# COMPARATIVE PERFORMANCE ANALYSIS BETWEEN MANUAL AND AUTOMATED MULTI-PRODUCT ASSEMBLY LINE*

**Pisal Yenradee and Suebsak Nanthavanij**

*Department of Industrial Engineering*
*International Institute of Technology*
*Thammasat University*
*Pathum Thani 12121*

## ABSTRACT

The performances of manual and automated multi-product assembly systems are studied and compared using a simulation approach. Performance measures under consideration are average throughput rate and average inventory level. Typical differences, namely, variations in operation time, defect rate, possibility of break-down of an assembly station, and functional flexibility, are discussed. The results reveal that at a given average throughput rate, the automated assembly system requires buffers with larger sizes than the manual one does. This large buffer size consequently results in higher inventory levels for part, work-in-process, and finished product. Other essential factors that play an important role in selecting and designing an assembly system include the degrees of functional flexibility and reliability.

## INTRODUCTION

The concept of automation has been widely adopted in manufacturing industry as a means to increase system productivity. Together with advances in computer technology, this automation concept subsequently gives birth to robotics, automated material handling, automated assembly, flexible manufacturing system, etc. Many companies have changed several of their manufacturing

* This paper was presented at the 3rd Pan-Pacific Conference on Occupational Ergonomics, held in Seoul, Korea during November 13-17, 1994. The original version of the paper was also published in the Conference Proceedings.

(and those related to manufacturing) operations from manual to automated. As a result, a number of workers have been replaced by either automated or semi-automated machines. This change has been justified economically and ergonomically as exemplified in engineering economy and ergonomics literatures. High labor cost, unreliability, fatigueability, physical capability constraint, slow speed, and safety are some of the factors which have often been brought up to argue against the utilization of workers in today's manufacturing industry.

Although it is true that automation can help increase productivity in several operations, such statement may not hold especially for part and product assembly lines (Paul and Norf, 1979; Mital et al, 1988; Mital, 1992) and for simple industrial tasks such as drilling (Wygant, 1986). While humans have several weaknesses when compared against machines, they do have some strong points. Functional flexibility and ability to make decision are their examples. These strong points allow workers to have a fighting opportunity in some operations such as a multi-product assembly line. This type of assembly line usually involves complicated operations which require a high degree of flexibility and/or a high skill level of dexterity. Failure to consider these requirements during a selection between manual and automated assembly systems may result in a sub-optimal decision. In companies which intensively utilizes manpower in most of their manufacturing operations, it is not uncommon to see a high level of integration of workers and machines in assembly operations. Several workers form an assembly team to keep pace with the machines and enable the line to flow continuously. This type of formation is believed to give them some advantages over machines especially when considering the possibility of the breakdown of an assembly station.

In this paper, we develop simulation models to study and compare the behaviors and performances between a manual and an automated multi-product, multi-stage assembly lines. The paper is organized as follows. Firstly, the differences, advantages, and disadvantages between manual and automated operations are discussed, and the performance measures are defined. Several models with various operational characteristics are then simulated. Finally, their results are discussed.

## MANUAL AND AUTOMATED ASSEMBLY OPERATIONS

Broadly speaking, an assembly task is the placement of individual discrete parts into a specific spatial relationship to form an end item. The assembly task basically consists of two activities-the gathering and organizing of parts, and the mating and fastening of one to another (Viswanadham and Narahari, 1992). In a typical manual assembly system, one or more operators assemble a product or subassembly. Generally, each assembly process is broken down into individual tasks. Each task is performed at a workstation by one or more human operators and all such workstations are arranged in a sequence. Work-pieces are transported from one workstation to another either manually or mechanically (using mechanized transporters such as conveyors). In an automated assembly system, various assembly operations are performed by separate workheads. The partially completed assemblies are transported automatically between workheads on work carriers. Part feeding devices are used to deliver the parts to the next assembly workheads.

Manual assembly systems typically differs from automated systems in several aspects. These differences, namely, operation time, defect rate, possibility of a break-down of an assembly station, and functional flexibility of a station, do affect the system performance. In manual systems, the operation times of individual workstations usually vary and inconsistent due to both inter-and intra-personnel differences between operators. The defect rate of such systems is normally high since human performance can be influenced by work procedures, work environment, boredom, fatigue, etc. Nevertheless, operators performing the same assembly operation at a station form several subunits of assembly workstation. It is not likely that all these subunits will malfunction at the same time (unless they are on strike!) which means that the probability that a break-down of the station is small (or zero). In terms of functional flexibility, operators can outperform machines since humans have greater learning ability and they can adapt to new tasks (with new conditions and situations) faster than machines. Switching between product types does not require changing operators or workheads; thus, nonproductive times due to changeovers and setups are small. Automated systems enjoy their superiority in shorter operation times and lower defect rate. However, since the assembly machine is normally equipped with mechanical workheads, transporters, and part feeders, it has a higher probability of malfunction. Once the machine malfunctions, the assembly station breaks down. Automated systems also need much longer time for changeovers and setups. These comparisons are summarized in Table 1.

