PRODUCTIVITY IMPROVEMENT OF A MANUAL ASSEMBLY LINE

A Thesis

by

PRANAVI YERASI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2011

Major Subject: Industrial Engineering

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Approved by:

Chair of Committee,	Jorge V. Leon
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ABSTRACT

Productivity Improvement of a Manual Assembly Line.

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Chair of Advisory Committee: Dr. V. Jorge Leon

The current project addresses the productivity improvement of a manual assembly line by making use of operations analysis in the framework of Lean production. A methodology is proposed that helps to improve the productivity of any production process. The methodology consists of selecting a product or product family to be studied followed by current process study. Once the existing process is documented, all the assembly tasks involved must be timed using time study techniques. Operations analysis enables the reduction of non-productive tasks and results in a set of standardized work elements along with the set of standard procedures for performing the operations.

Assembly line balancing along with the associated operations analysis assists in constructing or re-configuring an assembly system, which is the key step in improving the overall performance of an assembly line. Following this approach, two manual assembly line configurations (single stage parallel line and five-stage serial line) are constructed for a case study. The results show that by changing over to the single stage assembly line configuration the operator productivity is doubled when compared to the existing assembly method.

DEDICATION

To My Family

ACKNOWLEDGEMENTS

I would like to thank Dr. Jorge Leon for his time and advice during the course of this project. I would also like to thank Dr. Guy Curry and Dr. David Claridge for agreeing to be on the thesis committee and providing their input. I would also like to thank Judy Meeks and Laura Reinisch for their patience and support throughout the process. I would like to thank my parents and family for providing me with the best of opportunities and having faith in my abilities. Finally, I wish to thank all my friends who have made my stay away from home a joyous experience.

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1 INTRODUCTION

Assembly lines are one of the most widely used production systems. Productivity of a manufacturing system can be defined as the amount of work that can be accomplished per unit time using the available resources. Pritchard (1995) defines assembly line productivity as how well a production system uses its resources to achieve production goals at optimal costs. The conventional productivity metrics, namely throughput and utilization rate gives a substantial measure of the performance of an assembly line.

These two metrics alone are not adequate to completely represent the behavior of a production system Huang *et al* (2003). A set of other measures such as assembly line capacity, production lead time, number of value added (VA) and non-value added (NVA) activities, work-in-process, material handling, operator motion distances, line configuration and others, along with the throughput and utilization rate, completely characterize the performance of a production system. An assembly line yields optimal performance by an optimal setting of all these factors.

Flexibility and agility are the key factors in developing efficient and competitive production systems. For products involving light manufacturing and assembly, this level of flexibility can be easily achieved through the use of manual assembly systems. Manual assembly lines are most common and conventional and still provide an attractive and sufficient means production for products that require fewer production steps and

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This thesis follows the style of *International Journal of Lean Six Sigma* (IJLSS).

simple assembly processes. Global competition is forcing firms to lower production costs and at the same time improve quality with lower production lead times.

With the introduction of Lean Manufacturing, this systematically and continuously identifies and eliminates waste at all levels of a production system, many improvement opportunities which substantially increase the assembly line productivity can be successfully implemented.

1.1 Objectives

The objectives of this project are:

- To optimize the productivity of a manual assembly line by applying operations analysis in the realm of Lean production principles.
- To establish the material handling system for the manual assembly line.
- To compare and analyze the impact of two line configurations.

2 LITERATURE REVIEW

2.1 Lean Manufacturing

Lean Manufacturing or simply Lean is a production philosophy that targets the identification and elimination of any waste in the production processes; especially reduce waste in human effort, inventory, time to produce and production space etc. The concept of Lean was originally developed by Toyota (TPS) for their automobile manufacturing replacing mass production Womack and Jones (1990). According to Womack, the primary focus of Lean is to maintain the value of the product with less work. Lean drives a self-directed work-force and is driven by output-based goals aligned with customer satisfaction criteria Elizabeth and Cassandra (2010).

Waste is generally caused due to unnecessary delays, processes, costs and errors. The seven types of wastes associated with Lean are overproduction, transportation, processing, inventory (work-in-process and finished goods), waiting, motion and defects. These wastes are also associated with support functions involved in a production system. The main focus of Lean is to address the value-added and non-value added activities. A non-value added activity (NVA) is most commonly defined as any activity for which the customer is not willing to pay. Lean necessitates the reduction of these NVA’s by making the system perform better while consuming lesser resources Czarnecki and Loyd (2001). Some of the widely recognized benefits of Lean manufacturing include:

- Productivity Improvement.
- Reduced production lead times.
- Reduced inventory (Work-in-process and finished goods).

- Quality Improvement.
- Better utilization.
- Organized work flow and
- Safer operations.

The most commonly used Lean manufacturing improvement methodologies are Value Stream Mapping (VSM), 5-S (housekeeping), Visual Management, Standard Work and Mistake Proofing (Poka-Yoke).

Since its introduction to manufacturing, the concept of Lean with its fascinating principles has become a dominant strategy in managing the production systems (Womack and Jones, 1990). Shah and Ward (2003) explore the concept of Lean manufacturing and summarize that most of the modern manufacturing practices commonly associated with Lean production show strong operational performance. Implementing each of the Lean practices such as Continuous Improvement (Kaizen), Cycle time reduction, Pull System (Kanban), bottle neck removal, JIT, etc. contribute largely to the operating performance of a production system.

Felhann and Junker (2003) discuss about the developments of software tools that assist managers in planning human resources to meet with the variability in product demand and their changing volumes. The paper proposes a tradeoff between manual assembly systems and highly automated assembly lines. Manual assembly lines are more versatile and manual operators are more adaptable to changes in product demand and production structure. The author highlights the importance of ergonomic considerations while operating manual assembly systems.

Today's market environment demands for high quality products with low costs with a greater variety in products and at faster response times. The manufacturer faces the challenge to meet these demands while maintaining a profit. Implementing Lean is an ongoing and long term goal. Proper defining of the goals suitable to a production process and setting baselines is the key to productivity improvement.

2.2 Assembly Line Balancing

Moberly and Wyman (1973) propose the approach of using simulation two compare two assembly line configurations. According to Moberly, the study of production line configurations along the length of the line is called 'assembly-line' balancing. The set of work stations along the line that results from this balancing is the generated line configuration. They demonstrate splitting the assembly line width wise rather than length wise i.e., one workstation is replaced by two identical parallel stations and they named it as dual production line. A comparison of two assembly line can be seen in Figure 1.

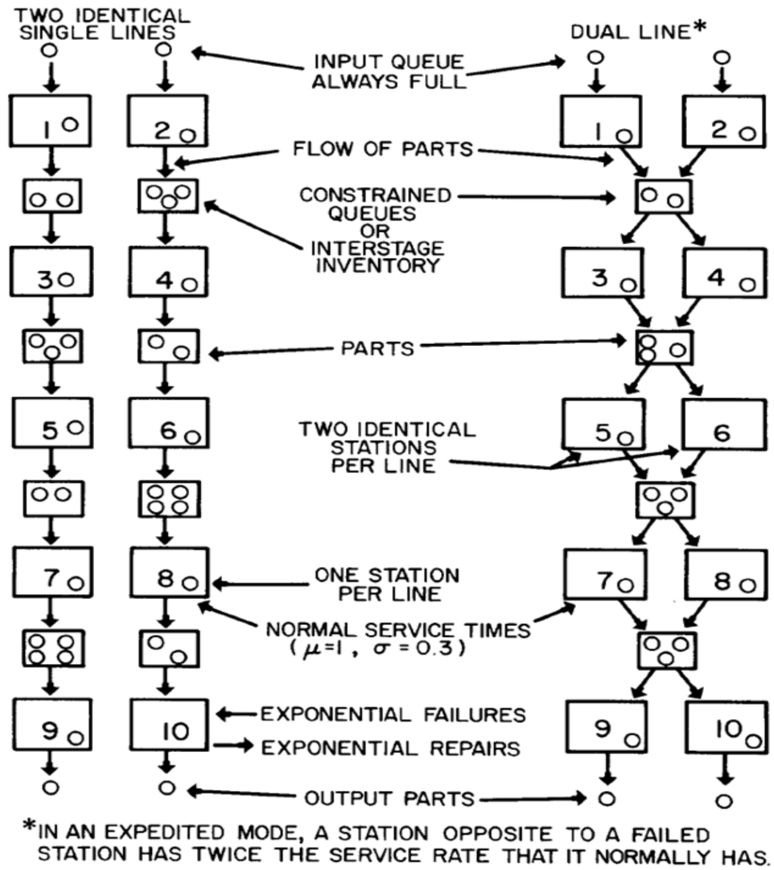


Figure 1 Two Assembly Configurations and Comparisons (Moberly and Wyman, 1973)

The author presents the concept of ‘expedited dual production line’, the feature which doubles the service rate of a non-failed work station. If one of the two parallel workstations is failed, the operator from the failed station moves to assist the operator at non-failed station and hence doubling the service rate. This is the main difference between single independent line and dual assembly line configurations. The objectives of this paper are to decide the best configuration to choose at the same given cost, two single independent lines or one dual line. Also, the configurations are compared based on the output rate. The model constraints are on the workstation failure rate and service rate for finding the output rate. Simscript II was used to simulate the model.

This paper presents close resemblance to the topic under consideration, the only difference being the assembly line configurations and the model constraints. The thesis model proposed considers the configurations along the length of the assembly line. Apart from the output rate, the operator or workstation utilization and the material handling requirements are also considered.

Bartholdi (1993) designs a computer program to balance a two-sided assembly line. The paper mainly focuses on the case study of a small utility vehicle manufacturing line. The important point to be noted about two-sided assembly lines is that the operators at each pair of work stations (mated-station) work on different tasks but on the same individual component. Hence, Bartholdi puts forward that two-sided assembly lines are more practical for large products like vehicles and heavy machinery than small products.

In contrast to Kim et al ’s (2009) proposition Bartholdi’s model tries to minimize the number of work stations for a given cycle time, by restricting the positions where tasks can be placed. The standard ALB problem considers assigning tasks only based on the processing times. This paper poses constraints on certain tasks that they should be always kept together. By doing so, the operator can learn more quickly and perform a particular set of tasks efficiently. This is good as long as the model yields sufficient results. The author mainly focuses on balancing two sided assembly lines where the operators at each station share the work elements assigned to that station and work on the same component simultaneously. This does not discuss about station imbalances and their impact on assembly utilization.

Becker and Scholl (2006) survey the simple assembly line balancing problem and several mathematical techniques that can be applied to solve this problem. They give an Integer Programming and Dynamic Programming approach to solve an assembly line balancing problem. Scholl and Becker (2006) define an assembly line balancing problem as optimally distributing the assembly work among the m workstations with respect to some objective. Given the number of work stations, m and assembly cycle time, c, several assembly line balancing problems arise by varying the objective function. A few examples are to minimize m given a c; minimize c given m, maximize the line efficiency, E, by considering the interrelationship between c and m.

Kim, Song and Kim (2009) propose a genetic algorithm approach to solve a two sided assembly line known as two-ALB. They present a mathematical formulation of the two sided assembly line balancing problem with the objective of minimizing the cycle time for a given number of paired workstations. They call these parallel paired stations which perform similar tasks as *mated-station.* The advantages of the two-sided assembly line over one-sided assembly are shorter line length, lesser material handling, reduced tools and fixtures cost and better throughput. The performance of the GA is compared with the heuristic approach and found to be better.

Rachamadugu and Talbot (1991) propose a heuristic procedure based on mixed integer programming formulation of an assembly line balancing problem. They present a procedure that rebalances an already balanced line such that the workload on all assembly stations is uniformly distributed. The authors review the importance of workload smoothing in manual assembly lines and develop the methods to measure the smoothness.

The sum of absolute deviations of workload from the cycle time, also known as Mean Absolute Deviation (MAD) is given as,

MAD = $\sum_{i=1}^{m}$ (Total workload at station i- $\frac{\text{Total Work Content}}{\text{m}}$), where m is the theoretical number of workstations, and the mean work load W, is defined as W = (Total Work Content/ m).

The authors suggest an iterative procedure to reduce this MAD by transferring elemental work tasks from a station with higher than mean work load (W) content to a station with lower than mean workload content. It must be made sure that this transferring is between precedence tasks only. If there is no precedence restriction on any task it can be assigned to any station so that MAD is reduced. The flowchart showing the workload variation minimization procedure is given in Figure 2.

Although this method proves to smoothen the workload on the assembly workstations, the model does not take into account the initial constraints or grouping of tasks to be performed at a single workstation. This model cannot be applied successfully under such circumstances.

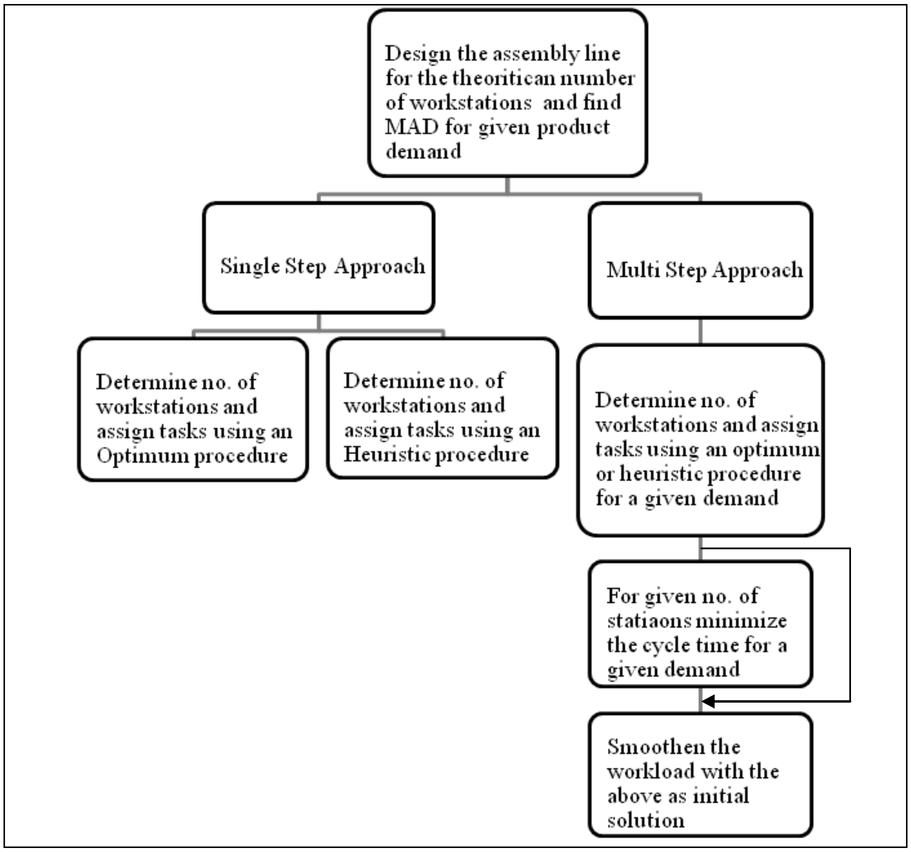


Figure 2 Re-Balancing an Assembly Line (Rachamadugu and Talbot, 1991)

Merengo *et al* (1999) analyses some of the most common issues associated with manual mixed-model assembly lines. This paper focuses on reducing the number of incomplete jobs at each assembly workstation. The problem formulation similar to Rachamadugu and Talbot (1991), but the objective is to minimize the mean number of incomplete jobs and even out the variation at each station to improve productivity of a mixed-model assembly line.

Boysen, Fliedner and Scholl (2007), put together the variety of assembly line balancing problems. The authors discuss about parallelization of assembly work i.e. increasing operator productivity by partitioning the total work content among different production units. This also includes division of work across several stations within the same serial line by making sure that the average station time does not exceed the cycle time. They survey a series of assembly line balancing problems faced and issues associated with assembly line design problem.

3 ASSEMBLY LINE PRODUCTIVITY IMPROVEMENT METHODOLOGY

The common methodology as listed below in Figure 3 is followed to improve the operational performance of the production system.

