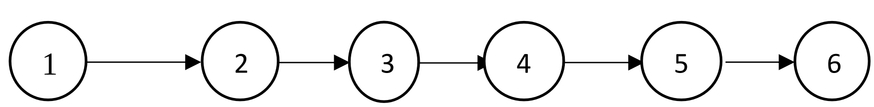


Figure 4.9. General Assembly Precedence Diagram

4.6. Total Observed Assembly Time for 12.7mm AAG

4.6.1. **Bottleneck Identification & Elimination**

Bottlenecking of workstation two, three and five i.e. sub-assembly process which was kept for next stage LOB. All the other workstations were one, four, six and seven was the non-Bottlenecking workstation. A workstation can become a bottleneck when the workload in that station was heavier than average observed time. In this research, when the workstation time was higher than the cycle time, it was considered as bottleneck. To determine if a workstation was a bottleneck, the following steps will be considered.

- Observe each workstation and record stopwatch time. Only targets one workstation to test the full capacity of that station. If it was close to the number of tasks produced a day, then:
- Calculate the cycle time, put more tasks in the bottleneck to check if the overall productivity increases significantly. If so, the workstation was considered a bottleneck in production

Table 4.10. Total Assembly Time for 12.7mm AAG

Work stations	Descriptions	Average Assembly time(in minutes)	Number of operators
01	Barrel subassembly	128.6	03
02	Receiver body subassembly	254.5	03
03	Receiver cover subassembly	331.9	03
04	Bolt body subassembly	*123.4*	03
05	Trigger mechanism subassembly	275.4	03
06	Shoulder rest subassembly	45.5	03
07	General assembly	59.6	03
Total number of workstations			07
Total number of operators			21
Helper			03
Bottleneck time			331.9, 275.4, 254.5
Total observed time			828.81 min for one weapon
Available time			8hr. per day

The observed data and time study show that the assembly lines indicate three bottleneck areas at 12.7mm AAG assembly line stations; two, three and five assembly line stations with respect to other stations in the following graph.

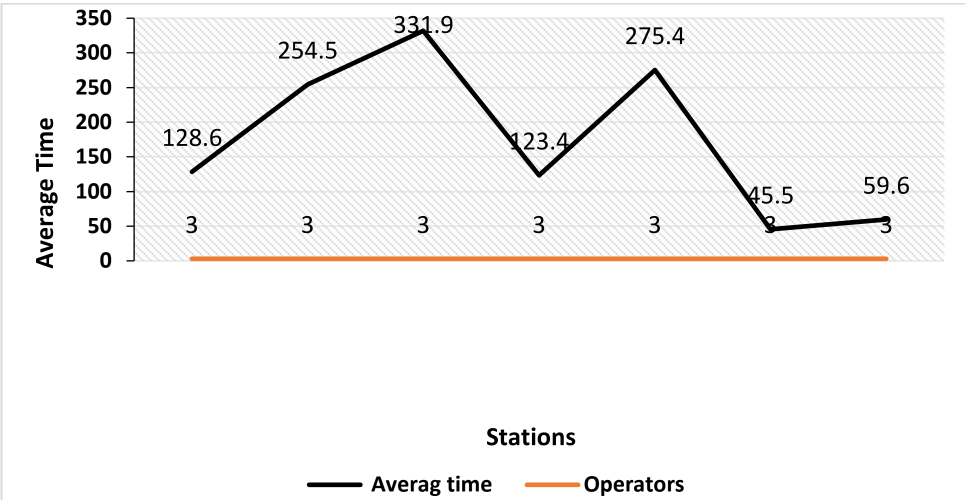


Figure 4.10. Cycle time for Current Workstations for 12.7mm AAG Weapon

Theoretical calculation

Bottleneck time for receiver cover subassembly was 331.9 minutes, Trigger mechanism subassembly 275.4 and Receiver body subassembly was 254.5 minutes. Time required for mounting subassemblies 480 minutes per day. Hence total task time for assembly one 12.7mm AAG machine gun was 828.81 minutes.

Annual demand = 700 units per year

Annual working day = 250 days

Working hour = 8 hr. per day and working days was 22 days per month.

Tea break = 30 mints (before lunch and after lunch)

Monthly

$$\text{Production} = \frac{\text{number of working days x total working time}}{\text{time required for one machine gun}} = \frac{22\text{x}450}{828.81} = 11.944$$

$$= 12 \text{ unit per month}$$

$$\text{Cycle time} = \frac{\text{production time avaliable per year}}{\text{units required per year}} \text{ or } \frac{\text{total task time for one unit}}{\text{units required per month}}$$

$$\text{Cycle time} \quad = \frac{112500}{700} = 160.714$$

$\text{Maximum production rate} = \frac{\text{avalible time}}{\text{bottleneck task time}} = \frac{450\text{min/hours}}{331.9 \text{ min/units}} = 1.356 \text{ units/hours}$. It was subassembly of receiver cover

Maximum production rate $= \frac{\text{avalible time}}{\text{bottleneck task time}} = \frac{450\text{min/hr}}{275.4 \text{ min/units}} = 1.634 \text{ units/hr}$.

It was subassembly of Trigger mechanism.

$\text{Maximum production rate} = \frac{\text{avalible time}}{\text{bottleneck task time}} = \frac{450\text{min/hours}}{254.5 \text{ min/units}} = 1.768 \text{ units/hours}$. It was subassembly of Receiver body

Efficiency

$$\text{Efficiency (\%)} = \frac{\sum \text{task time}}{\text{number of work station x maximum time at each work station}}$$

$$= \frac{828.81}{7\text{x}160.714} = 0.7367 = 73.67\% = 74\%$$

$\text{Balance delay} = 100\% - 73.67\% = 26.33\%$ or

Idle time;

$$\text{Percent of idle} = 1 - \text{efficiency} = 1 - 0.7367 = 0.2633 = 26.33\%$$

Total idle time per day = production time per day * percent of idle = 450 min * 0.2633 = 118.485 min.

Number of work stations for existing was seven

4.7. Ranked positional weight (RPW) method computation of RPW value and assembly line priority

RPW or R_i for Barrel Subassembly

- Calculate the RPW values from above precedence diagram and assign descending order of RPW values
- Rank position weight (RPW) or R_i values were calculated by using

Equation, $R_i = T_i + \sum_{j \epsilon Q_i} T_j$, as per this equation , the R_i value for Barrel Subassembly as follow