From the fact that the manual and automated assembly systems have both advantages and disadvantages, the process of comparing both systems and selecting the most suitable one is not an easy task. In order to accomplish it, we need to initially define some related performance measures. The suggested measures used in the assembly system evaluation are the average throughput rate and average inventory levels of raw material or part, work-in-process (WIP), and finished product. Since an economic analysis is not an objective of this study, differences in capital investment and operating costs of the two systems are not considered. We also assume that ideally both manual and automated systems yield the same amount of output per a given time unit in order to allow a direct comparison between the two systems.

**Table 1 Functional Differences between Manual and Automated Assembly Systems**

| | **Manual** | **Automated** |
|---|---|---|
| Operation time | Varied | Constant |
| Defect rate | High | Low |
| Possibility of break-down of assembly stations | Very low | Moderate |
| Functional flexibility | High | Low |

## SIMULATION MODELS

The assembly line under consideration has three main assembly stations (No. 1, 2, and 3) and one sub-assembly station (No. 4). Additionally, there are WIP buffers located between assembly stations (see Fig. 1). Some finished product inventory buffers are provided to store finished goods before being delivered to customers. Supplied part and component buffers are also provided in order to temporarily store purchased and manufactured parts or components before they enter the assembly line.

There are two products, A and B, to be manufactured by both assembly systems. The sequence of assembly operations for Product A is as follows. Parts A1 and A2 are first assembled at Station 1. Then the subassemblies are assembled with parts A3 and A4 at Station 2. They are finally assembled with part A5 at Station 3 to yield Product A. For Product B, parts B1 and B2 are assembled at Station 1, before being assembled with part B3 at Station 2. Parts B4 and B5 are brought to the Station 4 for assembly. Finally, the subassemblies from Station 4 and the output from Station 2 are then delivered to Station 3, and assembled to be Product B.

The following system parameters are then assumed for both manual and automated assembly systems. They can be described as follows. The demand from customers is in batches. The demand batch size for both Products A and B is normally distributed with a mean of 10 units and a standard deviation of 3 units. The inter-arrival times between batches for Products A and B follow a negative exponential distribution with a mean of 25 and 20 minutes, respectively. Parts for Products A and B are supplied to the assembly line in batches with a constant batch size of 5 pieces. The inter-arrival times between part batches follow a negative exponential distribution with a mean of 11.7 and 9.2 minutes, respectively.

