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# Analysis of Strategies for Installing Parallel Stations in Assembly Systems

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**Abstract.** An assembly system (AS), a valuable tool for mass production, is generally composed of a number of workstations and a transport system. While the workstations perform some preplanned operations, the transport system moves the assemblies by special designed pallets from one station to another. One common problem associated with automatic assembly systems is that some assembly operations may have relatively long cycle times. As a consequence, the productivity, as determined by the operations with the longest cycle time, can be reduced significantly. Therefore, special forms of parallel workstations were developed to improve the performance of an assembly system. In this paper, three most commonly used parallel stations: on-line, off-line and tunnel-gated stations in a free transfer assembly system are studied via discrete event simulation. Our findings revealed that the off-line parallel system has the best performance because the two independent parallel stations can lower the buffer requirement; reduce the sensitivity to variability of processing time and balance of a line. On-line parallel systems were found to have a relatively poor performance, because the operations of two parallel stations block each other, and higher buffer capacity is required to achieve similar capacity. The tunnel-gated system was more efficient than the on-line system since the first parallel station can operate independently. More importantly, we have quantified the productivity of the three different strategies mentioned. Engineers can choose the optimal strategies for installing parallel stations under their working environment.

**Keywords:** Assembly System, On-line Stations; Off-line Stations, Tunnel-gated Stations

## 1. INTRODUCTION

Assembly systems have long been considered as valuable tools for mass production since they can reduce the complexity of the assembly processes, improve the quality of the products, and increase the total output of a system.

In the early days, assembly processes were carried out solely by operators. However, with the rapid development of computer integrated technologies, assembly systems ranging from semi-automatic to fully automatic have been developed to improve productivity and the quality of the products being assembled.

An assembly system is characterized by a system of many interlinking workstations in which humans, or more often, machines perform simple assembly operations, and a transport system that moves the processing assembly from one workstation to another. Two types of transport systems exist: indexing systems and free-transfer systems. The index transport systems move all the assemblies simultaneously, and the entire assembly system would stop if one or more stations were down. Therefore, indexing transport systems would have low productivity as a result of such blocking. In free-transfer systems, assemblies do not move simultaneously. Hence, each individual workstation may operate independently, and there is no immediate delay resulting from the malfunctioning of other workstations. Free-transfer systems also allow buffer spaces to be installed between each workstation to hold in-process assemblies, thus blocking will only occur when the buffer space is full. Under normal operation, each station can be in one of the following states:

1. Starving-a station has no normal assemblies to process.
2. Busy- a station is processing a normal assembly.

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3. Forced down- the down stream buffer units are full and forcing the workstation(s) to stop working.

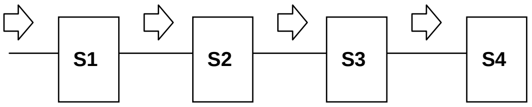
One common problem associated with automatic assembly systems is that some assembly operations may have relatively long cycle times. As a consequence, the productivity, as determined by the operations with the longest cycle time, can be reduced significantly. Therefore, special forms of parallel workstations were developed to improve the performance of an automatic assembly system. The performance of an assembly system depends on many factors. The important ones include: variability of processing time; buffer size and buffer location; length and balancing of line. Generally, all these variables will be considered in design parameters when evaluating the performance of the strategies for installing parallel stations.

## 1.1 Three Strategies of Installing Parallel Stations

Three common approaches are available for in-stalling parallel stations to improve the performance of a system. They are on-line installation approach, off-line installation approach and tunnel-gate installation approach.

### 1.1.1 On-line Stations in Series

The first method is to install parallel stations in series with an existing station. An assembly enters the system at station 1, where processing takes place. It is then transferred to station 2, which will process the assembly if station 3 is busy, or, if not, it will be transferred to station 3 for processing. Station 3 can detect whether the assembly has been completed by station 2. If the assembly has already been processed, S3 will pass the assembly to the next station without further processing. If station 2 is jammed, then station 3 will also be idle due to starvation of input (Figure 1).