From figure 4.4, the RPW value for Barrel Subassembly was calculated from left to right: therefore

$$R_{13} = 27.5$$

$$R_{12} = 27.5 + 3.3 = 30.8$$

$$R_{11} = 27.5 + 2.9 = 30.4$$

$$R_{10} = 27.5 + 3.3 + 2.9 + 3 = 36.7$$

$$R_9 = 36.7 + 4 = 40.7$$

$$R_8 = 36.7 + 6.3 = 43$$

$$R_7 = 36.7 + 4.8 = 41.5$$

$$R_6 = 36.7 + 5.9 = 42.6$$

$$R_5 = 36.7 + 11 = 47.7$$

$$R_4 = 27.5 + 3.3 + 2.9 + 3 + 11 + 21.2 = 68.9$$

$$R_3 = 27.5 + 3.3 + 2.9 + 3.0 + 25.8 = 62.5$$

$$R_2 = 27.5 + 2.9 + 3.3 + 3 + 4 + 6.8 + 4.8 + 5.9 + 25.8 + 10.9 = 94.9$$

$$R_1 = 27.5 + 2.9 + 3.3 + 3 + 4 + 6.3 + 4.8 + 5.9 + 25.8 + 11 + 21.2 + 10.9 + 3 = 128.6$$

Table 4.11. Barrel Subassembly of RPW Values and Descending Order

Element	RPW (R) values	Time (minutes)	Predecessor
1	128.6	3.0	---
2	94.9	10.9	1
4	68.9	21.2	1
3	62.5	25.8	2
5	47.7	11.0	4
8	43.0	6.3	2
6	42.6	5.9	2
7	41.5	4.8	2
9	40.7	4.0	2
10	36.7	3.0	3,5,6,7,8,9
12	30.8	3.3	10
11	30.4	2.9	10
13	27.5	27.5	11,12

RPW or R_i for Receiver Body Subassembly

- Calculate the RPW values from above precedence diagram and assign descending order of RPW values
- Rank position weight (RPW) or R_i values was calculated by using equation, $R_i = T_i + \sum_{j\epsilon Q_i} T_j$ as per this equation, the R_i value for Receiver Body Subassembly as follow

From figure 4.8**,** the RPW value for Receiver Body Subassembly was calculated from left to right: therefore $R_{16} = 5.4$

$$R_{15} = 5.4 + 6.4 = 11.8$$

$$R_{14} = 5.4 + 6.4 + 8.1 = 19.9$$

$$R_{13} = 19.9 + 11 = 30.9$$

$$R_{12} = 30.9 + 8.7 = 39.6$$

$$R_{11} = 39.6 + 11 = 50.6$$

$$R_{10} = 39.6 + +9.2 = 48.8$$

$$R_9 = 39.6 + 6.6 = 46.2$$

$$R_8 = 39.6 + 6.7 = 46.3$$

$$R_7 = 5.4 + 6.4 + 8.1 + 11 + 8.7 + 6.6 + 9.2 + 6.6 + 6.7 + 5.2 = 73.9$$

$$R_6 = 73.9 + 37.6 += 111.5$$

$$R_5 = 111.5 + 37.4 = 148.9$$

$$R_4 = 111.5 + 11 = 122.5$$

$$R_3 = 111.5 + 45.7 = 157.2$$

$$R_2 = 5.4 + 6.4 + 8.1 + 11 + 8.7 + \cdots + 45.8 = 251.4$$

$$R_1 = 5.4 + 6.4 + \cdots + 45.8 + 3.1 = 254.5$$

Table 4.12. Receiver Body Subassembly of RPW Values and Descending Order

Element	RPW (R) values	Time (minutes)	Predecessor
1	254.5	3.1	--
2	251.4	45.8	1
3	157.2	45.7	2
5	148.9	11.0	2
4	122.5	37.4	2
6	111.5	37.6	3,4,5
7	73.9	5.2	6
11	50.6	6.7	7
10	48.8	6.6	7
8	46.3	9.2	7
9	46.2	6.6	7
12	39.6	8.7	8,9,10,11
13	30.9	11.0	12
14	19.9	8.1	13
15	11.8	6.4	14
16	5.4	5.4	15

RPW or R_i for Receiver Cover Subassembly

- Calculate the RPW values from above precedence diagram and assign descending order of RPW values
- Rank position weight (RPW) or R_i values was calculated by using equation, $R_i = T_i + \sum_{j \epsilon Q_i} T_j$, as per this equation, the R_i value for Receiver Cover Subassembly as follow

From figure 4.6, the RPW value for Receiver Cover Subassembly was calculated from left to right: therefore

$$R_{31} = 5.3$$

$$R_{30} = 5.3 + 6.1 = 11.4$$

$$R_{29} = 5.3 + 6.1 + 7 = 18.4$$

$$R_{28} = 18.4 + 8.8 = 27.2$$

$$R_{27} = 27.2 + 9 = 36.2$$

$$R_{26} = 36.2 + 7 = 43.2$$

$$R_{25} = 36.2 + 7.7 = 43.9$$

$$R_{24} = 5.3 + 6.1 + 7 + 8.8 + 9 + 7.7 + 7 + 6.1 = 57$$

$$R_{23} = 57 + 7 = 64$$

$$R_{22} = 57 + 7.8 = 64.8$$

$$R_{21} = 5.3 + 6.1 + 7 + 8.8 + 9 + 7.7 + 7 + 6.1 + 7.8 + 7 + 9.1 = 80.9$$

$$R_{20} = 80.9 + 5.9 = 86.8$$

$$R_{19} = 80.9 + 5 = 85.9$$

$$R_{18} = 80.9 + 15 = 95.9$$

$$R_{17} = 80.9 + 15 + 5 + 5.9 + 6.1 = 112.9$$

$$R_{16} = 112.9 + 6.4 = 119.3$$

$$R_{15} = 119.3 + 10.3 = 129.6$$

$$R_{14} = 129.6 + 20 = 149.6$$

$$R_{13} = 129.6 + 21.7 = 151.3$$

$$R_{12} = 129.6 + 21.9 = 151.5$$

$$R_{11} = 129.6 + 21.6 = 151.2$$

$$R_{10} = 129.6 + 20 + 21.7 + 21.9 + 21.2 + 20.1 = 234.5$$

$$R_9 = 234.5 + 12 = 246.5$$

$$R_8 = 234.5 + 13 = 247.5$$

$$R_7 = 234.5 + 19.5 = 254$$

$$R_6 = 234.5 + 19.4 = 253.9$$

$$R_5 = 234.5 + 9 = 243.5$$

$$R_4 = 234.5 + 6.8 = 241.3$$

$$R_3 = 234.5 + 7.7 = 242.2$$

$$R_2 = 234.5 + 7.7 + 6.8 + 9 + 19.4 + 19.5 + 13 + 12 + 6 = 327.9$$

$$R_1 = 5.3 + 6.1 + 7 + 8.8 + 9 + 7.7 + 7 + 6.1 + 7.8 + 7 + 9.1 + 5.9 + \cdots + 6 + 4 = 331.9$$

Table 4.13. Receiver Cover Subassembly of RPW Values and Descending Order

Element	RPW (R) values	Time (minutes)	Predecessor
1	331.9	4	-
2	327.9	6	1
7	254	7.7	2
6	253.9	6.8	2
8	247.5	9	2
9	246.5	19.4	2
5	243.5	19.5	2
3	242.2	13	2
4	241.3	12	2