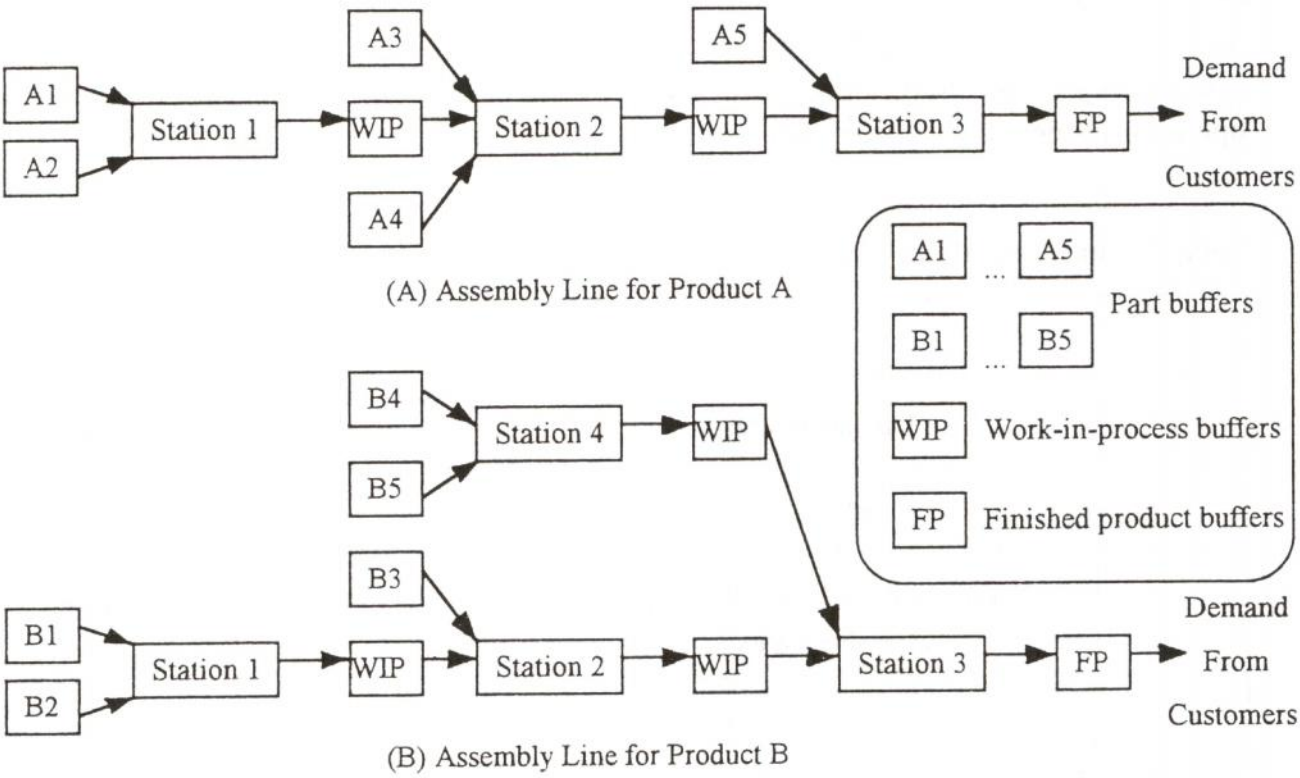


**Fig. 1. Assembly Line Configurations for Products A and B**

Table 2 shows operation times at three assembly stations for both products A and B. The assembly times for manual systems are assumed to be normally distributed while those of automated systems are constant. Setup times for both systems are assumed to be constant but differs depending on products. Manual systems are assumed to produce defectives at an average rate of 5% and time between break-downs is infinite, meaning that the assembly station never completely stops. Although the automated assembly stations do not produce defectives, they are assumed to break down more frequently, with the times between break-downs and to repair following a negative exponential distribution.

**Table 2 Operational Characteristics of Manual and Automated Assembly Systems**

| Factors | Manual | Automated |
|---|---|---|
| Assembly time of Product A on Station 1 | Normal (1.0, 1.7) | Constant (1.0) |
| Assembly time of Product A on Station 2 | Normal (1.1, 1.1) | Constant (1.1) |
| Assembly time of Product A on Station 3 | Normal (1.0, 2.4) | Constant (1.0) |
| Assembly time of Product B on Station 1 | Normal (1.2, 1.7) | Constant (1.2) |
| Assembly time of Product B on Station 2 | Normal (1.3, 1.1) | Constant (1.3) |
| Assembly time of Product B on Station 3 | Normal (1.3, 1.7) | Constant (1.3) |
| Assembly time of Product B on Station 4 | Normal (1.2, 1.7) | Constant (1.2) |
| Defect rate for all stations | 5.0% | 0.0% |
| Break-down: Time to repair | 0.0 | Neg. Exp. (3.0) |
| Break-down: Time between failures | Infinite | Neg. Exp. (60.0) |
| Setup time: From Product A to Product B | 10.0 | 50.0 |
| Setup time: From Product B to Product A | 15.0 | 75.0 |

*Note that the time unit is in minutes.

Additionally, there are two important parameters that can affect the performances of the assembly line, i.e., the process batch size and the buffer size for parts, WIP and finished product inventories. In this comparison, we assume the following production schedule. The manual assembly line will initially assemble Product A for 70 minutes, change (re-setup) the line for Product B, and then assemble Product B for 105 minutes. Once B is finished, the line will be resetup for A again. The automated assembly will also follow the same schedule. In order to maintain an equivalent production output, the automated system will assemble Product A for 350 minutes and then switch to assemble Product B for 525 minutes. The maximum buffer sizes of parts or components, WIP, and finished products, are varied in order to investigate their effects on the systems performance.

## RESULTS AND DISCUSSIONS

A number of automated and manual assembly operations with varying buffer sizes have been simulated. The results obtained from six selected automated assembly models (Models AT1 to AT6) and those from four selected manual ones (Models M1 to M4) are presented in Table 3.

