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# Assembly Cells Versus Assembly Lines: Insights on Performance Improvements from Simulation Experiments and a Case Study

## **Abstract**

With the current emphasis on short product delivery lead times and customized product configurations, there is a need for systems that can quickly assemble small batches of customized product. While some plants are converting their assembly lines to assembly cells to achieve this goal, the reasons for the performance improvement resulting from conversion have not been well documented or understood, making it difficult to know when and where assembly cells are applicable. This research adds to the sparse body of literature in this area by examining the planned conversion of an assembly line to a set of parallel assembly cells in a real plant. Analytical and simulation models are used to explain why the proposed cells are expected to outperform the current assembly line.

## **Disciplines**

Business Administration, Management, and Operations | Management Information Systems | Operations and Supply Chain Management

## **Comments**

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# ASSEMBLY CELLS VERSUS ASSEMBLY LINES: INSIGHTS ON PERFORMANCE IMPROVEMENT FROM SIMULATION EXPERIMENTS AND A CASE STUDY

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## ABSTRACT

With the current emphasis on short product delivery lead times and customized product configurations, there is a need for systems that can quickly assemble small batches of customized product. While some plants are converting their assembly lines to assembly cells to achieve this goal, the reasons for the performance improvement resulting from conversion have not been well documented or understood, making it difficult to know when and where assembly cells are applicable. This research adds to the sparse body of literature in this area by examining the planned conversion of an assembly line to a set of parallel assembly cells in a real plant. Analytical and simulation models are used to explain why the proposed cells are expected to outperform the current assembly line.

## INTRODUCTION

Many manufacturing plants are experiencing increased market demand for short product delivery lead times. At the same time, shorter product life cycles and increased demand for customization has reduced the viability of holding finished goods inventory as a way to meet these requirements. These demands are expected to continue in the future [2], requiring plants to develop systems that can quickly manufacture, assemble, and deliver small batches of customized products.

This study focuses on the assembly portion of such systems and, in particular, the performance improvements that can be achieved when lines performing manual assembly tasks are converted to assembly cells. While a number of companies have reported significant performance improvements from such conversions (see, for example, [4]), the reasons for the improvements are usually neither stated nor understood, making it difficult to know when and where assembly cells are applicable. In fact, the research literature examining environments where assembly cells are superior to assembly lines, and the reasons for their superiority, is not well developed.

This study examines the planned conversion of an assembly line to a set of parallel assembly cells in a real plant. Analytical models are first used to examine why the proposed cells are expected to outperform the current assembly line. Simulation models based on data collected from the plant are then used to illustrate the potential

magnitude of improvement possible, and to confirm the analytical results.

In this study, an assembly line is defined as a serial production system where each station performs a small number of assembly tasks. Raw material enters the first station and progressively moves through a series of adjacent stations where manual assembly operations are performed. The stations are connected by a material handling system and the output from the assembly line consists of a subassembly or a fully assembled product. Each station has the same mean processing time and buffers of inventory may or may not be allowed between stations.

Traditionally, workers on assembly lines of this type have been trained to perform the assembly tasks at a particular station. Some cross-training of workers has occurred in recent years but most training is limited to learning tasks of the previous and following stations. However, even where complete cross-training has been accomplished, the amount of help that workers can lend to other stations is often limited due to short cycle times. In addition, line reconfiguration may be required to assemble different products, accommodate changes in demand volumes, etc.

In an assembly cell, raw material is fed to the cell and a subassembly or fully assembled product leaves the cell. Workers are often cross-trained to do some or all assembly tasks and may have other extended responsibilities such as production scheduling or preventative maintenance. In multiple operator cells, workers are also responsible for dynamically balancing the flow of work as product mix or demand levels change. Thus, the main differences between assembly lines and assembly cells are the number of operators in each cell versus on the line, the range of cross-training, the dynamic balancing of work flow, and the amount of other extended responsibilities.

## LITERATURE REVIEW

The review of the relevant research literature on assembly lines and assembly cells is available from the author.