10	234.5	20.1	3,4,5,6,7,8,9
12	151.5	21.2	10
13	151.3	21.9	10
11	151.2	21.7	10
14	149.6	20	10
15	129.6	10.3	11,12,13,14
16	119.3	6.4	15
17	112.9	6.1	16
18	95.9	15	17
19	85.9	5	17
20	86.8	5.9	17
21	80.9	9. 1	18,19,20
22	64.8	7.8	21
23	64	7	21
24	57	6.1	22,23
25	43.9	7.7	24
26	43.2	7	24
27	36.2	9	25,26
28	27.2	8.8	27
29	18.4	7	28
30	11.4	6. 1	29
31	5.3	5.3	30

RPW or R_i for Bolt Body Subassembly

- Calculate the RPW values from above precedence diagram and assign descending order of RPW values
- Rank position weight (RPW) or R_i values were calculated by using equation, $R_i = T_i + \sum_{j \epsilon Q_i} T_j$, as per this equation, the R_i value for Bolt Body Subassembly as follow
- From figure 4.7, the RPW value for Bolt Body Subassembly was calculated from left to right: therefore

$$R_{15} = 26.5$$

$$R_{14} = 6.3$$

$$R_{13} = 6.0$$

$$R_{12} = 4.1$$

$$R_{11} = 4.1 + 6 + 6.3 + 26.5 + 4 = 46.9$$

$$R_{10} = 46.9 + 8.5 = 55.4$$

$$R_9 = 55.4 + \ 5.8 = 61.2$$

$$R_8 = 61.2 + 5.9 = 67.1$$

$$R_7 = 67.1 + 6 = 73.1$$

$$R_6 = 73.1 + 9.2 = 82.3$$

$$R_5 = 73.1 + 6.1 = 79.2$$

$$R_4 = 73.1 + 9.2 + 6.1 + 5.8 = 94.2$$

$$R_3 = 94.2 + 7.2 = 101.4$$

$$R_2 = 94.2 + 11 = 105.2$$

$$R_1 = 26.5 + 6.3 + 6 + 4.1 + 4 + 8.5 + 5.8 + \cdots + 11 + 11 = 123.4$$

Table 4.14. Bolt Body Subassembly for RPW Values and Descending Order

Element	RPW(R) values	Time (minutes)	Predecessor
1	123.4	11	-
2	105.2	11	1
3	101.4	7.2	1
4	94.2	5.8	2,3
6	82.3	6.1	4
5	79.2	9.2	4
7	73.1	6.0	5,6
8	67.1	5.9	7
9	61.2	5.8	8
10	55.4	8.5	9
11	46.9	4.0	10
15	26.5	4. 1	11
14	6.3	6.0	11
13	6.0	6.3	11
12	4.1	26.5	11

RPW or R_i for Trigger Mechanism Subassembly

- Calculate the RPW values from above precedence diagram and assign descending order of RPW values
- Rank position weight (RPW) or R_i values was calculated by using equation, $R_i = T_i + \sum_{j \epsilon Q_i} T_j$, as per this equation, the R_i value for Trigger Mechanism Subassembly as follow

From figure 4.8, the RPW value for Subassembly of Trigger Mechanism was calculated from left to right: therefore

$$R_{19} = 22.1$$

$$R_{18} = 22.1 + 15.4 = 37.5$$

$$R_{17} = 22.1 + 26.8 = 48.9$$

$$R_{16} = 22.1 + 15.4 + 26.8 + 16.5 = 80.8$$

$$R_{15} = 80.8 + 19.3 = 100.1$$

$$R_{14} = 100.1 + 17.3 = 117.3$$

$$R_{13} = 117.3 + 16.3 = 133.6$$

$$R_{12} = 117.3 + 15 = 132.3$$

$$R_{11} = 117.3 + 12 = 129.3$$

$$R_{10} = 117.3 + 8.5 = 125.8$$

$$R_{9} = 117.3 + 7.4 = 124.7$$

$$R_8 = 22.1 + 15.4 + 26.8 + 16.5 + 19.3 + 17.2 + 16.3 + 15 + 12 + 8.5 + 7.4 + 8.6 = 185.1$$

$$R_7 = 185.1 + 9.5 = 194.6$$

$$R_6 = 185.1 + 13.8 = 198.9$$

$$R_5 = 185.1 + 11 = 196.1$$

$$R_4 = 185.1 + 9.5 + 13.8 + 11 + 12.1 = 231.5$$

$$R_3 = 231.5 + 15.2 = 246.7$$

$$R_2 = 246.7 + 14.9 = 261.6$$

$$R_1 = 261.6 + 13.8 = 275.4$$

Table 4.15. Trigger Mechanism Subassembly of RPW Values and Descending Order

Element	RPW(R) values	Time (minutes)	Predecessor
1	275.4	13.8	--
2	261.6	14.9	1
3	246.7	15.2	2
4	231.5	12. 1	3
6	198.9	11.0	4
5	196.1	13.8	4
7	194.6	9.5	4
8	185.1	8.6	5,6,7
13	133.6	7.4	8
12	132.3	8.5	8
11	129.3	12.0	8
10	125.8	15.0	8
9	124.7	16.3	8
14	117.3	17.2	9,10,11,12,13
15	100.1	19.3	14
16	80.8	16.5	15
17	48.9	26.8	16
18	37.5	15.4	16
19	22.1	22. 1	17,18

RPW or R_i for Shoulder Rest Subassembly

- Calculate the RPW values from above precedence diagram and assign descending order of RPW values
- Rank position weight (RPW) or R_i values was calculated by using equation, $R_i = T_i + \sum_{j \epsilon Q_i} T_j$, as per equation, the R_i value for Shoulder Rest Subassembly as follow, From figure 4.9 , the RPW value for Subassembly of Shoulder Rest was calculated from left to right: therefore

$$R_{13} = 5$$

$$R_{12} = 5.9$$

$$R_{11} = 5 + 5.9 + 3.1 = 14$$

$$R_{10} = 14 + 4.1 = 18.1$$

$$R_9 = 14 + 2.7 = 16.7$$

$$R_8 = 5 + 5.9 + 3.1 + 4.1 + 2.7 + 3.2 = 24$$

$$R_7 = 24 + 3.1 = 27.1$$

$$R_6 = 27.1 + 3.1 = 30.2$$

$$R_5 = 27.1 + 4.1 = 31.5$$

$$R_4 = 27.1 + 3 = 30.1$$

$$R_3 = 27.1 + 2 = 29.1$$

$$R_2 = 5 + 5.9 + 3.1 + 2.7 + 4.1 + 3.2 + 3.1 + 4.1 + 3.1 + 3 + 2 + 3.6 = 42.9$$

$$R_1 = 5 + 5.9 + \cdots + 2.6 = 45.5$$

Table 4.16. Shoulder Rest Subassembly of RPW Values and Descending Order

Element	**RPW (R) values**	**Time (minutes)**	**Predecessor**
1	45.5	2.6	--
2	42.9	3.6	1
5	31.5	2.0	2
6	30.2	3.0	2
4	30. 1	4. 1	2
3	29. 1	3.1	2
7	27. 1	3.1	3,4,5,6
8	24	3.2	7
10	18.1	2.7	8
9	16.7	4.1	8
11	14	3.1	9,10
12	5.9	5.9	11
13	5.0	5.0	11