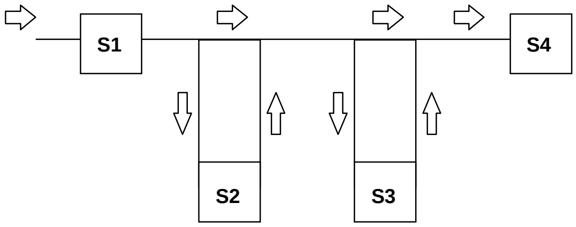


*Station 2 & 3 are parallel stations*

**Figure 1**. Schematic Diagram of On-line Stations Installation

### 1.1.2 Off-line Stations

The second method is to install off-line parallel stations beside the main line. The off-line stations require extra handling equipment, transferring material to and from the main line. After being processed by station 1, the assembly will be transferred to either off-line station 2 or 3 and returned to the main line after processing. The off-line stations work independently and therefore a breakdown of either one will not effect the operations of the other (Figure 2).

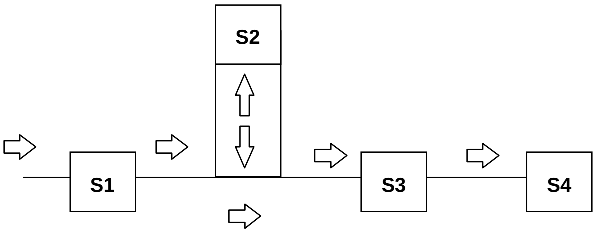


*Station 2 & 3 are parallel stations*

**Figure 2.** Schematic Diagram of Off-line Stations Installation

### 1.1.3 Tunnel-gated Stations

The third method is to install tunnel-gated station(s). An assembly enters the line at station 1 and, after processing, it is transferred to the elevated tunnel-gated station, S2, which will pick up and process it. While S2 is working, additional assemblies can pass under it for S3 to process (Figure 3).



*Station 2 & 3 are parallel stations*

**Figure 3.** Schematic Diagram of Tunnel-gated Stations Installation

## 1.2 Related Research

Due to the complex nature of the analysis of the performance characteristics of assembly systems, many researchers have attempted to study this type of problem by using simulation [4, 5, 8, 9, 10, 11, 12, 13, 14, 15, 16]. An excellent presentation on the techniques for studying the performance characteristics of different types of assembly systems can be found in Boothroyd [1]. Also, Buzacott and Shanthihumar have written an extensive review of modeling techniques for manufacturing systems [3]. Law [8, 9] analyzed the effects of different parameters by applying experimental design techniques to collect and analyze the simulation data. Jeong and Kim [6] presented an approximation method to evaluate assembly/disassembly systems consisted of multiple identical machines at each station. Some preliminary studies of the performance characteristics of parallel stations have been presented by the authors [10, 11, 12]. This paper extends those results and provides a better understanding of the effects of different design factors on the performance of AS using different strategies for installing parallel stations.

## 2. DESCRIPTION OF THE MODEL

A discrete-event simulation model was developed to evaluate and compare the performance of the three types of parallel systems under various assembly system design parameters. Rules governing the behavior of the different systems were identified, modeled and validated. The stochastic behavior of the systems was simulated by an appropriate probability distribution for the random variables. Processing times were generated by both uniform and exponential distributions, based on previous research.

### 2.1 Assumptions

There is no transfer delay between any two stations. The system produces a single product and has an unlimited availability of raw materials and an unlimited demand exists for the final product. The system consists of a standard 4-station line with 2 parallel stations (S2 & S3) and the two normal stations (S1 & S4).