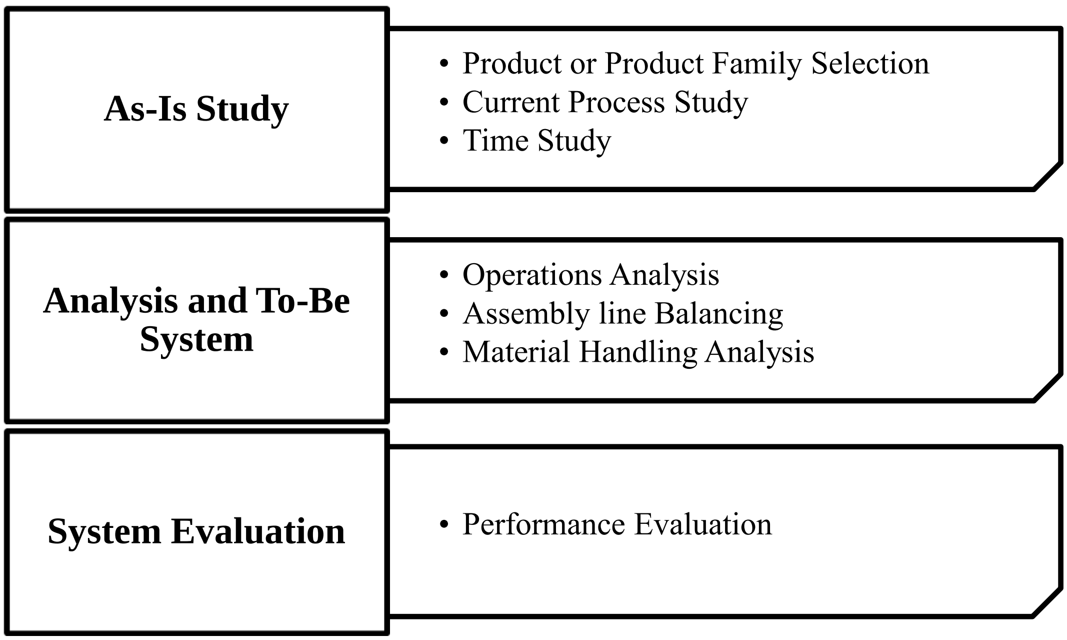


Figure 3 Productivity Improvement Methodology

3.1 Product Selection for Study

Product selection is critical as it provides focus to the project and produce tangible improvements in a timely manner. Trying to solve all problems at the same time creates confusion, inefficient use of resources and delays. Product selection refers to the process of identifying a “product” or “family” of similar products to be the target of an improvement project or study.

The selection should be based on the following criteria:

- Customer importance and importance of the product to customer.
- Potential to improve overall operations.
- Potential to impact other products.

Different product family classification methods are available, the most dominant in usage being the following methods

3.1.1 A-B-C Classification Method

The A-B-C classification process is a method that helps to identify products families based on three "importance" ratings namely A-Outstandingly important, B-Moderately important and C-Least important. This classification makes use of "Pareto's Principle" which can be generally told as 20% of the products account for 80% of the total dollar usage.

This method mainly focuses on:

- Classifying product families based on Demand volume and Sales turnover.
- Identifying product families that describe the majority of inventory, which in turn helps with better inventory management.

With the demand and sales data in hand the classification procedure is as follows:

1. List the products along with the respective demand and sales values. This is normally represented in terms of annual demand or for any relevant time period.
2. Calculate the product of demand, *D,* and value, *v*, i.e., *Dv* for each product.

3. Arrange the products in descending order, starting with the product with largest *Dv* value.
4. Then calculate the corresponding cumulative dollar usage and cumulative percentage of total usage for all the products.
5. Then the products are classified into A, B or C classes according to the dollar usage (*Dv)* values obtained. Initially products can be classified using the following guidelines:
    a. Class A: The first 5 to 10% of the products, as ranked by total dollar usage, fall under this "most important" category. They generally represent the 20% of the total inventory. Generally the account for 50% or more of the total dollar usage.
    b. Class B: The products accounting for more than 50% of the remaining dollar usage fall under this "not so important" class. Generally they represent the 30% of the total products.
    c. Class C: A majority of the remaining products fall in this "least important" category and they represent only a minor part of the total dollar usage.

Once an initial classification is obtained using the rules above, the decision maker can modify it to take into consideration other important business criteria; i.e., a product that has particularly long lead times, new critical products, products associated with new products, but has a low *Dv* can be moved into Class A.

3.1.2 Part-Process Matrix Method

A simple yet efficient and general method to identify product families is to generate a part-process matrix. This mainly focuses on identifying similarities in process steps. An example of a part-process matrix is shown in Table 1. It contains the list of products across the rows and processing steps in the columns.

Table 1 An Example Part-Process Matrix

Product				Process Sequence							
Product No	Product Name	Demand (Units/time)	Actual Sales ($/Unit)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
1	Product 1										
2	Product 2										
3	Product 3										
4	Product 4										
5	Product 5										
6	Product 6										
7	Product 7										
8	Product 8										
9	Product 9										
10	Product 10										

The examples of processing steps might be face grinding, drilling, threading, mechanical assembly etc. and each step must be clearly defined as it is carried out. Also repeat any processing step as many times as it occurs to show the actual product flow. For product list, give only the base model number because different models of the same product might have different packaging, manual language differences etc., but no process wise differences. Once the products have been listed down and process sequence for each product is identified, mark this process against the corresponding product. This should be done for all the products. The Table 2 shows part-process matrix with process steps marked against each product.

Table 2 Part-Process Matrix with Process Steps Filled

Product				Process Sequence							
Product No	Product Name	Demand (Units/time)	Actual Sales ($/Unit)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
1	Product 1			x	x		x			x	x
2	Product 2			x	x	x	x	x	x	x	x
3	Product 3						x		x	x	x
4	Product 4			x	x	x	x	x	x	x	x
5	Product 5			x	x		x			x	x
6	Product 6			x	x		x			x	x
7	Product 7			x	x	x	x	x	x	x	x
8	Product 8			x	x	x	x	x	x	x	x
9	Product 9			x	x		x			x	x
10	Product 10						x		x	x	x

The next step is to sort the parts based the processing steps. This sorting brings together all the products with almost similar processing steps. The example in table 3 shows this sorting and grouping of products.

Table 3 Part-Process Matrix Showing Product Families

			Process Sequence							
Product Name	Demand (Units/time)	Actual Sales ($/Unit)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Product 2			x	x	x	x	x	x	x	x
Product 4			x	x	x	x	x	x	x	x
Product 7			x	x	x	x	x	x	x	x
Product 1			x	x		x			x	x
Product 5			x	x		x			x	x
Product 6			x	x		x			x	x
Product 9			x	x		x			x	x
Product 8			x		x	x	x		x	x
Product 3						x		x	x	x
Product 10						x		x	x	x

After identifying the desired product groups, they can be labeled for easy identification. For the above example part-process matrix four product families can be defined and they are labeled for easy identification as:

P: Products 2, 4 and 7

Q: Products 1, 5, 6 and 9

R: Product 8

S: Products 3 and 10

Out of these product families, the one that is expected to yield maximum output (based on sales data) is selected. Also, under some special circumstances, a product from a different family can be dropped in the product family considered for study if the total work content for those families lies above 30%. For example, the product 8 can be grouped with family P, if it is a critical component. The wastes or improvement opportunities identified by following a single product family are likely to be translated in equal proportions in every other product or family of products.

3.2 Time Study

Time study is a technique used to establish a time standard to perform a given assembly operation. It is based on the measuring the work content of the selected assembly, including any personal allowances and unavoidable delays.

It is the primary step required to determine the opportunities that improve assembly operations and set production standards. The key objectives of a time study are:

- To increase productivity.
- To balance the work force with available resources.
- To determine the production capacities.
- To determine standard costs of a product.
- Effective production planning and control.
- Efficient plant layout.

3.2.1 What and How to Time?

The amount of work that can be performed by a qualified and well-trained employee at a normal pace, by effectively utilizing the time and resources, needs to be measured. For this purpose, the assembly operation is broken down into elemental work events and the standard time taken to perform these work elements is measured. This is because the operations are either too short (ex: inspection) or too long, but in elemental form, the times can be easily recorded by taking beginning and ending points of the work element Niebel (1982).

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,

- A reliable stopwatch to perform time study.
- A data collection sheet to record work elements and corresponding times (Appendix A).

The following points are observed before starting the actual Time Study,

- The obvious problems are taken care of first. There is no reason to spend time describing and timing work elements that are obviously unnecessary or redundant.
- The time study analyst should familiarize with the assembly operations before documenting the elemental times. Also there should be plenty of communication between assembly operator and the time study analyst. The operator participation must be encouraged and their ideas must be captured.
- Start the study capturing all work elements first (VA and NVA) – once all work elements have been captured, and then proceed to time them one by one. Trying to do both simultaneously can be overwhelming and confusing.

The first step is documenting all the assembly tasks in their work elements before timing them by observing the following points Ortiz (2006):

- All other work conditions should be in their current standard settings.
- Each work element should be listed in the sequence it is performed. One part of assembly might have many work elements associated with it. Any repeating steps should be listed down as many times they occur throughout the process.
- The 'level of detail' of the work element is such that it allow you to capture enough detail to provide useful insight about the process, but not too much to overwhelm you with unnecessary information.
- Work elements should be defined in a way that they can be reliably timed. If the level of detail is such that the work element is very short in duration, then

it will be impractical because this may be difficult or impossible to measure. In practice, an experienced time study analyst can measure reliably elements as short as 2.5 seconds. This can be reduced in half if the short work element is between two relatively long work elements.

Once the work elements are listed, classify the work elements as follows:

- The work elements are basically categorized as set up tasks, actual processing tasks and system or administrative tasks. Also, any movements associated with performing these work elements (ex: moving the subassemblies, looking for parts and tools etc.,) should be clearly noted. It is convenient to separate the study of setups, processing and system processes.
- The work elements are further marked as value added and non-value added activities. Value added work is the actual work that is valuable and is reflected in the final product. Examples of non-value added activities include searching for tools, moving the sub-assembly to a different location for next process, unnecessary moving of parts etc.

3.2.2 Time the Work Elements

Once all the work elements are identified, they are timed using a stopwatch and the same time units must be used throughout the study to keep the data consistent. The times taken for performing each element can be recorded in two ways. In "continuous" method, the stop watch is pressed on during the starting point of process, time is recorded at the end of each work element, and the stop watch is only stopped at the end of process. A stop watch with capabilities to measure "splits" is recommended for this situation. In "snapback" timing method, the watch is set back to zero at the end of each work element and the time for next work element is recorded.

It is recommended to take several time measurements for each work element (e.g. At least 12 time samples for each work element). Recording multiple samples allows us to better estimate the average time and also capture the variability associated with a given work element. Work elements can be timed two different ways: as they occur sequentially during the assembly process, or element-by-element. The Time Study Data Sheet can be used to record the times during the time study. If abnormal events occur while taking a sample, the sample must be discarded or annotated.

Calculations:

- Calculate the average and standard deviation.
- Calculate standard error = standard deviation/$\sqrt{(n)}$; A significant standard error indicates that the number of samples used was insufficient for the corresponding work element.
- Remove outliers (those outside ±3s) and recomputed until there are no outliers. It is important to document and explain the reason why an outlier occurred. Explaining outliers provides useful insight and knowledge about the assembly processes Ortiz (2006).

3.3 Operations Analysis

The operation analysis is a method used to identify and analyze the productive and non-productive activities described above by deployment of Lean elements and is concerned with developing techniques to improve productivity and reduce unit costs.

Any operation improvement is a continuing process and with sufficient study of all the operations, they can be practically improved. Some of the elements of Lean operations analysis are as follows.

3.3.1 Process Chart

A process chart is a graphical representation of any manufacturing process or an assembly operation. It contains the sequence of all operations in the order in which they are performed and includes inspections, time allowances and materials used in any business process – from the arrival of raw material to the final product.

There can be a variety of process charts depending upon the specific application such as the operation process chart, the man and machine process chart, the flow process chart, the operator process chart etc. It is essential to document all the work elements performed involved in an assembly process. The procedure that follows process charts analyzes all the work elements and the non-value added activities are given special attention with the goal of process improvement. During the operation analysis special consideration must be given to

- Material Handling
- Plant Layout
- Delay Times
- Storage

The questioning attitude – Improvements come from first examining what is happening actually with an open mind and then inquiring into what might be the other alternatives. While investigating the work elements nothing should be taken for granted and everything should be questioned. Answers should be given based on facts and actual available data. The most important question that one should ask while analyzing an operation is "why?", this immediately leads to other questions related to the process that take the form as shown below in Figure 4.

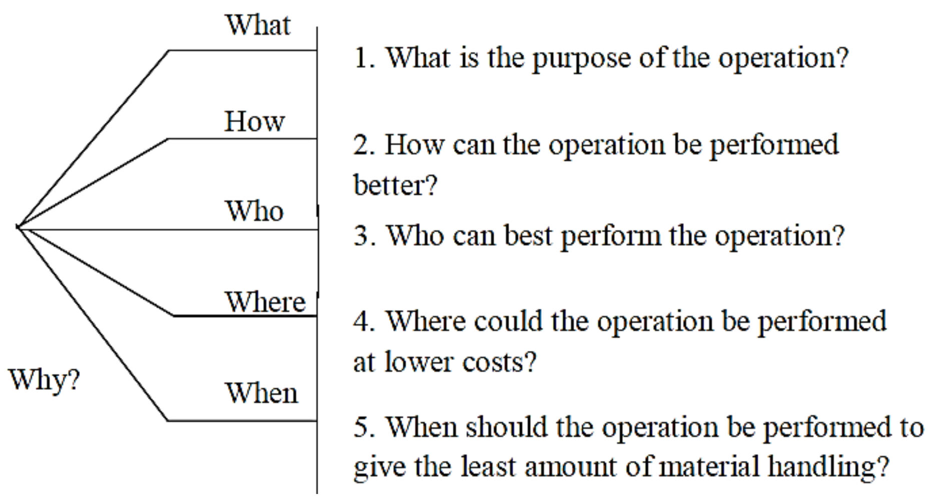


Figure 4 Showing the 'Why?' Analysis

Answering these questions may generate ideas that will lead to the process improvement. Questions should not be asked at random, but it should proceed systematically, in the order in which they should be acted upon. For example, it is unwise to question upon the tools and setup times is not recommended before defining the purpose of the operation. When this systematic questioning approach is followed, possibilities for improvements will be uncovered. The above discussed questioning approach should be carried out along with the following operation analysis approaches to analyze each operation and recognize improvements Maynard (2007).

3.3.2 Purpose of the Operation

To begin with the analysis of any assembly operation, the very first point is to define the purpose of the operation i.e. the process boundaries are defined and the entry points of the process inputs and the exit points of the process outputs are marked. The process is to be studied and any opportunities to eliminate or combine an operation must be considered before improving it. Many times unnecessary operations arise due to improper planning when the process was initially set up. So, an initial estimate should be made of things like volume or quantity, labor content, facilities used to perform the operation, transportation facilities, inspection facilities, storage facilities etc. so that there would be no interruption or delay while developing an improvement method.

Sometimes unnecessary operations may arise because of the improper performance of the previous operation. A second touch-up operation may be necessary to make the job acceptable. At times, this secondary operation may also be necessary to facilitate another operation that follows. Also, sometimes an unnecessary operation may develop because it would give the final product a decorative appeal. Some unnecessary operations are deliberately added to prevent any reworks that might arise during testing of the final product.

In this scenario the questioning attitude would provide better solution opportunities. But just asking the question “what is the purpose of the operation?” does not necessarily provide better understanding of the process. For example, further answers should be obtained for questions like:

- Is the required result accomplished by the operation?

- What makes this operation necessary?
- Was the operation established based on the requirements for subsequent assemblies?
- Is the operation added to improve the appearance of final product? Is this cost justified?
- Can the purpose of this operation be justified in a different method?
- Can any feasible changes be requested from the supplier to avoid any unnecessary operations?

Efforts should be made to obtain true answers to the questions. The result of the analysis would eliminate any obvious unnecessary operations and provides a base to subsequent operation analysis approaches.

3.3.3 Material

The following points should be considered related to direct and indirect materials utilized in the process:

- A less expensive alternative material can be studied and analyzed to minimize overall material costs.
- Standard operating procedures must be developed for the assembly process and followed to prevent any reworks and material wastage can be avoided.
- Available material and tools must be used conservatively and economically. Materials and tools can be standardized if possible to reduce the number of inventory and lesser storage space. This standardization is a continuous improvement process.