RPW or R_i for General Subassembly

- Calculate the RPW values from above precedence diagram and assign descending order of RPW values
- Rank position weight RPW or R_i values was calculated by using equation, $R_i = T_i + \sum_{j \epsilon Q_i} T_j$, as per this equation, the RPW or R_i value for General Subassembly as follow

From figure 4.10, the RPW value for General Assembly was calculated from left to right: therefore

$$R_6 = 6.6$$

$$R_5 = 6.6 + 11.2 = 17.8$$

$$R_4 = 17.8 + 6.0 = 23.8$$

$$R_3 = 23.8 + 15.6 = 39.4$$

$$R_2 = 39.4 + 11.1 = 50.5$$

$$R_1 = 50.5 + 9.1 = 59.6$$

Table 4.17. General Subassembly of RPW Values and Descending Order

Element	RPW(R) values	Time (minutes)	Predecessor
1	59.6	9.1	--
2	50.5	11.1	1
3	39.4	15.6	2
4	23.8	6.0	3
5	17.8	11.2	4
6	6.6	6.6	5

The calculation of performance indicators for the RPW method was presented as follows

- Number of existing workstations was seven

$$\text{Cycle time } = \frac{112500}{700} = 160.714 \text{ min}$$

$$\text{Theoretical minimum number of workstation } = \frac{\text{total work content time}}{\text{cycle time}} =$$

$\frac{828.81}{160.714} = 5.157 \approx 5$ Workstations

Efficiency;

$$\text{Efficiency (\%)} = \frac{\sum \text{task time}}{\text{number of work station x maximum time at each work station}}$$

$$\text{Efficiency (\%)} = \frac{828.81}{5\text{x}160.714} = 1.0314 = 103.14\%$$

$$\text{Balance delay } = 100\% - 103.14\% = -3.14\% \text{ or}$$

$$\text{Balance delay (\%) } = \frac{\text{number of workstation x cycle time } - \text{ total work content time}}{\text{number of workstation x cycle time}}$$

$$\text{Balance delay (\%)} = \frac{5\text{x}160.714 - 828.81}{5\text{x}160.714} = -0.0314 = -3.14\%$$

Idle time;

$$\text{Percent of idle} = 1 - \text{ efficiency} = 1 - 1.0314 = -0.0314 = -3.14\%$$

$$\text{Total idle time per day } = \text{production time per day } \times \text{percent of idle } = 450\text{min} \times 0.0314 = 14.13 \text{ min}$$

4.8. An Experimental study on the 12.7mm AAG Assembly Line Using RPW Balancing Techniques

Table 4.18. proposed of 12.7mm AAG assembly line

Workstations No.	Elements	Time (minutes)	RPW values	Sum of station times (minutes)
	1	3.0	128.6	
	2	10.9	94.9	
	4	21.2	68.9	

1	3	25.8	62.5	343.5
	5	11.0	47.7	
	8	6.3	43.0	
	6	5.9	42.6	
	7	4.8	41.5	
	9	4.0	40.7	
	10	3.0	36.7	
	12	3.3	30.8	
	11	2.9	30.4	
	13	27.5	27.5	
	14	3.1	254.5	
	15	45.8	251.4	
	16	45.7	157.2	
	18	11.0	148.9	
	17	37.4	122.5	
	19	37.6	111.5	
	20	5.2	73.9	
	23	5.7	50.6	
	21	6.6	48.8	
	22	9.2	46.3	
	24	6.6	46.2	
2	25	8.7	39.6	198.2
	26	11.0	30.9	
	27	8.1	19.9	
	28	6.4	11.8	
	29	5.4	5.4	
	30	4.0	331.9	
	31	6.0	327.9	
	36	7.7	254	
	35	6.8	253.9	
	37	9.0	247.5	
	38	19.4	246.5	
	34	19.5	243.5	
	32	13.0	242.2	
	33	12.0	241.3	
	39	20.1	234.5	
	41	21.2	151.5	
	42	21.9	151.3	
	40	21.7	151.2	
	43	20.0	149.6	
	44	10.3	129.6	
	45	6.4	119.3	
	46	6.1	112.9	

3	47	15.0	95.9	193.3
	49	5.0	85.9	
	48	5.9	86.8	
	50	9.1	80.9	
	51	7.8	64.8	
	52	7.0	64	
	53	6.1	57	
	54	7.7	43.9	
	55	7.0	43.2	
	56	9.0	36.2	
	57	8.8	27.2	
	58	7.0	18.4	
	59	6.1	11.4	
	60	5.3	5.3	
	61	11.0	123.4	
	62	11.0	105.2	
4	63	7.2	101.4	101.4
	64	5.8	92.4	
	66	6.1	82.3	
	65	9.2	79.2	
	67	6.0	73. 1	
	68	5.9	67.1	
	69	5.8	61.2	
	70	8.5	55.4	
	71	4.0	46.9	
	73	4.1	26.5	
	72	6.0	6.3	
	74	6.3	6.0	
	75	26.5	4.1	
	76	13.8	275.4	
	77	14.9	261.6	
	78	15.2	246.7	
	79	12.1	231.5	
	80	11.0	198.9	
	81	13.8	196.1	
	82	9.5	194.6	
	83	8.6	185.1	
	87	7.4	133.6	
	84	8.5	132.3	
	88	12.0	129.3	
	86	15.0	125.8	
	85	16.3	124.7	
	89	17.2	117.3	

5	90	19.3	100.1	377.8
	91	16.5	80.8	
	92	26.8	48.9	
	93	15.4	37.5	
	94	22.1	22.1	
	95	2.6	45.5	
	96	3.6	42.9	
	97	2.0	31.5	
	98	3.0	30.2	
	100	4.1	30.1	
	99	3.1	29.1	
	101	3.1	27.1	
	102	3.2	24.0	
	104	2.7	18.1	
	103	4.1	16.7	
	105	3.1	14.0	
	106	5.9	5.9	
	107	5.0	5.0	
	108	9.1	59.6	
	109	11.1	50.5	
	110	15.6	39.4	
	111	6.0	23.8	
	112	11.2	17.8	
	113	6.6	6.6	

Five workstations on the modified assembly line allow for the rank-position weighted method of subassembly merging. This thesis suggests creating a new production line with fewer operators by using computed workstations. The percentage of workstations that automatically improved production or line efficiency ranges from 73.67 to 103.14 percent. This kind of situation arises when operators sit idles a lot. Therefore, the productivity of the system can be increased by utilizing these operators' efficiency in production.

4.9. Equilibration of the Suggested Production Line

The quantity of tasks that would be completed was the basis for the assembly line's basic balancing strategy. The specified takt time, precedence, cycle time, and time units were the other key factors in balancing the line. The demand rate and available time were used to calculate the takt time below.

as per equation , $Takt\ time = \frac{available\ time\ per\ day}{customer\ demand\ per\ day}$

$$Takt\ time = \frac{available\ time\ per\ day}{customer\ demand\ per\ day} = \frac{450}{2.8} = 160.714 \text{ min}$$

as per equation, $\text{Balance loss (BL) (\%)} = \frac{N\times T - \sum_{i=1}^{n} t}{N\times T}$

$$\text{Balance loss (BL)(\%)} = \frac{7\times 160.714 - 828.81}{7\times 160.714} = 0.2633 = 26.33\%$$

4.10. Result and Discussion

This section examines a number of outcomes related to the new 12.7mm AAG assembly line, including worker utilization assessment, productivity, line efficiency, and overall time consumed.