## 3. THE EXPERIMENT

A simulation model with graphical animation capacity was designed [7] to conduct the experiments on the three different parallel systems. Running conditions were standardized to ensure comparability between simulation runs. The length of each of the five stimulation runs was 10,000 time units. The factors under investigation are:

- Buffer size
- Locations of buffer units
- Variability of processing time
- Total number of stations

### 3.1 Input Parameters

Data were carefully chosen for each factor to represent typical system conditions. The high and low values of each factor chosen are summarized as follows:

| Factor | Low Value | High Value |
|---|---|---|
| Buffer Size | 1 | 10 |
| Coefficient of Variation (CV) | 1 | 10 |
| Total Number of stations | 3 | 9 |

### 3.2 Output

To evaluate the performance of an AS with parallel stations, we use the maximum capacity as a common measurement. Capacity is defined as the total percentage of time that the last station, S4, is at the busy state.

## 4. RESULTS

### 4.1 Effects of buffer size

The function of the buffer units is to reduce the occurrences of force down. In other words, it helps to decouple the workstations. To evaluate the effect of adding buffer units, the average processing time of each normal workstation is assigned to be 10 while the processing time of the two parallel station is assigned to be 20. Since parallel stations are generally automatic in nature and normal workstations can either be automatic or manual in nature, the processing time of normal workstations is assigned to be randomly distributed and the processing time of parallel stations is fixed. From the experimental results, it suggests that the capacity increases as more buffer units are installed. However, the marginal effectiveness diminishes when its size grows larger (Table 1). This phenomenon can also be explained. As more buffer units are installed among the workstations, the force down occurrences can be reduced. However, increasing buffer units means increasing transport

**Table 1.** The Effect of Buffer Size on Different Parallel Stations

| Buffer | On-line | | Off-line | | Tunnel-gated | |
|---|---|---|---|---|---|---|
| Cap. | Optimal Allocation | Capacity | Optimal Allocation | Capacity | Optimal Allocation | Capacity |
| 1 | 1, 0, 0 | 0.716 | 1, 0, 0 | 0.909 | 0, 0, 1 | 0.748 |
| 2 | 1, 0, 1 | 0.750 | 1, 0, 1 | 0.945 | 0, 0, 2 | 0.784 |
| 3 | 1, 0, 2 | 0.934 | 1, 0, 2 | 0.954 | 1, 0, 2 | 0.892 |
| 4 | 1, 0, 3 | 0.946 | 1, 1, 2 | 0.966 | 1, 1, 2 | 0.949 |
| 5 | 2, 0, 3 | 0.965 | 2, 0, 3 | 0.975 | 1, 1, 3 | 0.968 |
| 6 | 3, 0, 3 | 0.970 | 2, 0, 4 | 0.977 | 1, 1, 4 | 0.969 |
| 7 | 3, 0, 4 | 0.973 | 2, 0, 5 | 0.979 | 3, 0, 4 | 0.977 |
| 8 | 2, 1, 5 | 0.976 | 3, 0, 5 | 0.987 | 2, 2, 4 | 0.980 |
| 9 | 4, 0, 5 | 0.979 | 4, 1, 4 | 0.988 | 1, 1, 7 | 0.981 |
| 10 | 3, 2, 5 | 0.982 | 6, 0, 4 | 0.983 | 3, 1, 6 | 0.985 |

time of pallets and consequently, decreasing the efficiency of the system. Therefore, adding more buffer units will not significantly improve the overall capacity after a number of buffer units are added. Table 1 shows that the improvement effect of buffer units diminishes as more than four buffer units are added.

## 4.2 Optimal buffer allocation between stations

Increasing the number of buffers means that the length of the assembly line increases. Also, it is discovered that the location of buffer units is an important factor [10,11,12] for automatic assembly systems. Therefore it is important to discover whether all buffers in the line with parallel stations are necessary and what the optimal allocation is. Since the capacity should have reached more than 95% capacity when eight buffer units are allocated, we conducted simulation experiments to study parallel systems with only eight buffer units to identify the pattern for optimal buffer allocation. Table 2,3 and 4 summarize the patterns of optimal buffer allocation for on-line, off-line and tunnel-gated systems respectively.