3.3.4 Setup and Tools

Before any work is done, certain preparatory or “make-ready” operations are performed. Setup time is the time required to prepare the equipment to perform an operation on the required number of units. This involves procuring tools and materials, receiving instructions, preparing the workstation, cleaning up the work station and returning the tools to the tool crib. It is often difficult to control the setup times and this can be improved through better production control. Suppose if the production operation involves a batch of units the setup time can be reduced per unit by increasing the batch size.

By making arrangements to provide the tools using palettes at work stations, dispatching instructions and materials at the work table at correct times and return them respectively, the need for operator to leave the workstation can be eliminated. Also by standardizing the tools and mechanizing the manual operations, the setup times and number of tools used can also be reduced. If required special purpose quick acting tools may be used to reduce the setup times.

For example, typical questions which lead to improvements in this area can be

- How is the job assigned to the operator?
- How are instructions given to the operator?
- How are materials and tools supplied?
- What are the possibilities of delays in procuring tools and materials?
- Could a supply boy be used to get tools, materials and instructions?
- How far is the operator responsible for maintaining the workstation?

3.3.5 Working Conditions

It is very important to provide good, safe, and comfortable working conditions. Studies have proven that providing good working conditions has positive impact on the overall productivity Drucker (1999). Some common considerations for improving the working conditions are as follows:

- Improve lighting conditions of work area. Eliminate shadows in work station areas as well as provide correct level of illumination as per the standards.
- Improve the temperature and comfort conditions of the work area. This reduces heat fatigue and cramps to the operator. Uncomfortable working conditions sometimes cause operator stress and reduce the productivity.
- Provide adequate ventilation.
- Promote orderliness, cleanliness and good housekeeping (5S). These reduce accidents; improve floor space usage and employee morale.
- Provide personal protective equipment.
- Provide guards at points of power transmission (if required).
- Provide well-formulated first-aid program.

3.3.6 Material Handling

Material handling involves motion, storage and quantity of materials throughout the process and it mainly focuses on the following points.

- The required material (raw material, in-process material, finished goods) must be supplied periodically from one location to another location.

- The production process should not be interrupted or the customer demand should not be lost due to early or late material arrivals.
- The delivery of materials must be assured at correct place in proper quantity and at correct time.
- Sufficient storage space should be assigned, both temporary and permanent.

Material handling improvements go hand in hand with other improvements like plant layout and working conditions. The major benefits of improving the material handling facilities are

- Reduced handling costs: The labor costs, material costs and overhead costs can be reduced due to effective material handling.
- Increased capacity: Improved material handling system along with improved facility layout increases material storage capacity.
- Improved working conditions: Better material handling system increases safety and less fatigue to operators and better availability of product at the required time and place.

Following are the few points that help analyze and improve the material handling system

- Time spent in picking up the material must be studied. Loose piling of material on the floor must be avoided. Material can be stored on pallets or trays that can be picked up directly and moved to desired location. Advanced material handling equipment like conveyers, portable elevators may be installed if necessary.

- Existing material handling equipment must be analyzed and equipment utilization should be studied. Appropriate measures should be taken to efficiently utilize the existing equipment. Repairs and preventive maintenance should be planned accordingly to prevent any material losses.

3.3.7 Line Layout

The primary objective of an efficient layout is to establish a production system that allows producing the desired quantity of products with desired quality at minimum cost. An effective layout should incorporate inventory control, material handling, scheduling, routing and dispatching. A layout that works best in a given set of operating conditions can be poor in a different set of working conditions. Since the working conditions can be continuously improved, there arise several opportunities to improve the layout over the time.

A variety of assembly line layouts, as shown in Figure 5 are feasible for any given assembly process (Straight line layout, U shaped layout). An ideal layout is considered to be the one that provides adequate output at each work station without causing bottlenecks and interruptions to the production flow Silver *et al* (1998). A careful study of the proposed layout should be carried out before changing to a different layout. A good analysis method is to construct a process flow chart for the proposed layout so that the expected improvements are highlighted such as reduced material travel distances, material storage, delays and overall costs etc., This will bring out any defects in the proposed method and thus can further be improved to achieve best results.

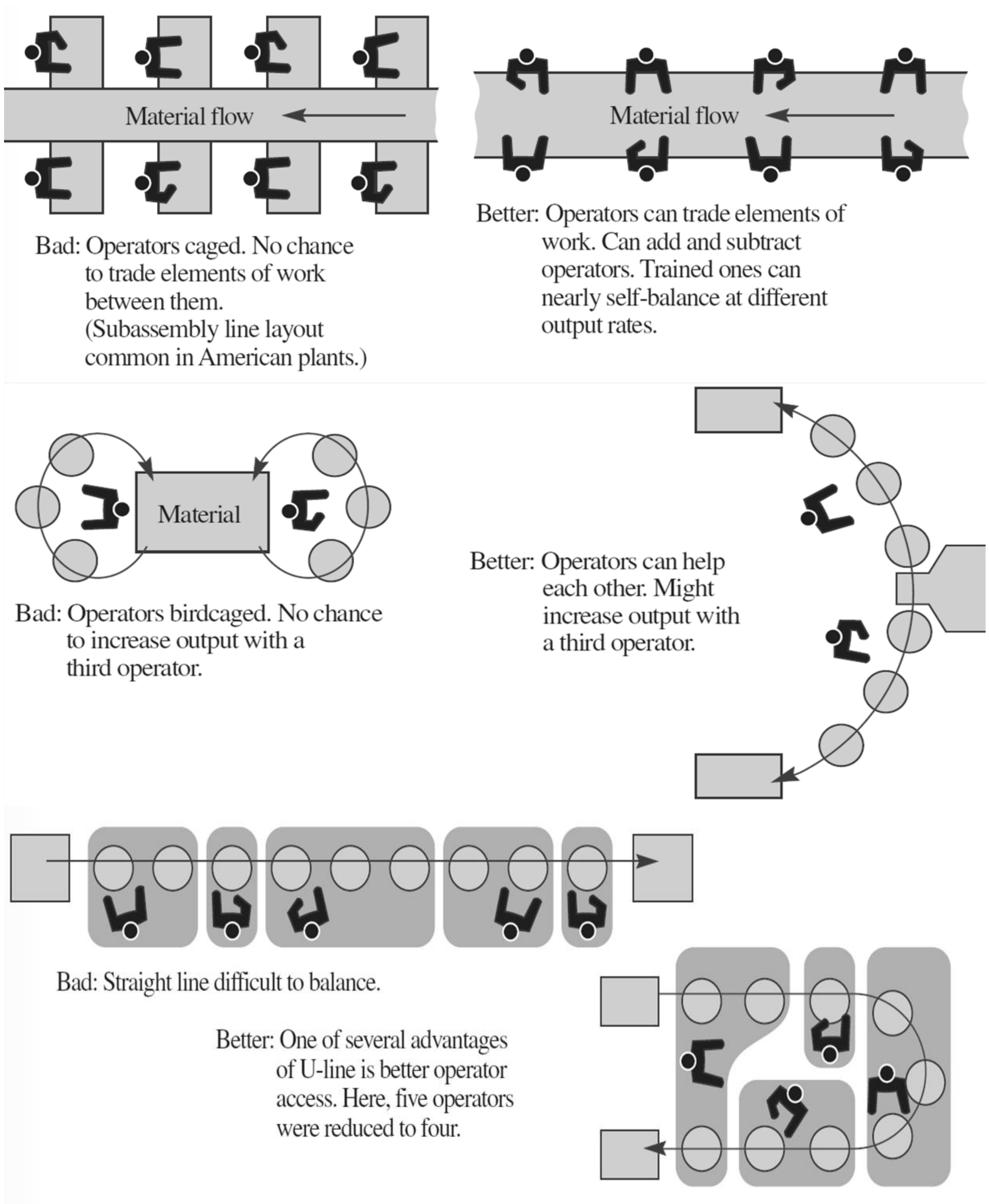


Figure 5 Showing Examples of Different Assembly Layouts (Source: R. W. Hall, Attaining Manufacturing Excellence Homewood, IL: Dow Jones-Irwin, 1987, p. 125)

3.3.8 Principles of Motion Economy

One of the most important operation analysis approaches is to simplify the operator body motion i.e. analyzing the operator's physical activity and reduce the work content. This approach helps to eliminate wasted motion, make operator tasks easy and reduce operator fatigue. This goes alongside principles of Ergonomics and provides a productive and safe work area.

The major focus of these principles is given below:

- The both hands should begin and end work at the same time. Work station design should be improved so that operator can work with both hands at same time. The work reach area is shown in Figure 6.
- Each hand should go through as few motions as possible.
- Hand movements should be limited to smaller areas and long reaches should be avoided. This can be enabled by placing the frequently used objects close to the operator and by installing efficient material and tool storage units.

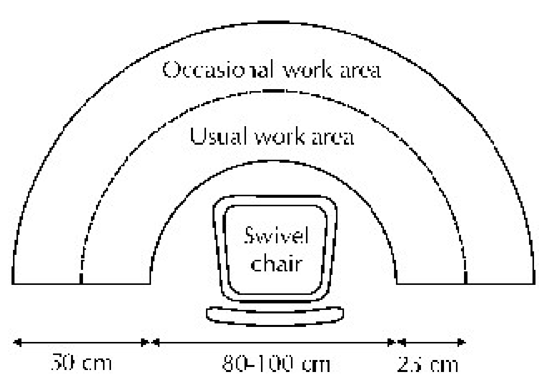


Figure 6 Showing Operator Work Reach Area (International Labor Organization Guidelines)

Operator unnecessary movements can be identified and eliminated for process improvement by answering the questions such as

- How can a sub-operation be made easier?
- Can this operator movement be eliminated?
- Can this movement be made easier?

By following the above approaches and by getting accustomed to the questioning attitude any business operation can be continuously improved.

3.4 Assembly Line Balancing Problem

Applying Lean thinking, the first step in increasing the assembly line productivity is to analyze the production tasks and its integral motions. The next step is to record each motion, the physical effort it takes, and the time it takes, also known as time and motion study. Then motions that are not needed can be eliminated also known as non-value added activities and any process improvement opportunity exists must be identified. Then, all the standardized tasks required to finish the product must be established in a logical sequence and the tools must be redesigned. If required, multiple stations can be designed and the line must be balanced accordingly. The distribution of work on each of these stations must be uniform. The productivity can be improved by incorporating a dedicated material handling system. This allows assembly operators to concentrate on the essential tasks.

Some of the most critical components of an assembly line are given as follows Chow (1990). The members of the list are mainly application dependent and can be altered according to the assembly requirements.

- Process design or standardization
- Line balance
- Material handling
- Parts procurement and feeding
- Work-in-process management
- Man power
- Line size
- Line configuration

All these factors are closely related with one another and have a considerable impact on the assembly line performance as well as production cost. Various line configurations would demand different material handling strategies and multiple levels of line re-balancing so that the desired performance level can be achieved. Assembly line design involves step-by-step approach by varying and analyzing each of these factors and arriving at a best feasible design.

The operations analysis of a manual assembly system results in a set of standardized production and assembly operations. The next step is to organize these assembly tasks in an optimal manner to achieve the required targets. The important decision problem that arises when constructing or re-configuring an assembly line is assembly line balancing. The assembly line balancing consists of distributing the total manufacturing work load uniformly among all the workstations present along the assembly line. The overall performance of the production system is greatly affected by this distribution of work.

An assembly line balancing problem is associated with the design of a process flow line, which, generally consist of a number of workstations that are joined together by some type of material handling system, for example a conveyor Van Zante-de Fokkert and de Kok (1997). For a given product, the entire assembly operation is broken down into a number of work elements or tasks. Each work station performs some of these assigned tasks. The product assembly is completed by sequential completion of all the tasks.

Every product goes through the same sequence of assembly tasks in the same order. The precedence relationship between the assembly work elements can be well represented using a precedence network diagram. This on the other hand forms the basic step in solving an assembly line balancing problem. Then, the strategic assignment of the work elements to consecutive work stations in the assembly line follows with respect to some objective. While doing so it must be ensured that the precedence constraints are met.

Some of the terms associated with general assembly lines and their definitions are given below Niebel (1982).

Precedence Diagram **:** The precedence diagram is a network showing the order of assembly tasks in a sequence in which they are carried out and including the restrictions on the performance of these tasks (such as position, precedence relationship etc.)

*Minimum Rational Work Element***:** A minimum rational work element is an assembly task that cannot be sub-divided into any further feasible tasks. The time taken by k^{th} work element can be denoted by T_{ek}. Before starting the line balancing process, all the work elements involved in an assembly must be clearly defined and the time taken for each work element must be estimated.

Let,

S Number of workstations, 1, 2, …, m

k Set of tasks, 1,2, … , n

Total Work Content: The total work content (T_{wc}) of an assembly is equal to the sum of all work element (k) processing times associated with that assembly.

$T_{wc} = \sum_{k=1}^{n} T_{ek}$, for all values of k

Station Time : Station time is the total time available at each work station. It is the sum of all the times of work elements that are being processed on a single work station (S).

Station time, $T_{si} = \sum_{k \in S} T_{ek}$, where work element *k* belongs to station *S*.

Cycle Time : Cycle time (T_c)can be defined as the rate of production. This is the time between two successive assembled units coming out of the line. The cycle time can be greater than or equal to the maximum of all times, taken at any particular station.

i.e. $T_c \geq \max \{T_{si}\}$

If $T_c = \max \{T_{si}\}$, then there exist ideal times at all the stations, i.e. having station time less than cycle time. It can be understood that the cycle time can be never less than the station time.

Cycle time T_c = (available time or total work content time)/(Target production rate)

Line balance efficiency: This denotes the performance of the assembly line. It is given by the ratio of total work content time to the total cycle time multiplied by number of work stations.

Line efficiency, $E = T_{wc} / (m\ T_c)$

Balance delay: This is the measure of line-inefficiency. This arises due to imperfect allocation of work elements to stations.

Balance delay, $d = (mT_c - T_{wc}) / mT_c$

The idle time or imbalance associated with the assembly line is $| T_c - T_{si} |$

If the demand rate for a product is known and given as D,

The theoretical number of workstations required can be calculated as follows:

$S = (T_{wc} / T_c)$

Then, the work elements will be assigned to these number of stations, one at a time, by meeting cycle time requirements and precedence constraints.

A number of objectives based on the specific requirements can be associated with assembly line balancing. A few examples of assembly line balancing objectives are:

- To minimize the number of work stations for a given cycle time.
- To minimize the cycle time for a given number of workstations.
- To minimize the number of incomplete jobs.
- To minimize the expected total costs.
- To maximize the profit.

Van Zante-de Fokkert and de Kok (1997) mention that the assembly flow lines can be classified into the following classes.

- *Single Model Lines* – Dedicated to the production of a single model. The tasks performed at each station are same for all the products.

- *Mixed Model Lines* – Handles the assembly of more than one product or model. Each assembly station is designed such that various tasks needed to produce any model that moves along the line can be performed. Most consumer products have mixed model lines.
- *Batch Model Lines* – Each model is assembled in batches. The assembly workstations are equipped so that a required quantity of first model is produced and then the stations are re-configured to produce the other model. This model is economical to assemble products with medium demand and to use one assembly line to produce various products in batches than construct a separate line for each model.

A number of researchers proposed various optimization techniques to solve an assembly line balancing problem, such as, linear programming method, (0,1) integer programming method, network and assignment problem methods, dynamic programming etc. Rekiek *et al* (2002). Ranked Positional Weight (RPW) heuristic was one of the first proposed heuristics to solve assembly line balancing problem. The ranked positional weight is defined as the sum of the operation time of the work element and the operation times of all work elements that come after it in the precedence network sequence. Two things need to be considered while an assignment is being made (1) The precedence relationship is maintained at all times and (2) The overall station time does not exceed cycle time. The manual assembly line problem considered in the case study is balanced using RPW heuristic approach. The procedure followed using RPW heuristic approach is given below:

1. For all the work elements precedence events are identified and the network diagram is drawn showing next to it the corresponding time taken to perform the task.
2. The total work content time, workstation cycle time and the theoretical number of work stations required are calculated.
3. The ranked positional weight for each node of the precedence network as given below.

   Let n (i) represent all the nodes in the path proceeding from node 'i' in the precedence diagram. Therefore, the RPW for node i is,

   RPW (i) = $T_{ei} + \Sigma\, T_{ej,}$ where $j \in n$ (i)

   = (work element time) + (sum of work element times of all tasks following node i)
4. Arrange the work elements in the decreasing order of the RPW value.
5. Following the ranked order, start assigning the work elements to work stations, one station at a time. While the tasks are assigned to the first station make sure that (1) the precedence relationship is maintained **and** (2) the overall station time does not exceed cycle time. If the following work element is making the station time value go higher than the cycle time, proceed to check with the next work element. A new station opens when there is no possibility of continuing assigning operations to the currently open station. Proceed with assigning tasks to the next station in a similar way.