The total task duration was reduced from 1470 minutes to 828.81 minutes using the RPW heuristics technique, and there were five work stations instead of seven. After workstation grouping, the line efficiency rises to 73.67 percent, and the balancing delay falls to 26.33 percent from 60.54 percent. This makes sure that each workstation has an equal workload, which leads to a much better assembly line flow.

The study's findings demonstrate that the line balancing for the 12.7mm AAG assembly line segment reduce workstations and increase line efficiency. Stated differently, the time margin for both internal and external work increases as the cycle time of the 12.7mm AAG production line reduces. Even though the outcomes differ amongst models, the main factors influencing these process line balancing would be superior to the previous one.

Table 4.19. Detailed Analysis of the Current and Adapted Assembly Line

Parameters	Existing Assembly Line	New Assembly Line
Time taken	1470 mints	828.81 mints
Line eefficiency	43.56 %	73.67 %
Balance loss	56.43%	26.33%
Number of workers	21	15
Workstation	7	5

To increase productivity and efficiency, Gafat Armament Engineering Industries uses the ranked position weighted (RPW) approach. In this thesis work, the 12.7mm AAG assembly line was redesigned using the ranking position weighted (RPW) technique, which increased productivity and efficiency by lowering the number of stations and necessitating the precedence task method. According to the study, the process industries can benefit equally from the (RPW) strategy for balancing assembly lines and production.

CHAPTER FIVE

CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1 Conclusion

This study presents the improvement of a 12.7mm AAG assembly line employing line balancing techniques like the RPW heuristic algorithm. The main objective of this thesis was to optimize the 12.7mm AAG assembly process in terms of the number of operators, work stations, cycle time, line efficiency, and balancing delay. The goal of assembly line balancing was to divide the workload equally among all of the work stations along the line.

This study's main objective was to show how to design and balance an assembly line using the RPW methodology. In this study, the RPW technique has been shown to be helpful in situations where data were scarce. Once more, work stations can be synchronized for work flow and sequencing using the RPW technique. Bottlenecking in the assembling process can therefore be minimized. This study has established the workstation count and used the RPW approach to offer a well-designed architecture. Prior to the RPW approach, there were seven workstations and 73.67 %-line efficiency. With five workstations, line efficiency rose to 103.14 % after applying the RPW technique. Businesses need to be more adaptable and productive in order to survive in the face of increased competition, constantly shifting customer demands, and shorter lead times. The efficiency of an assembly line was directly impacted by its balance.

5.2 Recommendation

The medium caliber production factory assembly line of Gafat Armament Engineering Industry was improved through the application of the RPW heuristic technique. The following recommendations have been made for the researcher based on the thesis result: -

- ✓ In order to determine the cost of assembly for the 12.7mm AAG in the suggested line balancing,
- ✓ It was also recommended that shop managers, supervisors, and operators receive multi-skill and mechanic training to increase production and efficiency.
- ✓ To allocate time for research and establish a standard time for every subassembly.

5.3. Future Work

A line-balancing approach might be used to conduct the current research and yield far more realistic findings. For the purpose of improving the balance of the 12.7mm AAG assembly line process between departments, the current study may incorporate a time study and line balancing.

upcoming tasks for the 12.7mm AAG assembly line;

- Ensure that operations' workloads were balanced.
- Use adaptable manufacturing systems to increase output.
- Apply the 5s methodology or kaizen principles for optimal line efficiency.

REFERENCE

Abdul Talib Bon, D.D., (2010). Time Motion Study in Determination of Time Standard in Manpower Process.

Bung Wai Kit, (2018), Redesigning of Lamp Production Assembly Line.

Covas, J. (2014). Production line balancing simulation: a case study in the footwear industry.

Chorkaew. Jaturanonda Heuristic Procedure for the Assembly Line Balancing Problem withPostural Load Smoothness‖ International Journal of Occupational Safety and Ergonomics(JOSE) 2013, Vol. 19, No. 4, 531–541.

Christian Becker ―A survey on problems and methods in generalized assembly line balancing‖ Friedrich-Schiller-Universität Jena, 2003 ISSN 1611-1311.

De Carlo, F., Arleo, M. A., Borgia, O., & Tucci, M. (2013). Layout design for a low capacity manufacturing line: a case study. International Journal of Engineering Business Management, (Godište 2013), 5-35.

Deshpande, V. A., & Joshi, A. Y. (2007, January). Application of Ranked Positional Weight Method for Assembly Line Balancing–A Case Study. In Proceedings of International Conference on Advances in Machine Design & Industry Automation (pp. 348-352).

Erel E, Gokcen H (1999) Shortest-route formulation of mixed-model assembly line balancing problem. Eu J Oper Res 116:194–204.

Erel E, Gokcen H (1998) Binary integer formulation for mixed-model assembly line balancing problem. Comput Ind Eng 23:451–461

Erel E, Gokcen H (1997) A goal programming approach to mixed model assembly line balancing problem. Int J Prod Econ 48:177–185

Groover, M.P., Automation Production-Systems-And-Cim-Groover 2001. 2002.

Helgeson WB, Birninie DP (1961) Assembly line balancing using the ranked positional weight techniques. Int J Prod Econ 48:177–185

Hisham, S. F. B. (2013). Assembly line balancing improvement: a case study in an electronic industry (Doctoral dissertation, UMP).

Islam, M. M., Mohiuddin, H. M., Mehidi, S. H., & Sakib, N. (2014). An optimal layout design in an apparel industry by appropriate line balancing: A case study. Global journal of research in engineering.

Kabir A, Tabucanon MT (1995) Batch-model assembly line balancing: a multi attribute decision making approach. Int J Prod Econ 41:193–201

Lucas K ―An Assembly Line Balance Optimization Model Using Ant Colony‖ 2009 IEEE DOI 10.1109/ICNC.2009.693

Micieta, B. & Stollmann, V ―Assembly Line Balancing‖, Daaam International Scientific Book 2011 Pp. 257-264 Chapter 21.

Micieta, B., & Stollmann, V. (2011). Assembly line balancing. DAAAM International p, 257-264.

Manoria, A., Mishra, S. K., & Maheshwar, S. (2012). Expert System based on RPW Technique to Evaluating Multi Product Assembly Line Balancing Solution. InternationalJournalofComputer Applications, 40(4), 27-32.

Mohamed, N. M. Z. (2013). The Development of a Hybrid Knowledge-Based System for Designing a Low Volume Automotive Manufacturing Environment. (Doctoral dissertation, University of Bradford).