## COMPANY BACKGROUND

Much of the information used in this study was obtained from a plant that manufactured sheet metal products of various dimensions and configurations. The plant's real name and the products it produces cannot be disclosed for

confidentiality reasons and the plant will be referred to as Sheet Metal Products (SMP). A group of 15 large products accounted for 75-80% of SMP's total sales and the production processes for these products were all similar. The component parts were stamped out of sheet metal, formed to the correct shape on press brakes, welded together to form a semi-finished unit or component, painted, assembled, and shipped to a distribution center or to the final customer. This paper concentrates on the final assembly portion of the production process.

These 15 products were large and heavy and a single line was used for final assembly. Each station on the line was manned by a single worker. The number of stations on the line varied with the product produced and ranged from 22 to 39, with a volume-weighted average of 30 stations. The planned cycle time per unit based on standard labor hours varied with the product produced and ranged from 0.75 to 4.10 minutes, with a volume-weighted average of 1.6 minutes. Thus, the volume-weighted average time to complete the task(s) at each station was 1.6 minutes. Due to the large size of the products, no buffers were used on the line and a powered conveyor transferred the units between stations. The conveyor was stopped while the assembly tasks were performed and it could not transfer a unit to the next station until all stations had finished the assigned assembly tasks (the movement of the assembly line was controlled by the workers). While the line was not paced per se, it exhibited many characteristics of paced lines and will be referred to as a linked line. All workers were cross-trained to do all assembly tasks and the workers rotated to the next station on the line every 1-2 hours to reduce the risk of repetitive motion injuries, relieve boredom, and to see how the quality of their work impacted other stations and the quality of the finished product.

The linked assembly line at SMP suffered from large amounts of worker idle time, long assembly lead times per unit, and inflexibility. At the time of this study, SMP was converting this assembly line to 18 parallel, two-person assembly cells. Products arriving from the paint line would proceed to the first available assembly cell (each cell could only hold one unit at a time), where two workers would assemble the unit. The assembly tasks would be done in the same order as on the assembly line and when all assembly tasks were complete, the fully assembled unit would leave the cell for shipping to the distribution center or final customer. The implementation and operation of these cells was expected to reduce the assembly flow time per unit by approximately 50%, reduce worker idle time, increase productivity, and increase flexibility. The reasons for these expected improvements are discussed in the next section.

### REDUCING THE IMPACT OF VARIABILITY

Statistical dependencies between stations on the linked assembly line at SMP were a major cause of the poor

performance. Since interstation buffers of inventory did not exist (due to the size of the products), the cycle time and total output of the line was dependent on the slowest station. Even with a balanced line, task time variability caused actual cycle times to be longer than the average station work content, resulting in low average station utilization.

To illustrate, consider a linked assembly line containing two stations, no interstation inventory buffers, an infinite source of raw material, a second station that is never blocked, and processing times at each station that are either 1, 2, or 3 minutes with equal probability. In steady state, the possible task time combinations that can occur at the first and second stations, respectively, are: (1,1), (1,2), (1,3), (2,1), (2,2), (2,3), (3,1), (3,2), and (3,3) minutes. Since both stations must complete their task before the line can move forward, the longest task time determines the cycle time, resulting in possible cycle times of 1, 2, 3, 2, 2, 3, 3, 3, and 3 minutes, respectively. Since each cycle time can occur with equal probability, the expected cycle time is  $22/9=2.44$  minutes and the average station utilization is the average task time divided by the expected cycle time, or  $2.0/2.44=82\%$ . The expected flow time is the expected cycle time multiplied by the number of stations, or  $2.44*2=4.88$  minutes.

The literature review indicated that the performance of this hypothetical system would deteriorate as additional stations with the same processing time distribution are added. Adding additional stations increases the probability that at least one station will have a processing time of three minutes. Since the actual cycle time for each cycle is determined by the processing time of the slowest station, increasing the probability that at least one station has a processing time of three minutes increases the expected cycle time, reduces the average station utilization, and increases the expected flow time.

To illustrate this degradation in performance, an Excel spreadsheet was used to calculate the average station utilization and average cycle time for this system as additional stations were added. The results of this analysis are shown in Figure 1. As the figure indicates, average station utilization decreases and average cycle time increases as additional stations are added, with the marginal degradation in performance decreasing as successive stations are added. Since the upper bound on cycle time for this system is three minutes, the lower bound on average station utilization is  $2/3=66.67\%$  and the average increase in flow time as additional stations beyond 10 are added will be almost linear, with a marginal increase of approximately three minutes per station. This degradation in performance as additional stations were added was also found in previous research on linked lines [3][5][1].