4 CASE STUDY

The three step productivity improvement methodology is applied to a real problem consisting of a manual assembly line. The assembly line contains mobile phone package assembly operations. The process involves initial disassembly, light assembly and inspection operations. Each package comes in a master box which contains ten such packages as shown in Figure 7. Once all the packages are ready they are placed in an empty master box and the master box is moved to bar-coding area and then to the shipping area.

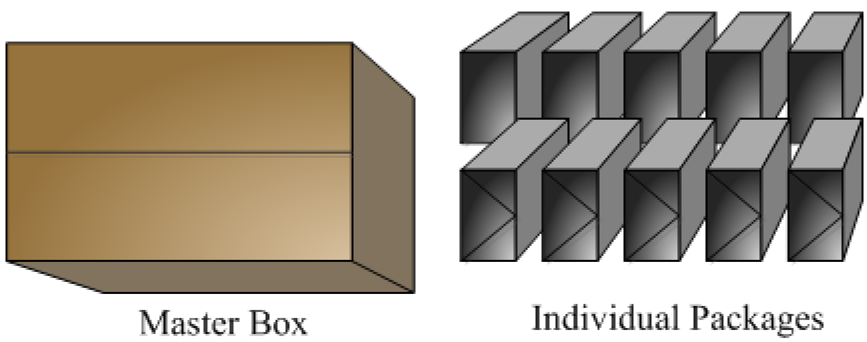


Figure 7 Figure Showing Master Box and Individual Packages

The bill of materials (BOM) list for a single package is as follows:

- Handset
- Battery
- USB data cable
- Hands free set
- Charger
- Installation disc

- User friendly manual kit
- Labels and pamphlets
- Package box
- Outer wrapper
- Bar-coding stickers

4.1 Current Assembly Method

In the original assembly method, the input buffer has no pre-specified capacity. The master boxes are piled at both input and output sides of the assembly table in stacks using storage pallets. Each pallet holds approximately 40 to 60 master boxes. The individual packages are then removed from the master box on to the table, all at a time, and the assembly is carried out on each package by four different operators.

The subassemblies and the headset components are pushed from one person to the next person on the table without an appropriate material handling arrangement. Once the assembly is completed, the packages are arranged in an empty master box and placed on storage pallet. These finished master boxes are then carried to bar coding area manually by an operator. The major drawbacks of the current assembly method are improper material handling structure, poor material storage system (including bins and dispensers for labels, pamphlets etc.) and undefined standard operating procedures. This causes repetition of tasks and unnecessary operator movements such as removing and replacing the same accessories at two consecutive stages, confusion in assembly, assembly reworks etc.

4.2 As-Is Study

The first step in productivity improvement methodology is the as-is study. For the current scenario, almost all the models produced have the similar processing steps. Hence, the product selection step has less significance in this context. In the next step, the current process is studied and all the assembly work elements are listed. Time studies are then carried out and the data obtained is analyzed to identify bottle neck situations and establish production standards. The list of operations with time study data for original assembly method is given in Appendix A.

The precedence network diagram is drawn by the plant engineers for the original assembly process as shown in Figure 8. Of notice is that this network is a simple sequence of operations as performed, rather than a network showing all the possible assembly sequences.

The target given for this assembly line is 35 boxes/operator/hour. Due to the drawbacks associated with this method, the actual measured assembly output is observed to be 29.8 boxes/operator/hour. From the process study and the network diagram, it can be seen that the assembly line has large scope for improvement by careful analysis. The next step explores these opportunities and develops methods to perform the assembly better.

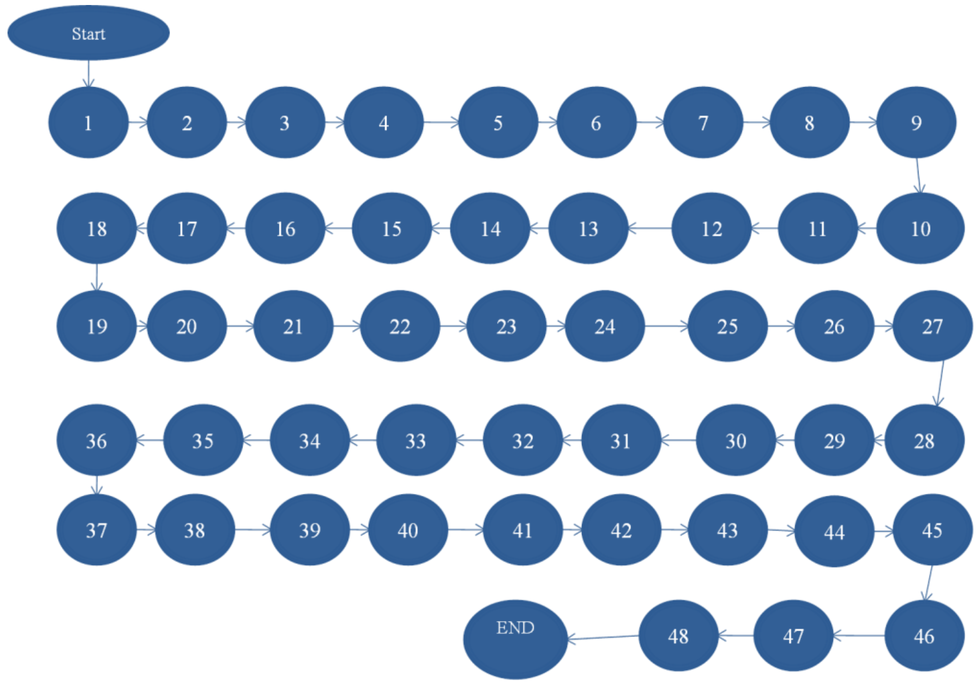


Figure 8 Original Precedence Network Diagram

4.3 Analysis and To-Be System

The next step, operations analysis, helps to identify improvement opportunities by highlighting productive and non-productive operations. This step also facilitates effective ways of doing things by suggesting alternate methods to perform operations to reduce operator fatigue and unnecessary movements to improve the overall performance. The operations analysis step adapts certain principles of Lean manufacturing such as standardization, visual management, 5-S and ergonomics, making the assembly line Lean.

For the assembly line, the operations analysis is carried out and the assembly operations are standardized by reducing the non-value added activities and the corresponding standard times are established. This standardized list of operations along with time study data and cycle time is shown in Appendix A. The precedence network diagram for the standardized assembly is given in Figure 9.

It can be seen from the precedence diagram that certain tasks are grouped (like tasks 20 to 26; 15 to 19) which enables improve operator efficiency. It is preferable to have a single operator complete a sequence of operations and pass a finished sub-assembly to next stage. Setting such sub goals enables operators learn the tasks more quickly and help perform them more dependably and faster. Also grouping of tasks facilitates better material storage at each stage, supports visual management of work space and mistake proofing (Poka-Yoke).

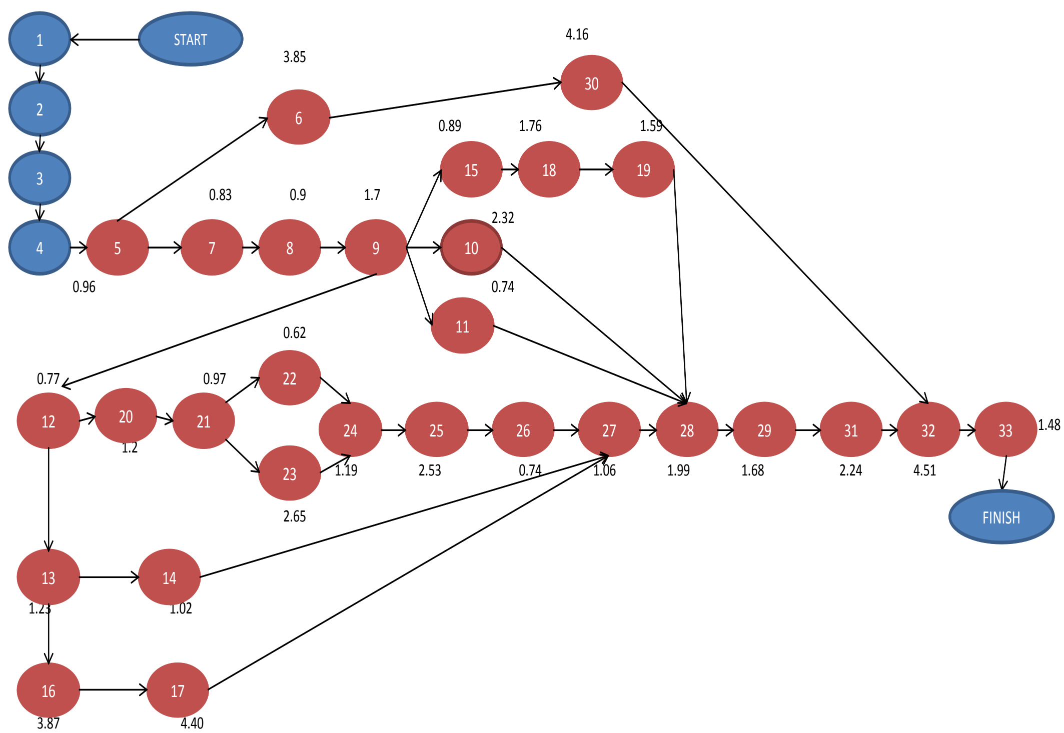


Figure 9 Modified Precedence Network Diagram

Operations analysis step also results in selecting the most suitable assembly line layout, which further helps in planning a good material handling system. Taking into account the total assembly time required to produce one package (which is considerably small), the simplicity of the assembly operations, the feasibility to modify the existing layout without causing much effect on current production, the traditional straight line configuration is chosen. A straight line configuration is well suitable for assemblies involving operators perform a set of tasks continuously in a given sequence for all the products (Aase *et al*, 2004).

The two proposed assembly line configurations for the current assembly method are shown in Figure 10. The next step to improve the assembly line productivity is to design and balance the assembly line accordingly to satisfy the cycle time and demand requirements.

Both the configurations take into consideration Lean manufacturing principles such as Standard Work, 5-S, Visual Controls, Kaizen (Continuous Improvement) and knowledge sharing, to improve productivity, reduce work-in-process inventory, floor space reduction, minimize operator unnecessary motion and reworks. A brief description of each configuration with the workstation specifications follows.

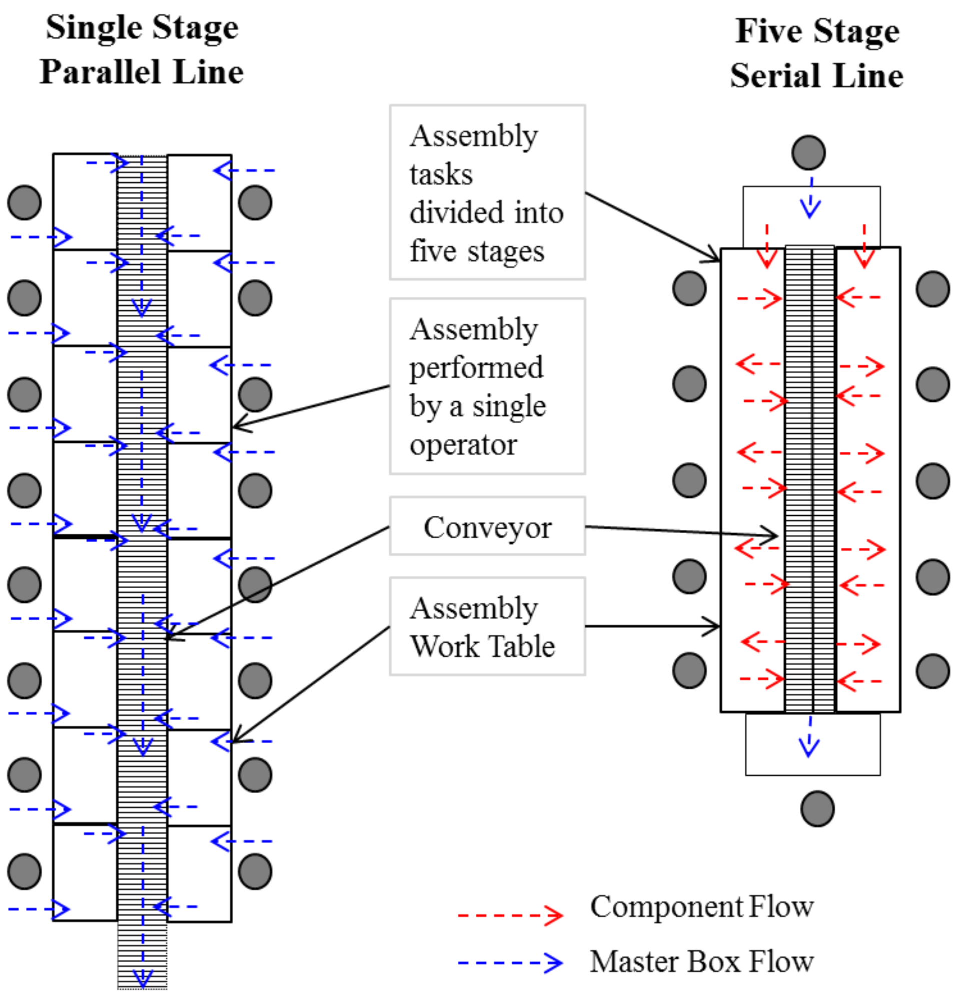


Figure 10 Proposed Assembly Line Configurations

4.3.1 Single Stage Parallel Line Configuration

The entire set of assembly operations required to produce one package will be performed by single operator at one workstation. The number of operators is reduced from four to one operator per assembly table from the original method. The completed package will be placed in a master box and the finished master box with ten of these packages is moved through conveyor to an output buffer. The master box is then transferred to bar coding area by a material handler. A schematic of the proposed assembly station design and the entire line can be seen in Figure 11 and Figure 12 respectively.

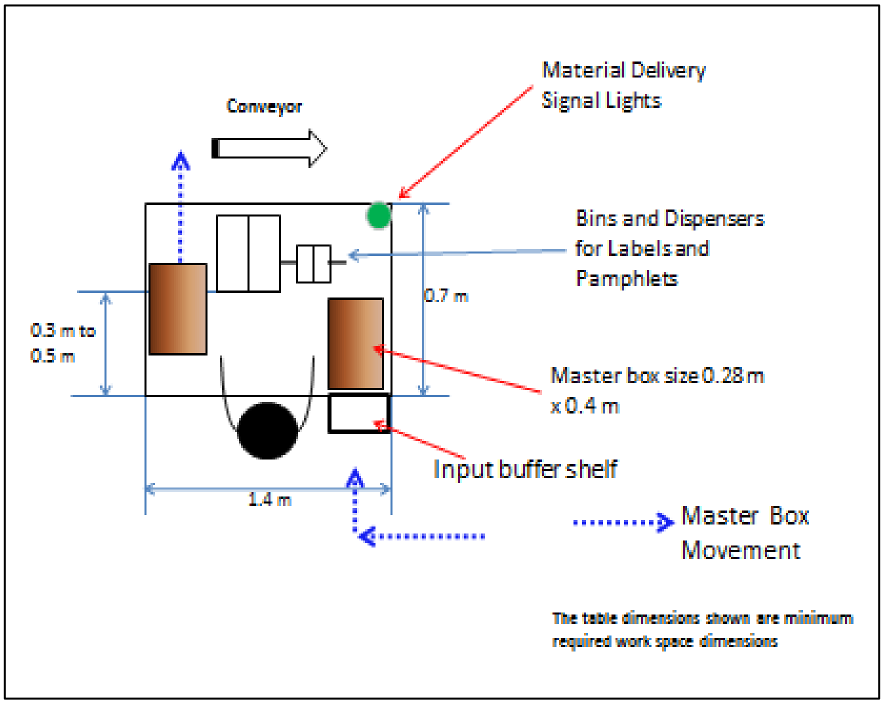


Figure 11 Single Stage Workstation Design

The light signals at each table serve as Lean visual management tool and allow efficient material handling.

- Green light ON denotes that there is a box in the buffer at the table.
- Orange light ON denotes an empty buffer at the table.
- Red light ON denotes idle assembly table.