Monden Y (1993) Toyota production system, second edition. IndustrialEngineering and Management Press, Institute of Industrial Engineers, Norcross, GA.

Miltenburg GJ (1989) Level schedules for mixed-model assembly lines in just-in-time production systems. Manage Sci 35:192–207.

Naveen Kumar ―Assembly Line Balancing: A Review of Developments and Trends in Approach to Industrial Application‖ Global Journal of Researches in Engineering Industrial Engineering Volume 13 Issue 2 Version 1.0 Year 2013.

Nils boysen ―A Classification of Assembly Line Balancing Problems‖ friedrich-schiller-universität jena issn 1611-1311(2006).

Pearce, B. W. (2015). A study on general assembly line balancing modeling methods and techniques (Doctoral dissertation, Clemson University).

Patel, R., & Davidson, B. (2011). Forsknings metodikens grunder: At planera, Genom for a och rapportera en undersökning. Lund: Studentlitteratur

Parvez, M., Amin, F., & Akter, F. (2017). Line Balancing Techniques To Improve Productivity Using Work Sharing Method. IOSR Journal of Research & Method in Education (IOSRJRME), 7(03), 07-14.

Pisuchpen, R., & Chansangar, W. (2014). Modifying production line for productivity improvement: A Case Study of Vision Lens Factory. Songklanakarin Journal of Science & Technology, 36(3).

P. Sivasankaran ―Literature review of assembly line balancing problems‖ Int J Adv Manuf Technol (2014) 73:1665–1694.

Reyneke, M. (2011). Assembly line layout and process optimization at Powertech Transformers.

Ranjith, R. (2015). Assembly line design and balancing (Master's thesis).

RashmiSarmah, R., A Review on Assembly Line Balancing. International Journal of AdvancedResearch, 2019. **7**(9): p. 465-470.

Rekiek, B., Dolgui, A., Delchambre, A., & Bratcu, A. (2002). State of art of optimization methods for assembly line design. Annual Reviews in control, 26(2), 163-174.

Sproul, R. (2019). Theory of constraints, Lean, and Six Sigma improvement methodology: making the case for integration. New York: Routledge: Taylor& Francis Group.

Singh, G., (2019). Modeling And Optimization Of The Tv Assembling Line Using Arena Simulation Software. International Journal Of Engineering Sciences & Research Technology,.

Torenli, A. (2009). Assembly line design and optimization. Chalmers University of Tech., Chalmers University of Technology, Goteborg, Sweden, Master of Science thesis.

Thomopoulos NT (1967) Line balancing-sequencing for mixed model assembly. Manage Sci 4(2): B59–B75

Vilarinho PM, Simaria AS (2002) A two-stage heuristic method for balancing mixed-model assembly lines with parallel workstations. Int J Prod Res 40:405–1420.

Vrittika Pachghare ―Assembly Line Balancing – A Review‖ International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Volume 3 Issue 3, March 2014.

Wenqiang Zhang ―A Multi objective Genetic Algorithm for Assembly Line Balancing Problem with Worker Allocation‖ 2008 IEEE International Conference on Systems, Man and Cybernetics (SMC 2008).

Wiyaratn, W., & Watanapa, A. (2010). Improvement plant layout using systematic layout planning (SLP) for increased productivity. International Journal of Industrial and Manufacturing Engineering, 4(12), 1382-1386.

Xavier Delorme ―A Survey on Cost and Pro_t Oriented Assembly Line Balancing‖ Preprints of the 19th World Congress the International Federation of Automatic Control Cape Town, South Africa. August 24-29, 2014.

Yerasi, P. (2012). Productivity Improvement of a Manual Assembly Line (Doctoral dissertation, Texas A & M University).

Yin, M., & Jiang, W. (2016, June). The Theory of IE Assembly Line Balance and Optimization. In 6th International Conference on Machinery, Materials, Environment, Biotechnology and Computer. Atlantis Press.

Yin, R. K. (2007). Fallstudier: design och genomförande. Malmö: Liber.

Yin, R. K. (2014). Case Study Research: Design and methods. London: Imprint.

Appendix I: Time Observed

Reading stopwatch time for 12.7mm AAG of whole assembly line

Table A. Time assessment of the barrel subassembly assembly procedure using 12.7mm AAG

St No	Barrel Subassembly	Time Observed (minutes)											
		1	2	3	4	5	6	7	8	9	10	Total	Average
01	Barrel	1.0	1.1	1.9	1.1	1.0	1.8	1.2	1.9	1.0	1.9	13.9	1.39
	Front sight base	8.9	9.0	8.1	8.8	9.2	7.7	9.2	7.8	8.8	9.0	86.5	8.65
	Front sight base pin	23.8	23.7	23.8	23.9	23.0	23.8	23.9	23.8	24.0	24.0	237.7	23.77
	Flash eliminator (muzzle break)	19.2	19.0	19. 1	19.2	19.0	19. 1	19.0	19.2	19.0	19. 1	190.9	19.09
	Flash eliminator lock pin	9.0	9.0	9.0	9.0	9. 1	9. 1	9.2	9.0	9. 1	9.0	90.5	9.05
	Front sight bolt	3.9	4.0	3.8	3.9	3.9	4.0	4.0	4.0	4.0	4. 1	39.6	3.96
	Front sight nut	2.8	2.8	2.9	2.9	2.8	2.9	2.0	2.9	2.8	2.9	27.7	2.77
	Front sight mount	4.3	4.3	4.2	4. 1	4.0	4.0	4.2	4.2	4.3	4.2	41.8	4.18
	Front sight mount pin	2.0	2.2	2. 1	2.0	2.0	2.0	2. 1	2.2	2.0	2. 1	20.7	2.07
	Gas regulator	1.0	1.0	1.0	1. 1	1.2	1.0	1. 1	1.2	1.0	1.0	10.6	1.06
	Gas regulator nut	1.9	1.8	2.0	1.9	2.0	1.8	2.0	1.9	2.0	2.0	19.3	1.93
	Gas tube	1.3	1.3	1.2	1.0	1.1	1.3	1.3	1.2	1.1	1.3	12.1	1.21
	Barrel lock assembly parts	24.5	24.4	24.5	24.6	24.5	24.5	24.5	24.4	24.5	24.5	220.4	22.04
Total													101.17

Table B. Time analysis of receiver body subassembly using 12.7mm AAG assembly technique