Results of optimal allocation of buffer units show that both the quantity and location of buffer units are important. Different systems have different patterns of optimal allocation. For on-line and off-line parallel systems, there should be heavier weighting of buffers before the first parallel station and after the second parallel station. Five buffers are required to achieve 95% of system capacity in the case of the on-line system, and 3 buffers, the lowest requirement of all the systems, for the off-line system. For the tunnel-gated system, the buffers should be more heavily weighted after the second parallel station, with a lesser weighting before the first parallel station. In this case, 4 buffer units are required to obtain 95% capacity.

## 4.3 Effects of variability of processing time for parallel stations

In a balanced assembly line, the mean processing time for all stations is identical. However, the variance of processing times may be different for each station. Table 2,3 and 4 show the experimental results of a balanced line with parallel stations, which have variable processing times or different forms of distribution.

Our analysis suggests that optimal buffer allocations of the on-line systems are sensitive to variances in processing time. However, neither the off-line nor the tunnel-gated systems are influenced by the variance of processing time (Table 2,3,4). For the on-line parallel system, more buffer units should be placed between S1 and S2. For the off-line parallel system, the optimal buffer allocation remains as (4,0,4) when the coefficient of variation is increased from 1 to 19. For the tunnel-gated system, it appears that no more buffer units are necessary to be added between S1 and S2 even when the coefficient of variation increases. However, when the C.V. is at 3 and 19, one more buffer unit needs to be added between S2 and S3.

**Table 2.** Optimal buffer allocation for the on-line parallel system

| Optimal Allocation | Capacity | C.V. s Ratio |
|---|---|---|
| ** | 0.999 | 0 |
| 2, 0, 6 | 0.930 | 1 |
| 4, 0, 4 | 0.868 | 2 |
| 2, 3, 3 | 0.817 | 3 |
| 2, 2, 4 | 0.784 | 4 |
| 1, 2, 5 | 0.728 | 19 |

**Table 3.** Optimal buffer allocation for the off-line parallel system

| Optimal Allocation | Capacity | C.V. s Ratio |
|---|---|---|
| ** | 0.998 | 0 |
| 5, 0, 3 | 0.991 | 1 |
| 4, 0, 4 | 0.987 | 2 |
| 4, 0, 4 | 0.971 | 3 |
| 4, 0, 4 | 0.961 | 4 |
| 4, 0, 4 | 0.923 | 19 |

**Table 4**. Optimal buffer allocation for the tunnel-gated parallel system

| Optimal Allocation | Capacity | C.V. s Ratio |
|---|---|---|
| ** | 0.997 | 0 |
| 2, 1, 5 | 0.989 | 1 |
| 2, 1, 5 | 0.982 | 2 |
| 2, 2, 4 | 0.960 | 3 |
| 2, 1, 5 | 0.938 | 4 |
| 2, 2, 4 | 0.870 | 19 |

** Independent of buffer allocation
Optimal Allocation = (buffer size between S1 and S2,
buffer size between S2 and S3,
buffer size between S3 and S4)
C.V. = Coefficient of Variation

## 4.4 Effect of total number of stations

As the number of station increases, the variance of overall processing times also increases. Consequently, the occurrences of force down will also be increased. Therefore, the overall capacity of an assembly system will be decreased. Figure 4 shows that the overall capacity decreases within 10% when total number of stations is increased from 3 to 9. However, the decrease in capacity appears to be more significant as the variability of processing time increases. For off-line system, the decrease in capacity ranging from 5% to 25% when the number of stations increases from 3 to 9. The decrease in capacity reaches 25% when the variance of processing time has increased to 4 (Figure 5). For tunnel-gated system, the decrease in capacity is within 10% when total number of stations increases. Again, the decrease in capacity is the most significant when the variance of processing time is set equal to 4 (Figure 6).