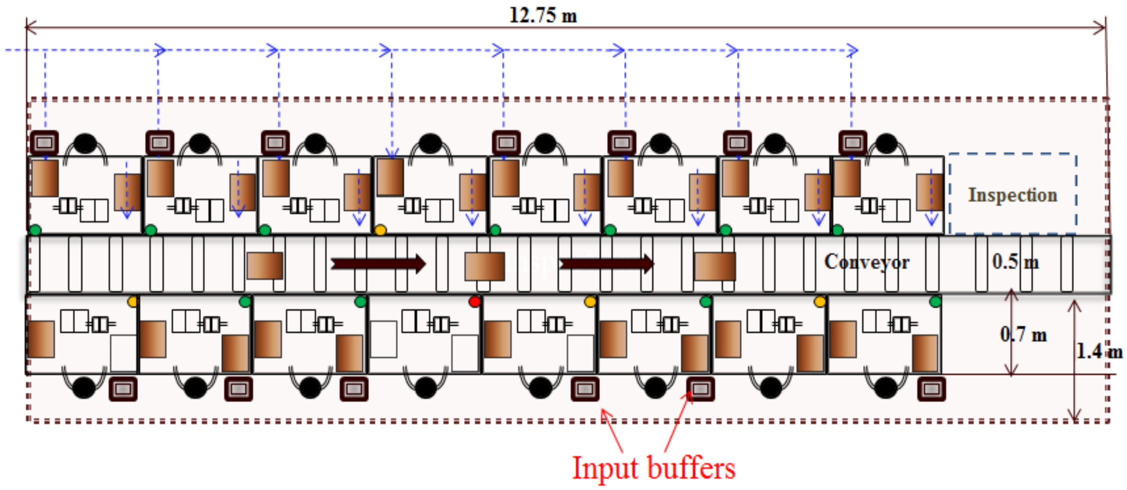


Figure 12 Single Stage Parallel Line Design

Having the input buffer shelf helps reduce the excess inventory of master boxes at the assembly station as compared with original method. Also, with the single stage layout the floor space usage is reduced from 42.07 m^2 to 24.22 m^2.

4.3.2 Five-Stage Serial Line Configuration

The assembly table consists of five work stations and each stage is assigned with a defined set of work elements. The work elements are assigned to each station using Ranked Positional Weight (RPW) heuristic method (Section 3.4). The balanced line with five assembly stages is shown in Figure 13.

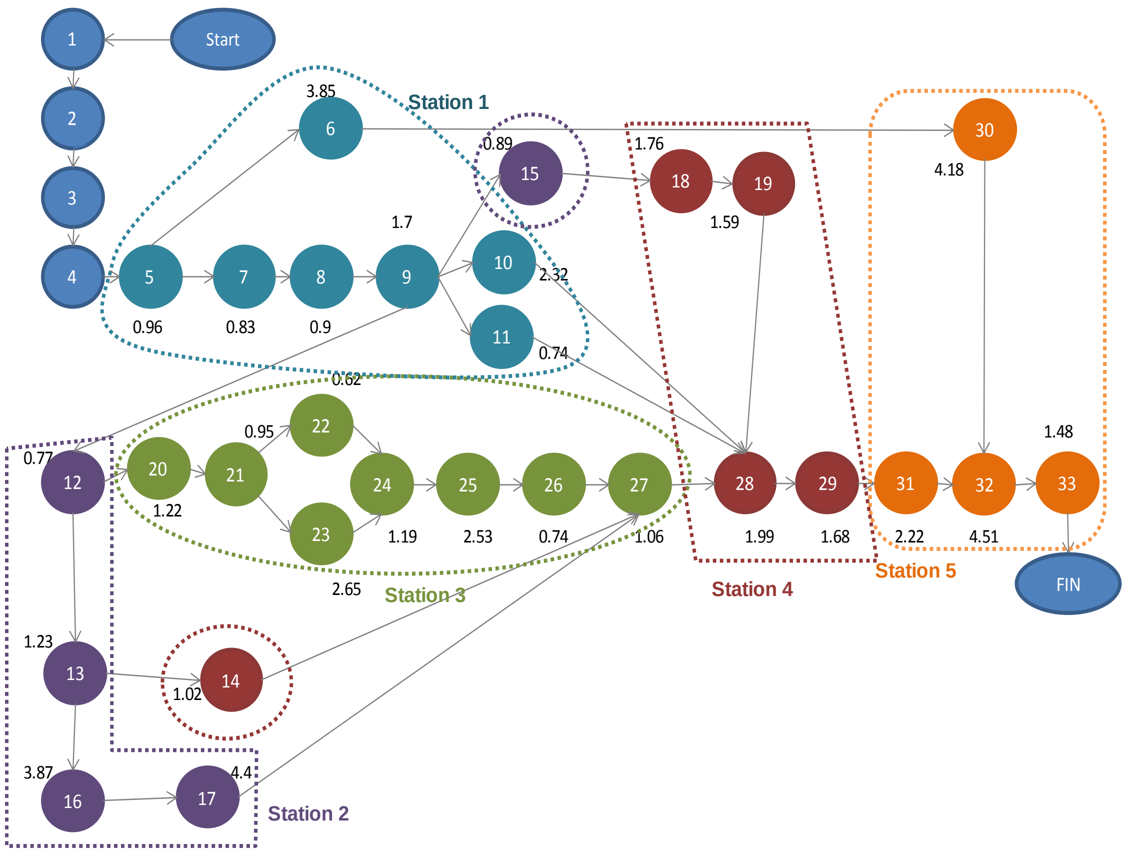


Figure 13 Precedence Diagram Showing Five Assembly Stages

After the completion of tasks at each stage, the components or sub-assemblies are pushed on to a conveyor located along the center of work table by using a material tray. The operator at the next stage pulls the tray from the conveyor and completes the assembly. Once the package reaches the end of assembly table it is placed in the master box and then the master box is moved to bar-coding area by a material handler. The light signals and input buffers help make the assembly line Lean. Figure 14 and Figure 15 give the design of assembly workstation and assembly line for the five-stage configuration.

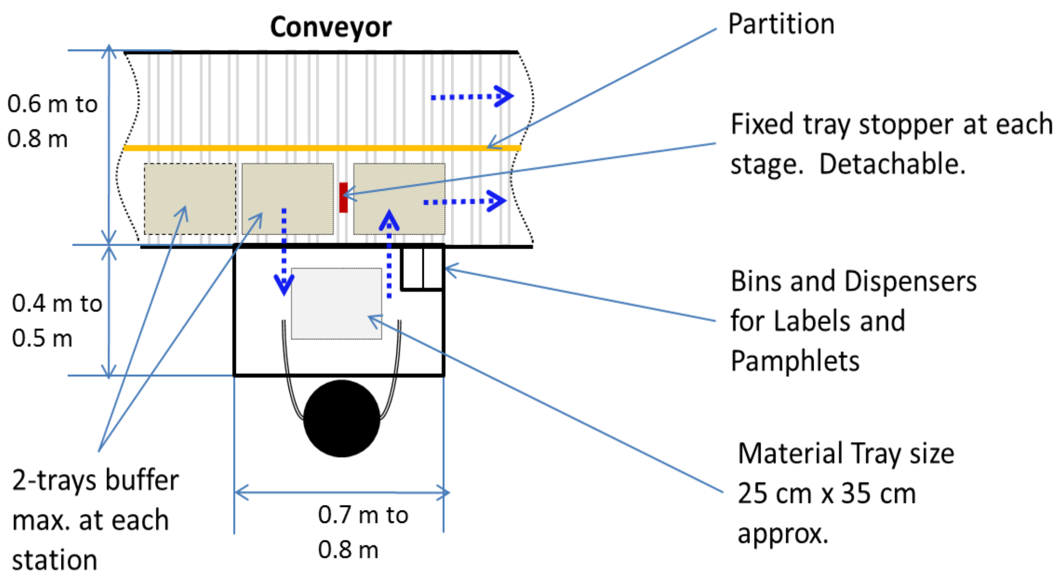


Figure 14 Five-Stage Workstation Design

The conveyor at each assembly stage can hold only two material trays. This prevents excess work-in-process inventory in terms of packages. The stopper acts as mistake proofing tool by avoiding accidental tray movement to the next stage.

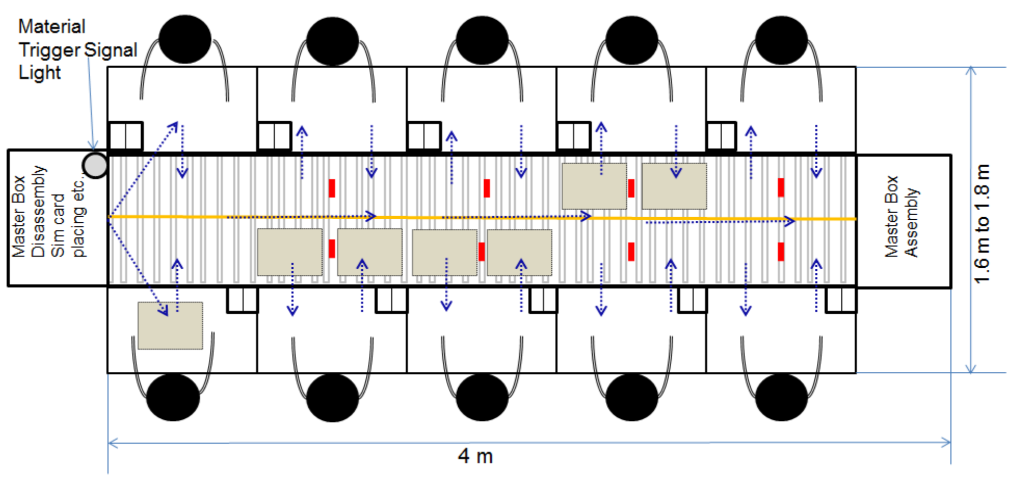


Figure 15 Five-Stage Serial Line Design

4.4 System Evaluation

Under ideal conditions, experimenting with the real assembly line would be excellent, but is not feasible always. The costs associated with manipulating the system, parameters, operators and workstations may be quite large. These costs can be in terms of capital required to bring about the changes and the output lost during this process. Simulation proves to be an exceptional tool in such scenario and efficiently provides an estimation of all the performance parameters (Banks *et al,* 2000).

4.4.1 Objectives of the Simulation Analysis

Simulation was used to analyze the assembly line and the associated material handling and distribution system for the proposed assembly layouts. The objectives of the simulation analysis are to determine

- The number of master boxes to be loaded per material delivery cart.
- The input and output buffer sizes of the assembly tables.
- The number of material handling carts required to deliver the master boxes from storage area to assembly tables.
- To determine number of material handlers required to deliver finished boxes from assembly tables to bar-coding area.

WITNESS simulation software is used to model the two proposed manual assembly line configurations. For all the experiments carried out, the simulation is run for 40 hours of simulation time with a warm up period of 8 hours.

The basic assumptions of the simulation analysis are

- No breakdowns are considered.

- Set-up times are considered to be zero.
- All the time units are considered in seconds.
- All the dimensions are considered in meters.
- The station times are normally distributed (Appendix A).

4.4.2 Material Handling System - Proposed Operation

Manually operated push carts are used to deliver master boxes from the pallet storage locations to the assembly tables. Input and output buffers located at each table ensure a constant and controlled work-in-process at the lines, and also appropriately protecting each station from possible material starvation. Labels and other documentation to be assembled with each product do not need frequent replenishment and will be stored at the point-of-use bins on the assembly table.

The master boxes are picked by material handling carts at the pick-up point which is approximated as the centroid location of the main storage. Geometrically, the centroid defines the center of a plane considered. While simulating, the centroid storage location is assumed for master boxes, such that the material handling cart travels uniform distance while dispatching material across various assembly lines following specified logic (Appendix B). Then, the loaded carts move along the pre-determined path and transfer master boxes to the input buffers located in front of assembly tables. The empty cart then moves along the defined path to the pickup point to load master boxes again.

If all the buffers are full, the cart waits at the specified point until any of the buffers becomes empty. Once a buffer becomes empty, the cart proceeds to the buffer to fill material. The cart always moves along the specified path and in one direction only. And also the material is always filled in the order in which the cart moves. The finished master boxes are transported to bar-coding area in a similar fashion. See Appendix B for detailed material handling logic followed by carts.

The parameters used by the cart and related assumptions are given below

- The cart speed is determined experimentally so that it is not too fast or too slow. Cart speed = 0.7 m/s.
- The cart's loading and unloading times at each assembly table are Triangular-distributed with mean 4 seconds and lower limit and upper limit as 3 seconds and 5 seconds respectively (Appendix A).

Once this logic is set, the buffer size required at each assembly table, the cart capacities and the quantity needs to be determined. The simulation model is tested for two assembly line configurations with different material handler inputs. The results in terms of average station utilization and the part output are plotted against the quantity carried by material handling cart. The detailed description of material handling and routing logic is given in Appendix B.

The schematics of the simulation model are shown in Figure 16 and Figure 17 respectively.

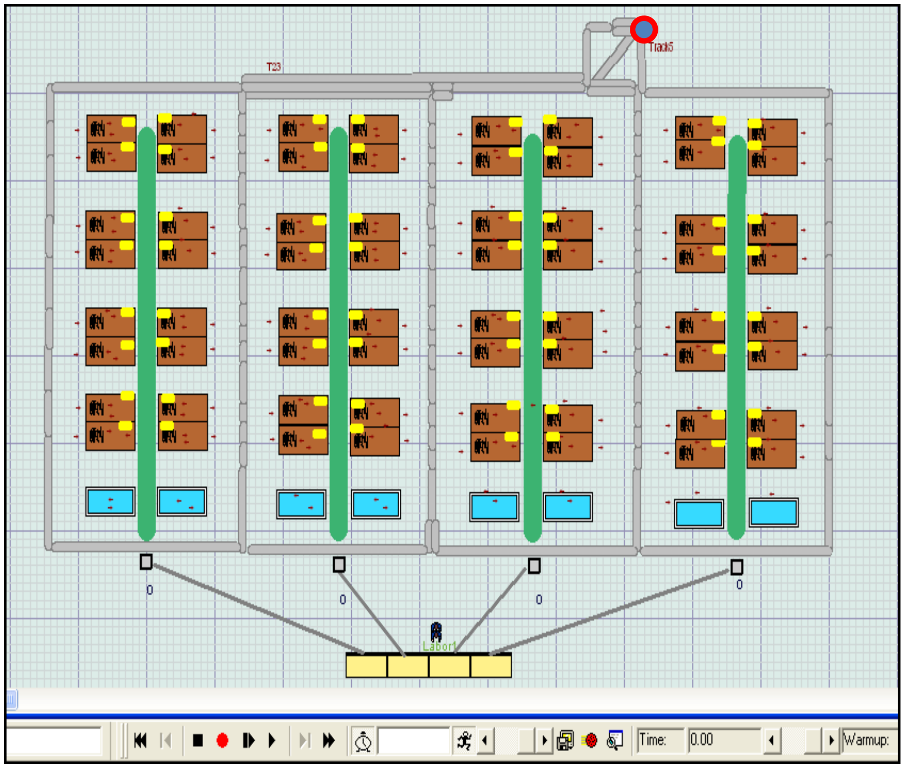


Figure 16 Simulation Model for Single Stage Parallel Line Configuration Showing Pick-up Point

For a Single Stage Line,

- The model contains 4 assembly modules with 16 tables and operators in each module.
- The material handlers move along the path shown in grey across the tables. The conveyor is located between the tables.
- Cycle Time has Normal Distribution with mean = 538.7 seconds and std. dev. = 10 (for one complete master box assembly) (Appendix A).