**Table 3 Buffer Sizes and Performances of Automated and Manual Assembly Systems**

| | | Automated Assembly | | | | | | Manual Assembly | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AT1 | AT2 | AT3 | AT4 | AT5 | AT6 | M1 | M2 | M3 | M4 |
| Buffer Sizes (Given) | Part | 10 | 50 | 100 | 150 | 150 | 200 | 10 | 50 | 100 | 100 |
| | Work-in-process | 10 | 10 | 10 | 10 | 50 | 100 | 10 | 10 | 10 | 50 |
| | Finished product | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Performance Measures | Average part inventory level | 77 | 416 | 860 | 1283 | 1249 | 1668 | 70 | 402 | 900 | 862 |
| | Average WIP inventory level | 18 | 18 | 22 | 20 | 115 | 252 | 17 | 21 | 21 | 64 |
| | Average finished product inventory level | 21 | 46 | 58 | 45 | 68 | 84 | 19 | 39 | 35 | 53 |
| | Average throughput rate | 105 | 145 | 179 | 166 | 239 | 259 | 150 | 247 | 254 | 276 |

*All units are in pieces.

It is seen that both part (component) and WIP buffer sizes greatly affect the average throughput rate and average inventory levels. Within the same assembly system, increasing part, WIP, and finished product buffer sizes also increase the average throughput rate; thus, requiring a trade-off compromise between inventory cost and productivity. When comparing between both systems at a given average throughput rate and at the same buffer sizes, the average throughput rate of the manual system is higher than that of the automated one. In other words, should one want to obtain the same throughput rate, the manual system requires smaller buffer sizes (either for part, WIP, or finished product) which will subsequently result in smaller average inventory levels (see Fig. 2).

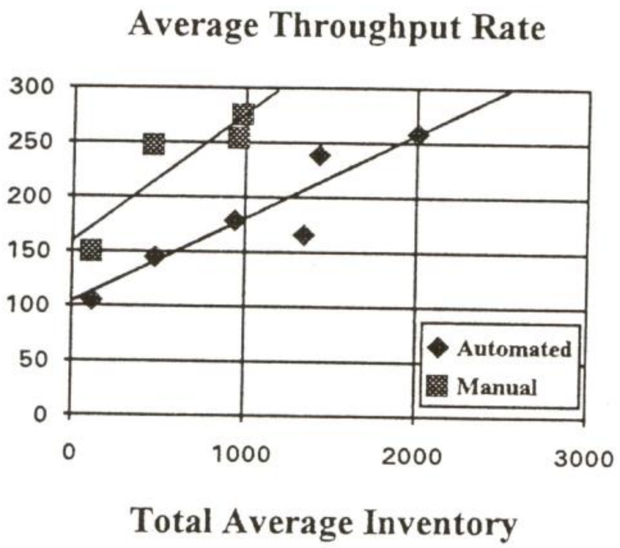


**Fig. 2. Relationships Between Total Average Inventory and Average Throughput Rate**

Since WIP buffers normally provide protection for shortages either due to the break-down of assembly stations or the variations in assembly times, a larger buffer size requirement in automated systems implicitly indicates that their throughput rate is more affected by the assembly station break-downs than the variations in the assembly times. Although this argument is in favor of the manual assembly system, it may hold only under the assumptions used in this study. One should also be concerned about the effect of productivity increase, defective rate, and cost involved as well. Ergonomic improvement of work place can be introduced to further improve the productivity of the manual system, such as workstation design, work environment (illumination level, temperature, humidity, noise level, etc.), and work procedure (duration, rest period, etc.).

In conclusion, although the automated system has several advantages over the manual one, it normally has less functional flexibility (due to its relatively long change-over and setup times) and higher possibility of assembly station break-downs; resulting in a considerably higher total average inventory level than that required in the manual system. Hence, functional flexibility and reliability are additional important factors for a selection or design of an assembly system.

## REFERENCES


1. Mital, A. (1992). "Economics of Flexible Assembly Automation: Influence of Production and Market Factors" In H.R. Parsaei and A. Mital (eds.): *Economics of Advanced Manufacturing Systems*, Chapman and Hall, 45-72.

2. Mital, A., Mahajan, A., and Brown, M.L. (1988). "A Comparison of Manual and Automated Assembly Methods," *Proceedings of the IIE Integrated Systems Conference,* 206-211.

3. Paul, R. P. and Norf, S. Y. (1979). "Work Methods Measurement - A Comparison between Robot and Human Task Performance," *International Journal of Production Research,* 17, 277-303.