St. No	Receiver body subassembly	Time Observed (minutes)											
		1	2	3	4	5	6	7	8	9	10	Total	Average
02	Receiver body	9.1	9.1	8.9	9.0	9.2	8.8	9.2	9.0	8.8	9.2	90.3	9.03
	Rear sight base	8.9	9.0	9.0	9.1	9.2	8.8	8.9	9.1	8.9	9.1	90.0	9.0
	Rear sight base rivet (pin)	5.3	5.3	5.2	5.1	5.1	5.2	5.3	5.3	5.3	5.3	52.4	5.24
	Rear sight base spring	3.8	3.8	3.9	3.7	3.8	3.8	3.9	3.7	3.8	3.8	38.0	3.8
	Rear sight base cup	4.1	4.1	4.1	4.0	4.0	4.2	4.1	4.2	4.0	4.1	40.9	4.09
	Rivet for base	7.3	7.3	7.3	7.2	7.1	7.1	7.2	7.3	7.2	7.3	72.3	7.23
	Link puller	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	40.0	4.0
	Link puller side plate	3.9	4.0	4.0	3.8	3.9	3.9	3.9	4.0	3.8	3.9	39.1	3.91
	Link puller spring	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	38.0	3.8
	Link puller pin	6.5	6.5	6.6	6.4	6.5	6.6	6.4	6.5	6.5	6.5	65.0	6.5
	Link puller screw	1.9	2.0	2.1	2.0	1.9	1.9	1.9	2.0	1.9	1.9	19.5	1.95
	Dust protector	2.0	2.0	2.0	2.0	2.1	2.2	2.1	2.0	2.1	2.0	20.5	2.05
	Dust protector pin	4.0	3.9	4.1	4.1	4.0	4.0	4.1	3.9	4.0	4.0	40.1	4.01
	Gas piston	4.4	4.3	4.2	4.1	4.4	4.4	4.4	4.5	4.3	4.2	43.2	4.32
	Rear sight assembly parts	24.6	24.5	24.4	24.5	24.6	24.4	24.6	24.5	24.6	24.6	245.3	24.53

	Rear sight pin	3.5	3.5	3.4	3.3	3.5	3.4	3.5	3.5	3.3	3.5	34.4	3.44
Total													96.9

Table C. Time analysis of the 12.7mm AAG assembly procedure for the subassembly of the receiver cover

St. No	Receiver cover subassembly	Time Observed (minutes)											
		1	2	3	4	5	6	7	8	9	10	Total	Average
03	Receiver cover body	1.9	2.0	2.1	1.9	1.9	2.0	2.0	1.9	2.1	2.0	19.8	1.98
	Upper pawl base	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	40.0	4.0
	Upper pawl base guide pin	5.8	5.7	5.6	5.7	5.8	5.8	5.7	5.6	5.7	5.8	57.2	5.72
	Upper pawl base plate	4.7	4.8	4.9	4.6	4.9	4.7	4.7	4.8	4.9	4.7	47.7	4.77
	Upper pawl base plate pin	7.0	6.9	6.9	7.1	7.9	7.0	7.0	7.1	6.9	7.1	70.9	7.09
	Upper pawl right	17.5	17.4	17.3	17.3	17.5	17.4	17.3	17.5	17.4	17.5	174.1	17.41
	Upper pawl left	17.5	17.5	17.4	17.4	17.3	17.5	17.4	17.3	17.8	17.4	174.5	17.45
	Upper pawl spring	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	110.0	11.0
	Upper pawl spring pin	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	100	10.0
	Feed pawl	18. 1	18.0	18.0	18. 1	18.0	18. 1	18. 0	18. 2	18. 0	18. 0	180.5	18.05
	Feed pawl spring	19. 2	18. 1	19. 2	18. 1	18. 3	19. 1	18. 3	19. 1	19. 3	19. 0	187.7	18.77
	Feed pawl spring pin	19. 9	20.0	19. 8	19. 8	19. 9	20.0	20.0	19. 9	19. 9	20.0	199.2	19.92
	Feed pawl base	19.6	19.5	19.6	19.5	19.6	19.5	19.5	19.6	19.5	19.6	195.5	19.55
	Feed pawl base guide pin	18.0	18.0	18.0	18. 1	18. 1	18.0	18.0	18.2	18.0	18.0	180.4	18.04
	Feed lever	3.9	4.0	4.0	48.0	3.8	3.9	4.0	4.0	3.9	3.9	83.4	8.34
	Feed lever spring washer	4.5	4.5	4.4	4.4	4.5	4.3	4.3	4.4	4.4	4.5	44.2	4.42
	Receiver cover locker	4. 1	4. 1	4. 2	4. 0	4. 1	4. 2	4. 1	4. 2	4. 1	4. 2	45.44	4.544
	Receiver cover locker handle	6.7	6.8	6.8	6.7	6.6	6.6	6.5	6.8	76	6.7	136.2	13.62
	Receiver cover locker spring	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	30.0	3.0
	Receiver cover locker pin	3.9	4.0	3.9	4. 1	3.0	3.9	3.8	3.9	4.0	4.0	38.5	3.85
	Feed lever limiter bracket	7.2	7.2	7. 1	7.0	7. 1	7.0	7. 1	7.2	7.2	7.0	71. 1	7. 11
	Feed lever limiter pin	5.8	5.7	5.8	5.8	5.9	5.7	5.7	5.8	5.9	5.8	57.9	5.79
	Feed lever limiter pin spring	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	50.0	5.0
	Plunger	4.2	4.2	4. 1	4.0	4.0	4.2	4.2	4.0	4. 1	4.2	41.2	4. 12
	Feed lever plunger pin	5.8	5.0	5.7	5.7	5.8	5.8	5.5	5.8	5.7	5.8	56.6	5.66
	Feed lever plunger bolt	4.9	5. 1	5.0	5. 1	5.0	4.9	4.8	4.9	5.0	5.0	94.7	9.47
	Feed lever lock washer left	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	70.0	7.0
	Feed lever lock washer right	6.9	6.9	6.8	6.9	6.7	6.9	6.9	6.8	6.7	6.9	68.4	6.84
	Receiver cover lock bracket	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	50.0	5.0
	Receiver cover plate spring	4.2	4. 1	4.2	4.0	4.0	4.2	4.2	4.0	4. 1	4. 1	41. 1	4. 11
	Bolt motion	3.3	3.3	3.2	3.3	3.2	3.3	3.3	3. 2	3. 1	3.3	32.5	3.25
Total													282.794

Table D. Time analysis of the bolt subassembly assembly process for 12.7mm AAG

St. No	Bolt subassembly	Time Observed (minutes)											
		1	2	3	4	5	6	7	8	9	10	Total	Average
	Bolt head	1.2	1.1	1.2	1.0	1.2	1.2	1.1	1.0	1.0	1.0	10.8	1.08
	Bolt right side	43.9	43.7	43.9	43.8	43.7	43.7	43.9	43.9	43.8	43.8	394.4	39.44

04	Bolt left side	43.8	43.6	43.5	43.6	43.7	43.8	43.8	43.6	43.8	43.7	393.1	39.31
	Extractor	8.9	8.8	9.0	9.0	8.9	9. 1	8.9	8.8	9. 1	9.0	89.5	8.95
	Extractor pin	35.5	35.3	35.5	35.4	35.4	35.4	35.5	35.5	35.4	35.5	354.4	35.44
	Extractor spring	35.7	35.5	35.6	35.5	35.4	35.5	35.7	35.7	35.7	35.7	356.0	35.60
	Firing pin	3.3	3.3	3.2	3.2	3.3	3.2	3.1	3.3	3.2	3.3	32.4	3.24
	Firing lock pin	4.8	4.6	4.8	4.6	4.8	4.8	4.7	4.8	4.6	4.8	47.3	4.73
	Ejector	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	40.0	4.0
	Ejector pin	7.3	7.3	7. 1	7.3	7.2	7. 1	7.3	7. 1	7.3	7.2	72.2	7.22
	Bolt head body	4.7	4.7	4.5	4.7	4.6	4.5	4.7	4.6	4.7	4.7	46.4	4.64
	Buffer spring rod	6.8	6.6	6.8	6.7	6.6	6.8	6.8	6.7	6.6	6.7	67.1	6.71
	Buffer spring	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	90.0	9.0
	Buffer spring pad	6.2	6.0	6.0	6.2	6.0	6. 1	6.2	6.0	6.2	6.2	61.1	6.11
	Buffer spring pin	4.5	4.5	4.5	4.4	4.4	4.3	4.5	4.5	4.4	4.4	44.4	4.44
Total													205.186