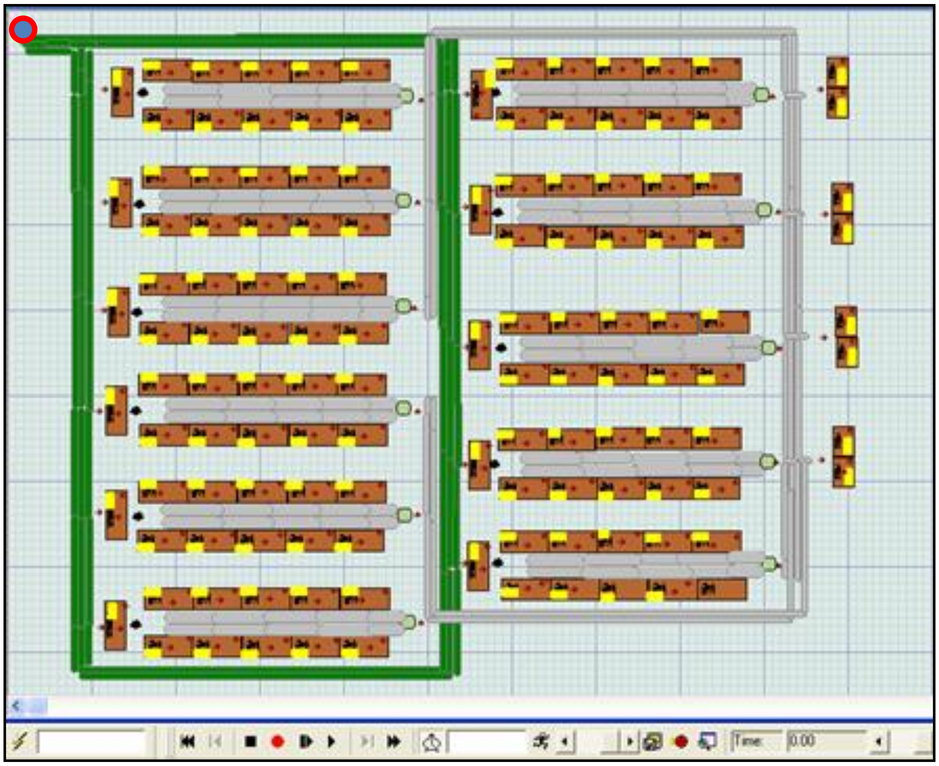


Figure 17 Simulation Model for Five Stage Serial Line Configuration Showing Pick-up Point

For Five-Stage Line,

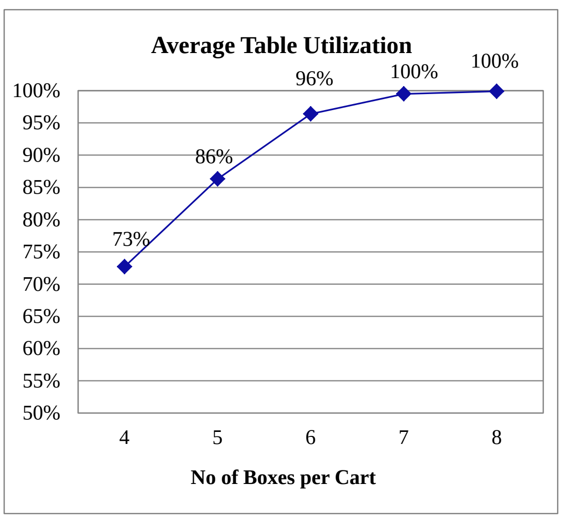
- The model contains 11 assembly modules with two assembly tables in each module. Each table contains five stations and one operator working at each stage.
- Each module contains a worktable at the front of the line which pulls out packages from master box and places sim card on each package. The packages are then pulled by assembly workstation one at a time.

- The material supply carts move along the path shown in green and the finished master boxes are moved to bar-coding area along the path shown in grey. A conveyor is located between the tables.

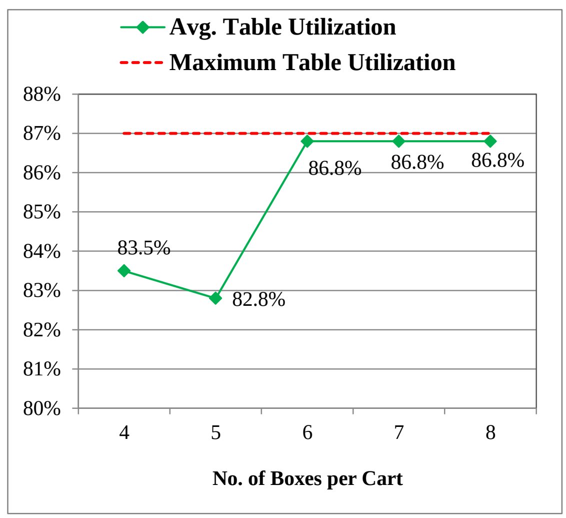
4.5 Simulation Results

4.5.1 Material Handling Cart Capacity

For single stage line it can be seen from Figure 18 that at cart capacity as 6 boxes maximum utilization is achieved. The idle time for material carts increase when the capacity exceeds 6 units although utilization is 100%, which is not recommended. Similarly for five-stage line, maximum table utilization is observed at a capacity of 6 boxes. So, for both the configurations the material handling cart loads 6 boxes per trip.



Single Stage Parallel Line Layout



Five-Stage Serial Line Layout

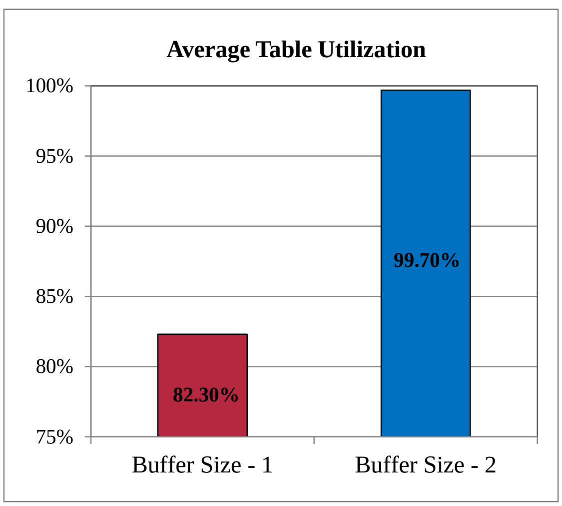
Figure 18 Cart Capacities for Both Configurations

4.5.2 Material Handlers Required – Supply Side

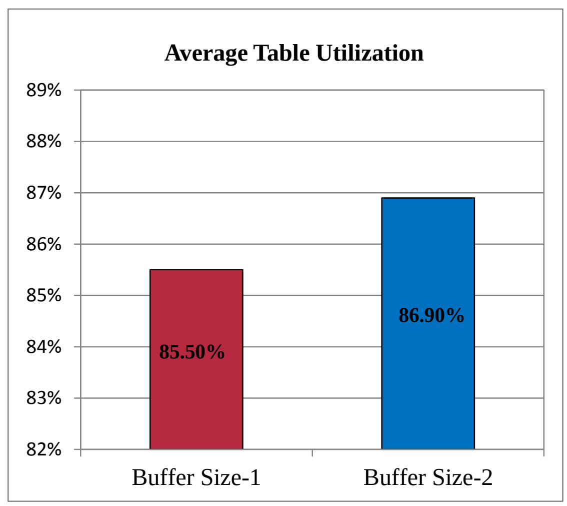
With the cart capacity fixed as 6 units, iterations are run by varying the cart quantities. For both the configurations, 2 carts are required to supply master boxes to input buffers.

4.5.3 Input Buffer Size

The assembly tables yield maximum utilization when the input buffer size is 2 units. Figure 19 gives the analysis of changing buffer sizes on the average table utilization.



Single Stage Parallel Line



Five-Stage Serial Line

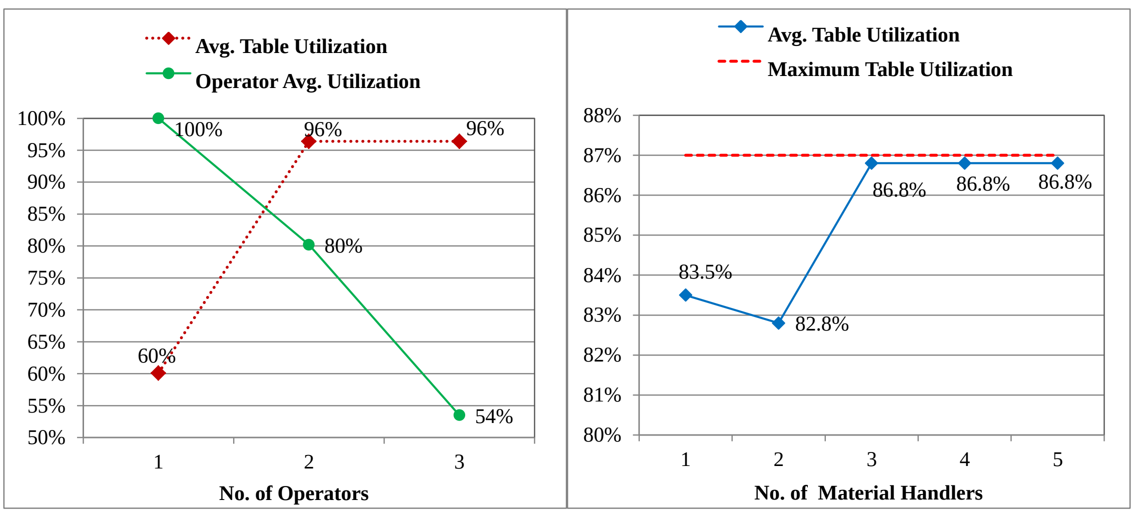
Figure 19 Buffer Sizes for Both Configurations

4.5.4 Output Buffer Size

The output buffer size is determined by performing iterations by varying the output buffer capacity for fixed input buffer sizes, cart capacity and quantity. The output buffer capacity is obtained for single stage line as 5 units and for five-stage line as 2 units per table

4.5.5 Material Handlers Required – Bar Coding Side

The single stage line requires two operators to carry finished master boxes to bar coding area. The five-stage line requires three material handlers with carts to transfer master boxes to bar coding area. This is determined based on how the finished box removal from output buffer affects the assembly utilization. The material handling requirements based on the table utilization is shown in Figure 20.



Single Stage Parallel Line **Five-Stage Serial Line**

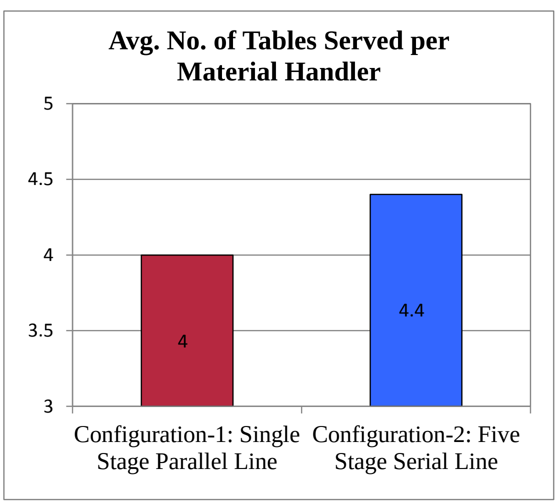
Figure 20 No. of Material Handlers Required

4.5.6 Analysis of Results

The Table 4 consolidates and compares the results for the two assembly configurations tested.

Table 4 Consolidated Results

Parameter	Single Stage Parallel Line	Five Stage Serial Line
No. of material handlers required – Supply side	2 Carts with operators	2 Carts with operators
No of material handlers required – Bar coding side	2 Operators	3 Carts with operators
Cart capacity	6 Boxes	6 Boxes
Input buffer size	2 Boxes	2 Boxes
Output buffer size	5 Boxes	2 Boxes



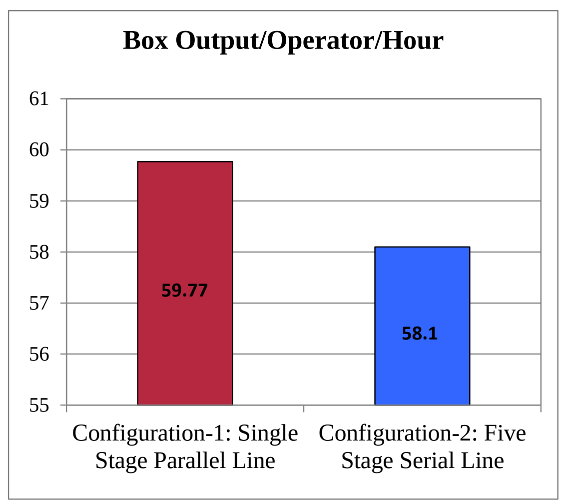


Figure 21 Results Comparing Two Configurations

The consolidated results comparing the two assembly line configurations are as follows.

Tables Served Per Material Handler: Number of tables served by each material handling unit is higher for five stage serial line configuration. Figure 21 shows that the five stage serial line requires less material handlers than the single stage line. The number of tables to be served is lesser in five stage configuration compared to the single stage configuration. But it can be observed that the difference is not highly dominating.

Productivity: The single stage configuration gives output as 59.7 boxes/operator/hour where as five stage line gives 58 boxes/operator/hour. There is a considerable improvement in productivity in both the assembly lines from the original method.

Operator Utilization: Figure 22 shows that the average operator utilization for single stage line is about 99% and for five stage line is 86.9%. It can be seen that for a five-stage line all the operators at different stages of assembly line are not uniformly utilized.

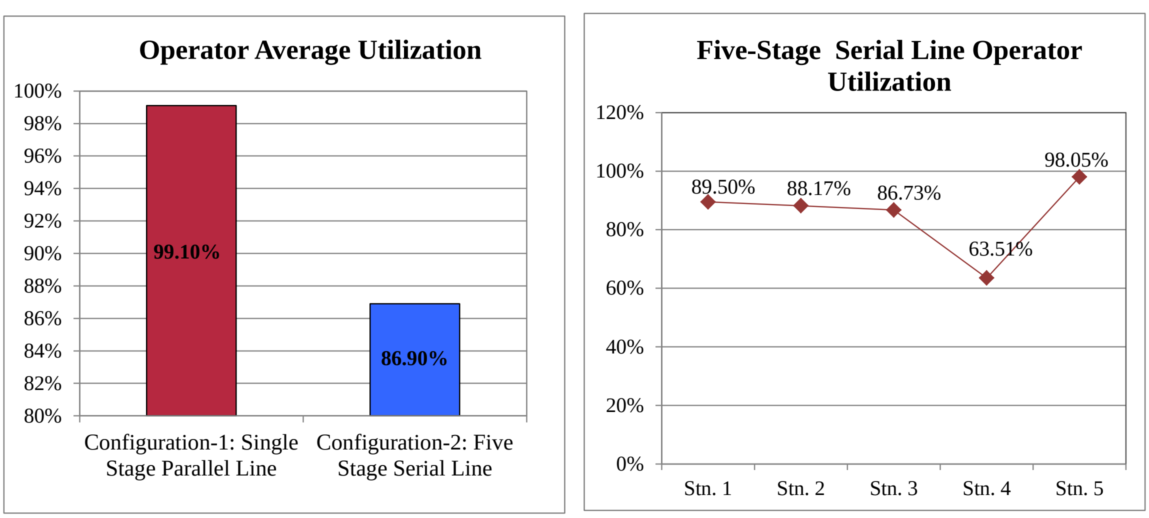


Figure 22 Operator Utilization

While solving an assembly line balancing problem, certain amount of imbalance in station times is inevitable. In this case, the level of imbalance shows a great impact on the assembly line utilization. The Table 5 shows the imbalances in station times for the five stage line.

Table 5 5 Stage Assembly Line Balancing Showing the Imbalance Associated With Each Stage

S. No	Operation	Avg. Time	Work Stn.	Station Times	Cycle Time	Imbalance
5	Take individual box	0.96	Stage 1	11.31	10.77	-0.54
6	Peel original import label	3.85				
7	Breaking the seal of approval	0.83				
8	Open Individual box	0.90				
9	Remove pamphlets and disk from the box	1.70				
10	Stick the label on the disc manual	2.32				
11	Verify the internet address booklet	0.74				
12	Check handset	0.77	stage 2	11.16		-0.39
13	Remove handset tray from box	1.23				
15	Check full pamphlets	0.89				
16	Paste label on charger box	3.87				
17	check charger	4.40				
20	Remove the Phone from bag	1.22	stage 3	10.97		-0.20
21	Remove the flip	0.95				
22	verify the sd card for handset	0.62				
23	Verify the serial number and logo of NOM	2.65				
24	Place lid back on the phone	1.19				
25	Save phone in the bag	2.53				
26	Arrange phone on tray	0.74				
27	Return the tray in the box	1.06				
14	Check complete accessories	1.02	stage 4	8.04		2.73
18	Add user policy to the pamphlets	1.76				
19	Add user guide to pamphlets	1.59				
28	Returning pamphlets to the box	1.99				
29	Close Individual box	1.68				
30	Paste import tag	4.18	stage 5	12.39		-1.62
31	Place security seal	2.22				
32	Place on individual box the outer wrapper	4.51				
33	place individual box in master	1.48				

Hence, it is recommended to implement the single stage parallel line in order to achieve higher productivity and better overall assembly performance.