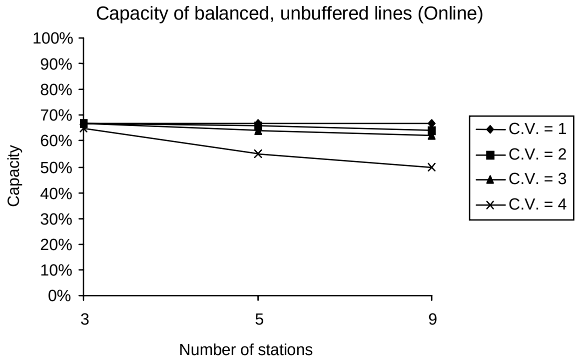


**Figure 4.** Capacity of systems with on-line parallel stations (zero buffer)

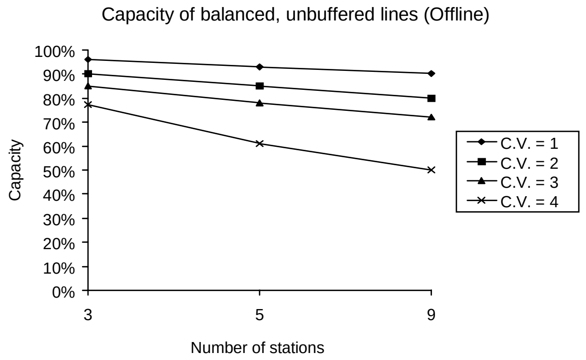


**Figure 5.** Capacity of systems with off-line parallel stations (zero buffer)

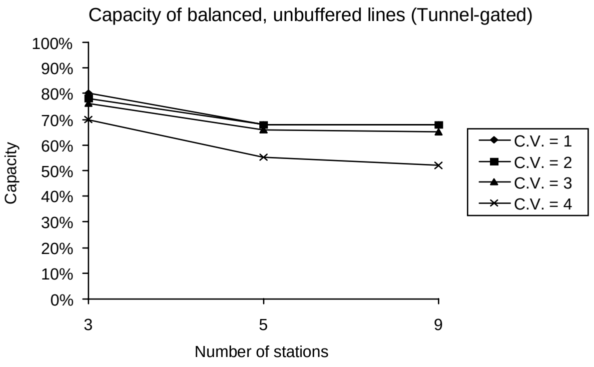


**Figure 6.** Capacity of systems with off-line parallel stations (zero buffer)

## 5. CONCLUSION & RECOMMENDATION

The three different parallel systems have different performances if the parameters of assembly line are changed. The off-line system was found to have usually the best performance among the three parallel systems. The tunnel-gated system was found to be better than the on-line system, which had a relatively poor performance. The effect of buffer size, buffer allocation, variability of processing time and total number of stations will all affect the capacity of an assembly systems no matter what strategy for installing parallel station is used.

Therefore, to select the optimal strategy for installing parallel stations, all the mentioned factors and the space requirement should be considered. If extra buffers units are not available to be added, the on-line parallel station should not be considered. However, if buffers units are available, installation costs of a longer conveyor, investment costs of work-in-progress and cost of extra spaces should also be considered. If extra floor space is not an issued to be concerned, off-line parallel station(s) should be used. Tunnel-gated parallel stations do not require so much floor space as off-line parallel stations, however, overall capacity is superior to on-line parallels stations. In terms of installation and operation costs, on-line parallel systems are lowest. Both off-line and tunnel-gated parallel systems have high installation and equipment costs. A comparison of three different types of stations can be summarized as follows:

| | On-line Stations | Tunnel-gated Stations | Off-line Stations |
|---|---|---|---|
| Extra Space Required | No | Low | High |
| Installation Cost | Low | High | Medium |
| Capacity | Low | Medium | High |

## 6. FURTHER RESEARCH

This study could be extended to more research areas. Transfer delay and a greater number of parallel stations could be considered. Moreover, repair times and failure rates could be further studied. The number of pallets in the system could be optimized if there are only limited number of pallets circulating in the system.

This study focused on the free-transfer assembly system with parallel stations. The models could be modified to simulate other assembly systems, such as indexing-transfer and manual serial assembly lines. Moreover, pallets can be loaded into the system dynamically to eliminate some blockings or forced downs according to preplanned schemes. These potential research areas are under investigation by the authors.

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