Table E. Time analysis of the trigger body subassembly 12.7mm AAG assembly procedure

St. No	Trigger body subassembly	Time Observed (minutes)											
		1	2	3	4	5	6	7	8	9	10	Total	Average
05	Trigger body	2.0	2.0	1.9	1.8	1.8	1.9	1.9	2.0	2.0	2.0	19.3	1.93
	Safety spring	3.8	3.8	3.7	3.7	3.9	3.9	4.0	3.8	3.9	4.0	38.5	3.85
	Safety spring rivet 3x5	2. 1	2. 1	2.2	2.0	2.0	2. 1	2.0	2.2	2.0	2. 1	20.8	2.08
	Release handle shaft	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	30.0	3.0
	Release handle rivet	6.7	6.7	6.6	6.6	6.8	6.6	6.7	6.8	6.8	6.7	67.0	6.7
	Release handle washer	3.3	3.3	3.2	3. 1	3.2	3.3	3.2	3. 1	3.2	3.3	32.2	3.22
	Release handle shaft spring	1.8	1.8	1.9	1.9	1.7	1.8	1.9	2.0	1.9	1.8	18.5	1.85
	Percussion rod	2.9	2.9	2.9	3.0	3. 1	3. 1	3.0	2.9	2.9	2.8	26.728	2.673
	Percussion spring	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	40.0	4.0
	Percussion push pin	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.7	15.3	1.53
	Percussion push pin spring	3.2	3.0	3.1	3.2	3.0	3. 1	3.0	3.2	3.0	3.0	30.8	3.08
	Percussion push plate	4.7	4.8	4.6	4.8	4.6	4.7	4.7	4.8	4.9	4.9	47.5	4.75
	Percussion push pin	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	40.0	4.0
	Safety lock rivet	3.7	3.6	3.5	3.5	3.6	3.7	3.5	3.6	3.5	3.7	35.9	3.59
	Safety lock	5.0	5. 1	5.0	5.2	5.0	5. 1	5.2	5.2	5.0	5.0	50.8	5.08
	Sear	6.0	6.2	6.2	6.2	6. 1	6. 1	6.0	6. 1	6.0	6.0	60.9	6.09

	Sear disconnecting rod spring	4.7	4.6	4.7	4.8	4.8	4.7	4.6	4.7	4.8	4.6	47.0	4.7
	Sear disconnecting rod spring pin	5.9	6. 1	6.0	6.0	6. 1	5.9	5.9	6.0	5.9	5.9	59.7	5.97
	Plastic handle	4.0	4.0	4.0	4.0	4. 1	4. 1	4. 1	4.0	4.0	4.0	40.3	4.03
Total													70.593

Table. F. Time analysis of the 12.7mm AAG shoulder subassembly assembly process

St. No	Shoulder rest subassembly	Time Observed (minutes)											
		1	2	3	4	5	6	7	8	9	10	Total	Average
06	Back plate	1.5	1.6	1.5	1.7	1.5	1.6	1.5	1.6	1.7	1.5	15.7	1.57
	Shoulder rest	1.5	1.5	1.6	1.7	1.5	1.6	1.5	1.7	1.5	1.6	15.7	1.57
	Shoulder rest rod	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	10.0	1.00
	Shoulder rest spring	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	10.0	1.00
	Shoulder rest tube	2.0	2.1	2.1	2.2	2.2	2.0	2.0	2.1	2.1	2.2	21.0	2.10
	Shoulder rest pin	1.9	1.8	1.9	2.1	2.0	2.0	2.1	1.9	1.9	1.9	19.5	1.95
	Shoulder rest connecting pin	1.1	1.0	1.0	1.1	1.1	1.0	1.1	1.0	1.1	1.0	10.5	1.05
	Back plate lock	1.3	1.3	1.2	1.1	1.1	1.2	1.3	1.3	1.2	1.3	12.3	1.23
	Back plate lock spring	1.7	1.7	1.8	1.6	1.8	1.7	1.7	1.8	1.8	1.8	17.4	1.74
	Back plate lock pin	1.0	1.1	1.1	1.0	1.1	1.2	1.2	1.2	1.1	1.0	11.0	1.10
	Pusher	1.0	1.1	1.1	1.0	1.0	1.0	1.1	1.2	1.1	1.0	10.6	1.06
	Pusher spring	2.9	2.9	2.8	3.0	3.0	3.0	2.9	2.8	2.9	2.9	29. 1	2. 91
	Pusher screw	2.1	2.0	2.1	2.0	2.1	2.0	2.0	2.0	2.1	2.0	20.4	2.04
Total													20.32

Table G. Time analysis of 12.7mm AAG assembly procedure for general subassembly

St. No	General assembly	Time Observed (minutes)											
		1	2	3	4	5	6	7	8	9	10	Total	Average
07	Barrel subassembly	7.0	7.0	7.1	7.2	7.1	7.1	7.0	7.0	7.1	7.0	70.6	7.06
	Receiver body subassembly	8.9	9.0	9.1	9.1	9.1	9.1	9.2	9.2	9.0	9.0	90.7	9.07
	Shoulder rest subassembly	4.5	4.6	4.5	4.6	4.7	4.5	4.6	4.5	4.6	4.6	45.7	4.57

	Receiver cover subassembly	13.5	13.5	13.7	13.6	13.5	13.6	13.6	13.5	13.6	13.5	135.5	13.56
	Bolt subassembly	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	40.0	4.0
	Trigger mechanism subassembly	9.3	9.2	9.1	9.0	9.0	9.2	9.3	9.3	9.0	9.2	91.6	9.16
Total													47.42

Appendix II: - Typical Allowance Percentages (Stevenson, 2009)

1. Constant allowances:		
	Men	**Women**
Personal needs allowances	5%	7%
Basic fatigue allowance	4%	4%
2.Variable additions to basic fatigue allowance:		
a. Sting allowance	2 %	4%
b. Sitting allowance	1%	3%
3. Abnormal position allowance:		
i. Slightly awkward	0 %	1%
ii. Awkward (bending)	2 %	3%
iii. Very awkward (lying, stretching up)	7 %	7 %

Appendix III: - Confidence Level (Stevenson, 2010)

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7703	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.8995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8325	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9533
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9317
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	ρ.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998