5 SUMMARY AND RECOMMENDATIONS

5.1 Summary

The objective of this project was to improve the productivity of the manual assembly line. The three step methodology incorporating Lean principles is applied to a case study problem and two different assembly configurations are developed and compared, namely Single Stage Parallel Line and Five Stage Serial Line. Based on the simulation performance results, the Single Stage Parallel Line is suggested to be implemented. From Figure 23 it can be observed that the proposed system results in doubled productivity. The original assembly line has a target output of 35 boxes/operator/hour, whereas the actual measured output came up to 29.8 boxes/operator/hour.

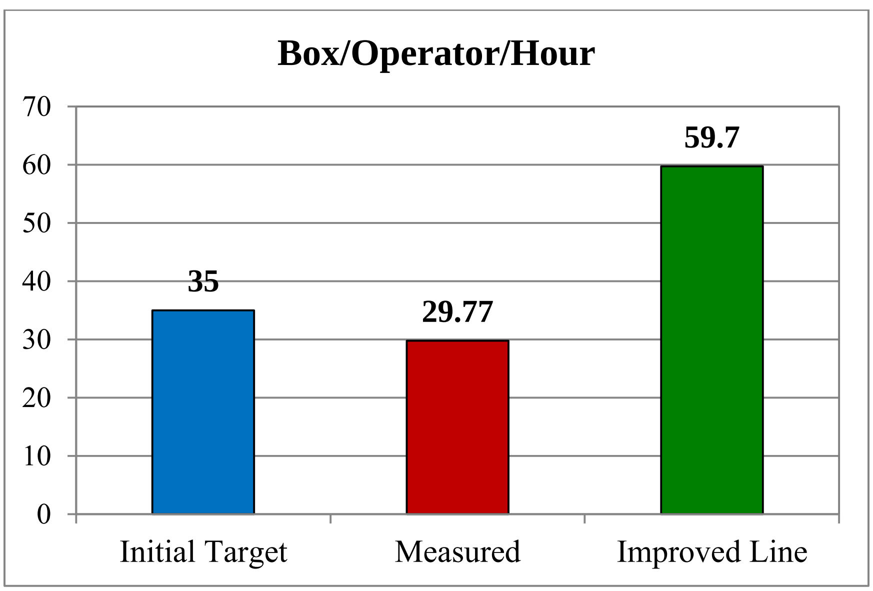


Figure 23 Production Rate for Improved Assembly Line

The improved assembly line gives an output of 59.8 boxes/operator/hour, which is about a 100% increase in operator productivity from the original method. Also, with this Single Stage Parallel Line, the floor space usage is reduced by half compared to original method. The material handling requirements as well as the input and output buffer sizes are also determined for this new assembly line. When having an assembly line with multiple stations, the impact of having station imbalances on the individual operator performance is also recognized.

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APPENDIX A

Table A. 1 Work Element Sheet with Time Data

Company : ABC		Date :						
Product code:								
Work Element Sequence No.	**Work Element**	**Type of Activity**					**Time**	
		S	**P**	**A**	**VA**	**NVA**	**Avg.**	**SD**
1	Take Master Box	✓						
2	Open Master Box	✓						
3	Pull packages out from master box	✓						
4	Moves master box aside	✓						
5	Take individual package		✓				0.82	0.21
6	Break the seal of approval		✓				3.10	1.91
7	Check the handset model					✓	2.80	1.06
8	Peel original import label		✓				7.82	1.89
9	Open individual package		✓				1.42	0.61
10	Check complete guidebooks					✓	1.91	0.50
11	Take out the user manual with disk					✓	1.93	0.74
12	Paste label on disk		✓				3.89	1.55
13	Remove the charger from box		✓				3.56	1.88
14	Verify complete accessories				✓		1.87	0.55
15	Take user friendly guide and user		✓				2.44	0.82

	policy							
16	Place user policy and guide		✓				1.05	0.50
17	Place charger on the package					✓	0.80	0.32
18	Pass to person 2					✓	0.57	0.16
19	Remove the charger					✓	0.69	0.24
20	Remove the user manuals		✓				2.36	1.05
21	Take the handset tray		✓				1.78	0.65
22	Take out the charger box					✓	0.76	0.34
23	Paste the charger label		✓				5.49	2.53
24	Check user policy guide					✓	1.43	0.75
25	Check user friendly kit					✓	1.00	0.82
26	Check the user guide labels					✓	1.29	0.69
27	Take the charger with box and place at the bottom of package		✓				2.01	0.51
28	Place accessories		✓				1.69	0.45
29	Remove handset from tray and bag		✓				14.53	44.56
30	Remove handset lid		✓				1.70	0.69
31	Place sim card		✓				2.21	1.52
32	Pass to person 3					✓	0.71	0.39
33	Check the SD card in handset				✓		1.40	0.66
34	Check handset NOM					✓	0.76	0.30
35	Check user manuals and pamphlets				✓		2.12	0.98
36	Place handset lid back		✓				2.96	1.54
37	Secure handset in its bag		✓				1.87	0.86

38	Place handset on its tray		✓				0.98	0.59
39	Place tray in the package		✓				2.41	0.73
40	close the package		✓				3.10	1.32
41	Paste import label		✓				7.09	1.53
42	Pass to person 4					✓	0.77	0.40
43	Check the import label		✓				0.78	0.21
44	Paste security seal		✓				4.02	1.88
45	Place outer wrapper		✓				6.72	3.44
46	Place the package in master box		✓				1.36	0.43
47	Tape master box	✓						
48	Move to storage	✓						

Total

Time 107.99 Seconds

Key:
S – Set-up Tasks
P – Actual Processing Tasks
A – Administrative or System Tasks
VA – Value Added Activities
NVA – Non-Value Added Activities

Note: Operation description and time data slightly modified from the original data.

Table A. 2 Time Study Data Sheet with Work Elements

Company Name : ABC														Date :				
Product code:																		
Work Element Sequence No.	**Work Element**	**Time Samples**												**Avg. Time**	**Std. Dev.**	**Standard Error**	**Allowances**	**Remarks**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**					
1	Take the master box																	
2	Open master box																	
3	Pull package out from the master box																	
4	Move the master box aside																	
5	Take package	1.33	1.18	0.68	0.87	1.00	0.87	0.87	0.85	0.89	1.01	0.83	1.17	0.96	0.18	0.05		
6	Peel original import label	4.24	3.30	3.10	2.68	5.90	2.72	4.62	4.58	4.09	3.97	4.31	2.71	3.85	0.94	0.27		
7	Break the seal of approval	1.13	0.65	0.52	0.63	0.86	0.72	0.62	0.61	0.92	1.30	1.22	0.75	0.83	0.25	0.07		
8	Open package	1.22	0.67	1.15	0.52	0.74	0.72	0.72	0.94	1.12	1.50	0.69	0.81	0.90	0.28	0.08		
9	Remove pamphlets and disc from the box	3.78	1.66	1.83	1.68	1.42	1.26	1.36	1.64	1.74	1.25	1.71	1.08	1.70	0.67	0.19		
10	Stick the disc label	2.49	3.31	1.64	1.59	2.40	2.45	2.26	2.40	2.36	1.12	3.73	2.12	2.32	0.68	0.20		
11	Verify the manuals	0.95	0.68	0.41	0.70	0.33	1.77	1.38	0.57	0.56	0.56	0.39	0.63	0.74	0.41	0.12		
12	Check handset	1.00	0.91	0.59	0.57	1.13	0.68	1.63	0.31	0.43	0.70	0.66	0.64	0.77	0.34	0.10		
13	Remove handset tray from package	1.12	1.16	1.14	2.09	0.93	0.79	1.43	1.28	1.13	1.24	1.16	1.30	1.23	0.3	0.09		
14	Check complete accessories	1.08	0.68	1.07	1.09	1.30	1.07	0.76	0.90	1.37	1.02	0.88	0.97	1.02	0.19	0.05		
15	Check pamphlets	1.70	1.30	0.73	1.17	0.30	0.86	0.76	0.82	0.80	0.74	0.73	0.74	0.89	0.34	0.10		
16	Paste label on charger box	3.54	3.62	3.88	6.89	2.92	4.19	3.21	3.43	3.47	3.87	3.69	3.72	3.87	0.96	0.28		
17	Check charger	3.91	7.51	4.53	5.14	4.06	5.39	4.11	3.20	5.10	3.27	3.02	3.57	4.40	1.21	0.35		
18	Add user policy to the pamphlets	2.27	1.37	1.43	1.45	2.26	1.53	1.80	1.63	1.72	1.54	1.97	2.16	1.76	0.32	0.09		
19	Add user guide to pamphlets	0.84	1.48	1.19	2.12	3.23	1.14	1.60	1.56	1.92	1.07	1.17	1.76	1.59	0.61	0.18		
20	Remove the Phone from bag	1.91	1.83	1.16	1.23	0.98	1.02	1.24	1.14	0.97	0.85	0.91	1.43	1.22	0.33	0.09		
21	Remove the flip	1.04	0.57	0.83	0.94	1.11	1.06	1.12	1.18	0.89	0.90	0.85	0.96	0.95	0.16	0.05		
22	Verify the sd card for handset	0.61	0.65	0.30	0.73	0.80	0.59	0.44	0.64	0.76	0.56	0.65	0.74	0.62	0.14	0.04		
23	Verify the serial number and logo	2.42	2.11	1.94	1.98	2.89	3.51	2.96	3.11	3.01	2.62	3.00	2.30	2.65	0.48	0.14		
24	Place lid back on the phone	1.08	1.27	0.94	1.08	0.70	0.88	1.56	1.91	1.09	1.06	1.80	0.89	1.19	0.36	0.10		
25	Save phone in the bag	3.51	2.21	2.06	2.48	2.36	2.89	1.39	3.01	2.01	3.11	2.00	3.32	2.53	0.61	0.18		
26	Arrange phone on its tray	0.88	0.59	0.72	0.50	0.66	0.62	0.79	0.81	0.67	0.87	1.00	0.73	0.74	0.13	0.04		
27	Return the tray in the box	2.38	1.81	0.71	0.81	0.80	0.87	0.68	0.81	1.13	0.65	1.18	0.91	1.06	0.5	0.14		
28	Returning pamphlets to the box	2.63	1.78	2.50	1.52	1.55	1.66	2.28	2.69	1.89	0.88	2.34	2.16	1.99	0.52	0.15		
29	Close Individual box	1.90	1.99	1.47	1.28	1.64	1.56	1.81	1.56	1.86	1.37	2.24	1.50	1.68	0.27	0.08		
30	Paste import tag	4.92	4.42	5.12	4.42	2.46	3.64	5.95	4.37	3.20	4.07	3.82	3.74	4.18	0.88	0.25		
31	Place security seal	1.56	2.00	2.56	1.06	1.67	1.75	2.10	2.75	4.70	2.13	2.21	2.16	2.22	0.86	0.25		
32	Place the outer wrapper	5.25	4.32	4.50	4.14	3.90	6.86	4.62	4.08	4.19	3.19	4.31	4.78	4.51	0.85	0.25		
33	Place the package in master box	1.56	1.18	1.39	1.62	1.62	1.36	1.41	2.35	1.18	1.23	1.31	1.56	1.48	0.3	0.09		
34	Tape the box																	
35	Move to storage																	
	Total Time (Per one individual apckage)													53.87	seconds			

The mean station times follow a Normal Distribution and the loading and unloading times are estimated to have Triangular Distribution. The distribution is found from the available data for station times.

Table A. 3 Time Study Data Sheet with Station Times

	Cycle Time in Seconds	Avg. Station Time in Seconds	Std. Dev.
Stn 1	10.77	11.31	1.52
Stn 2		11.16	1.72
Stn 3		10.97	1.12
Stn 4		8.04	0.96
Stn 5		12.39	1.6

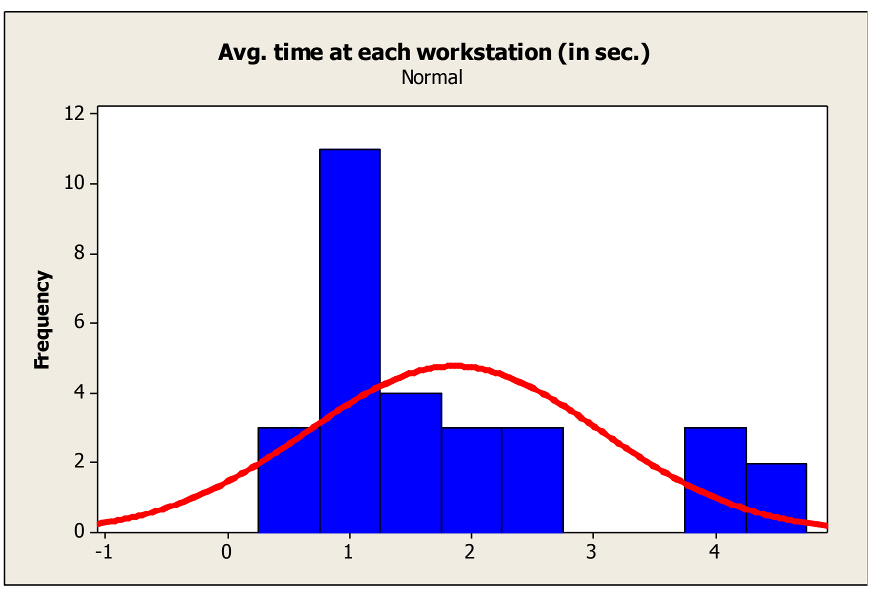

Figure A. 1 Station Time Distribution

The actual data is not available for loading and unloading times. Hence, it estimated that these times lie between 3 seconds and 5 seconds. MINITAB Statistical Tool is used to draw both the distributions.

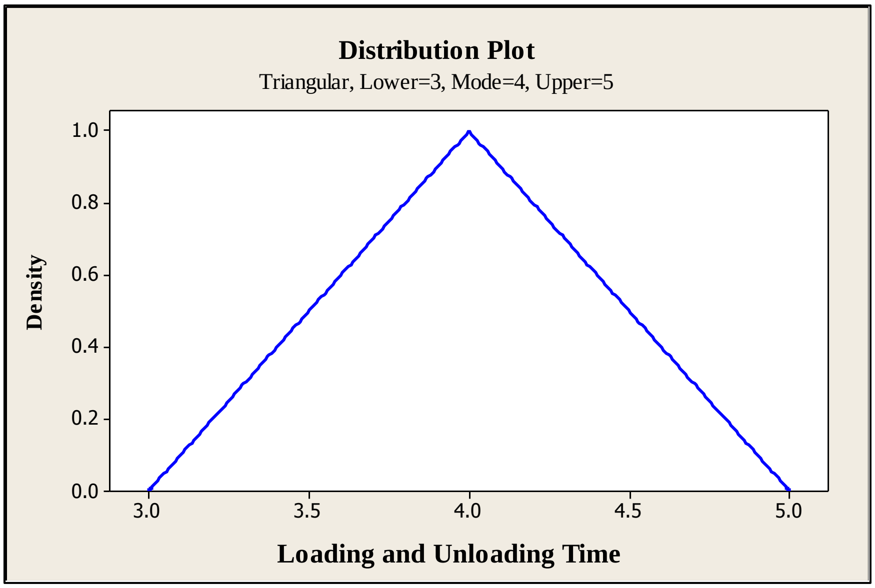

Figure A. 2 Loading and Unloading Time Distribution

APPENDIX B

Material Handling Logic

Single Stage Parallel Line Configuration

The dimensions and the layout used for simulation of Single Stage Parallel Line configuration is given below.

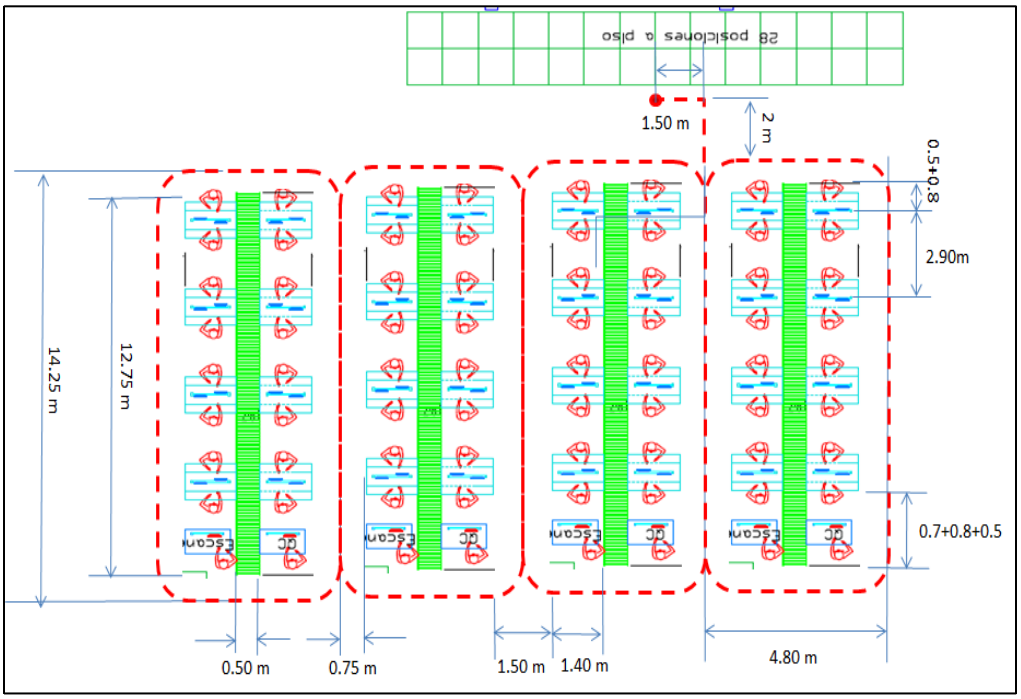

Figure B. 1 Assembly Layout With Dimensions

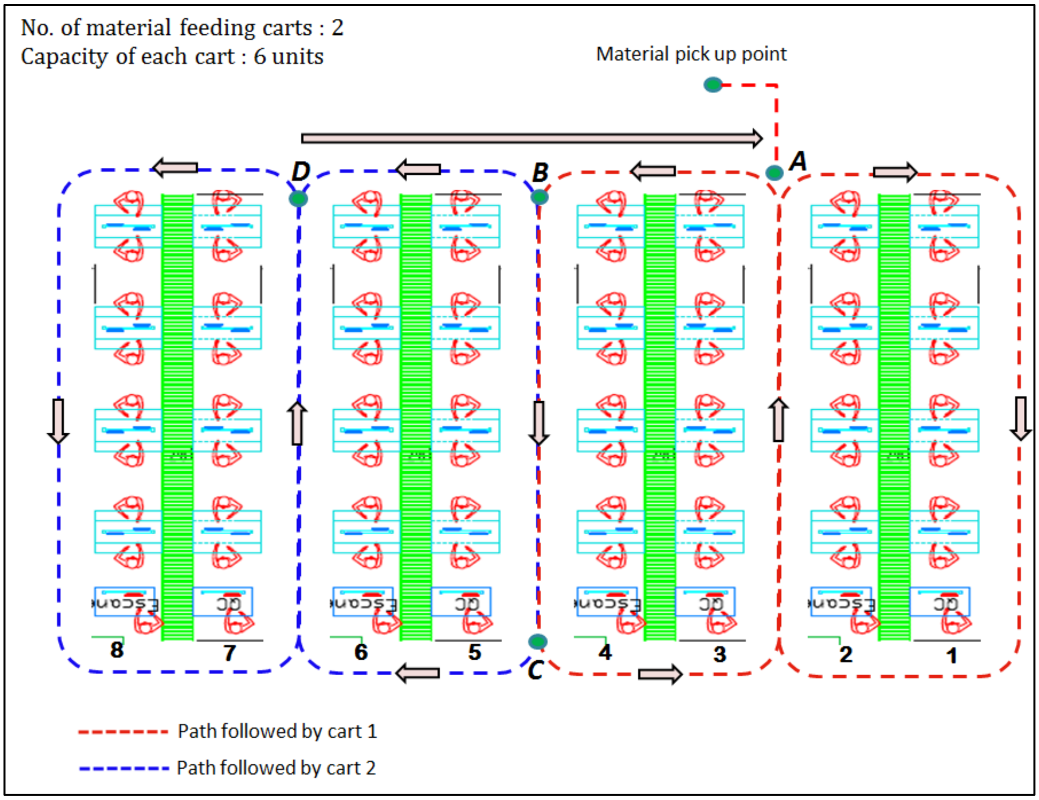

Figure B. 2 Material Handling Cart Routing Logic

Cart movement logic

- Both the carts 1 & 2 pick-up boxes at the pick-up point and go to A.
- At A,
  - Cart 1 checks for the total number of boxes across buffers in line 1 and line 4. It then proceeds to the fill the line with less number of boxes .
  - Cart 2 directly proceeds to point B.
- At B,
  - Cart 2 checks for the total number of boxes across buffers in line 5 and line 8. It then proceeds to the fill the line with less number of boxes.

- At C,
  - Cart 1 proceeds to fill lines 2 and 3. If empty, goes to the pickup point.
  - If cart 2 is empty, it proceeds along line 3 to the pickup point, else goes to fill lines 6 and 7.
- At D,
  - If cart 2 is empty it directly goes to pick up point to load boxes, else goes to fill line 8.

Then, the finished master boxes are moved to bar-coding manually by operators.

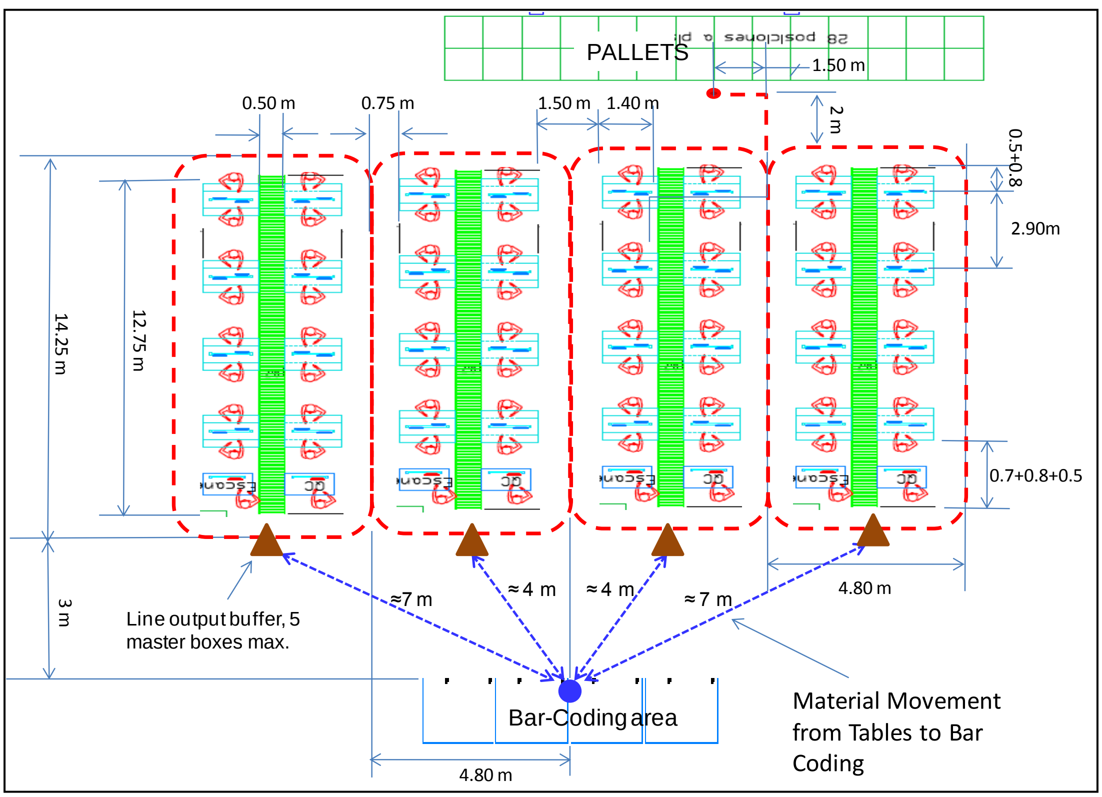

Figure B. 3 Improved Assembly Layout

Five-Stage Serial Line Configuration

The material handling for five stage assembly line is broken down into two parts based on master box supply and finished master box transport to bar-coding area.

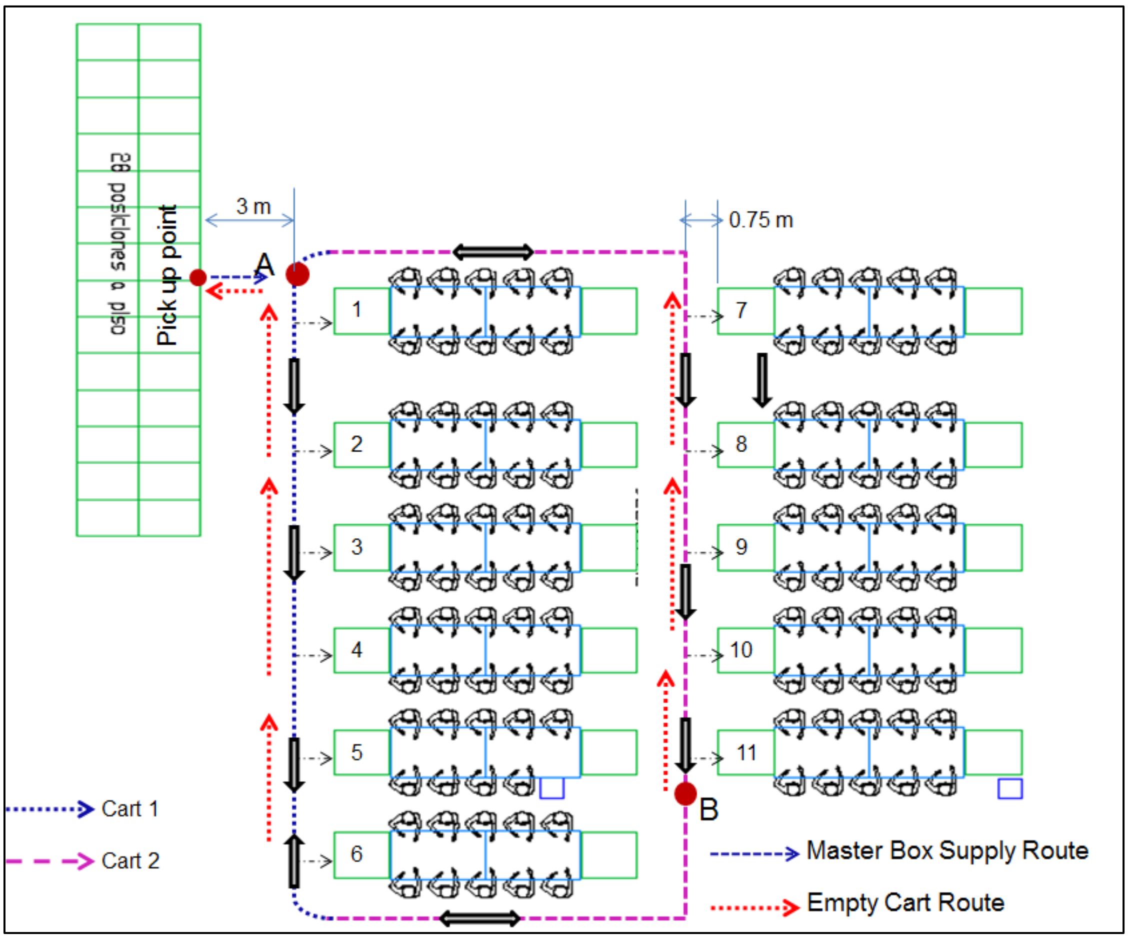

Figure B. 4 Material Handling – Supply Side

- Carts 1&2 load master boxes at the pickup point and proceed to point A
- At point A, cart 1 goes to fill tables numbered from 1 to 6. Cart 2 goes to fill tables numbered from 7 to 11

- After unloading at each table, if the empty carts go to the pickup point to load master boxes through the path shown in red. Else proceeds to the next table
- At point B, if the cart 2 has enough master boxes goes to fill tables 6 to 1, else goes to the pickup point though the path shown in red
- If all the buffers are full, the carts wait at point A
- Cart 1 is dedicated to tables numbered 1 to 6 and Cart 2 to tables 6 to 11

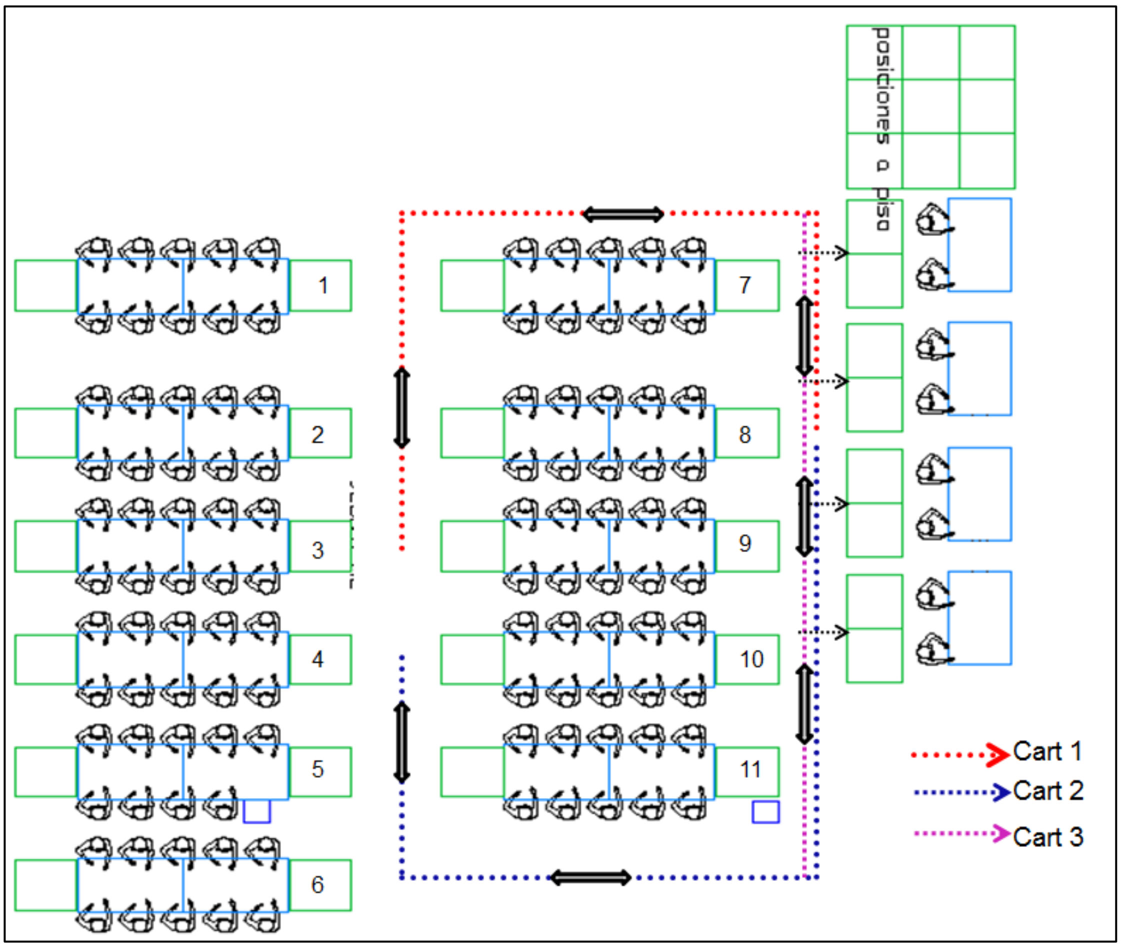

Figure B. 5 From Assembly to Bar-Coding

- The carts wait until at least one master box is ready at each of the buffers

- Cart 1 serves tables1, 2 and 3
- Cart 2 serves tables 4, 5 and 6
- Cart 3 serves tables 7,8,9,10 and 11
- Cart 1 unloads at bar-coding stations BC1, BC2 and in that order. Once empty goes back along the same path to load boxes at tables 1,2 and 3
- Cart 2 unloads at bar-coding stations BC4, BC3 and in that order. Once empty goes back along the same path to load boxes at tables 4,5 and 6
- Cart 3 starts at table 11 and proceeds to table 7. If full unloads at the corresponding bar-coding station. If it has free space, goes to load at next table and so on.
- It is assumed that the empty master box is available at the end of table

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