In theory, if the two station linked assembly line was converted to two single-person assembly cells, each of which does both assembly tasks for each product, both tasks

would be done sequentially with no delay between tasks; the variability in task times, on average, would cancel out; idle time would be eliminated; and worker utilization would be 100%. The expected flow time would be  $2 \times 2 = 4$  minutes, for an average improvement of  $(4.88 - 4) / 4.88 = 18.0\%$  over the two-station linked line. In addition, the expected cycle time would be  $4/2 = 2$  minutes (i.e., the expected flow time divided by the number of cells).

In this example, the number of stations ( $n$ ) on the assembly line was equal to the number of assembly tasks. Consequently, as longer lines were converted to cells, the average flow time of the cellular system increased linearly, with an expected flow time of  $2 \times n = 2n$  minutes. However, since the number of stations and the number of assembly tasks also equaled the number of cells formed when conversion took place, the expected cycle time of the cell system was not affected by the length of the original line and remained unchanged at  $2n/n = 2$  minutes. Hence, as Figure 2 shows, the percent reduction in flow time resulting from converting the  $n$  station assembly line to  $n$  single-person assembly cells increased as the number of stations on the line increased, with the marginal improvement decreasing. In contrast, the absolute reduction in flow time increased in a nearly linear fashion as the number of stations increased.

### SIMULATION RESULTS

Simulation experiments using exponential and normal processing time distributions were conducted for assembly lines and assembly cells with 10, 20, 30, or 40 tasks. The results for both distributions confirm the analytical results presented. Tables showing the simulation results are available from the author.

### CONCLUSIONS

This study clearly shows that assembly cells have the ability to generate significant performance improvements over unbuffered, linked assembly lines. The ability of the assembly cells studied to handle a wide range of task time variability without a substantial increase in flow time creates a very robust assembly system.

However, the cellular assembly system described in this study is not without cost. Installing multiple, parallel cells will require component parts to be delivered to each cell rather than to a single station on the line. This, in turn, will require changes to SMP's production control and material handling systems. In addition, a substantial investment in tooling, lifting, and holding devices, etc., will be required to form the assembly cells, but SMP estimated the performance improvements would pay for the changes in less than two years.

Figure 1: Performance of a linked line as the number of stations increase

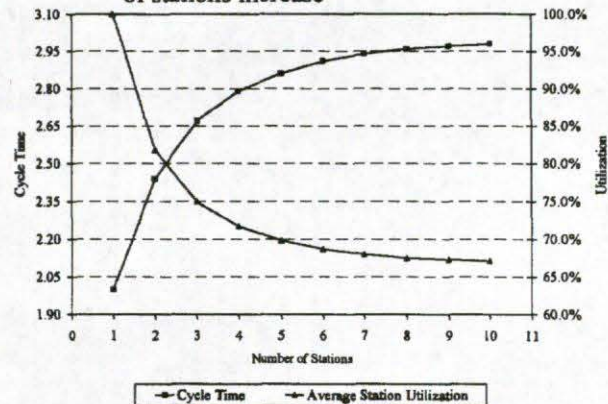
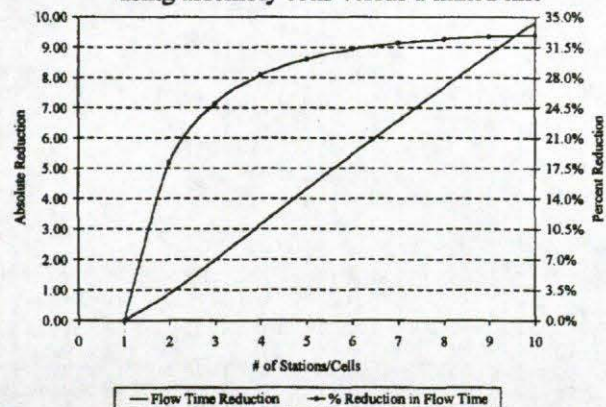


Figure 2: Absolute and percent reduction in flow time using assembly cells versus a linked line



### REFERENCES

- [1] Conway, R., Maxwell, W., McClain, J. O., & Thomas, L. J. (1988). The role of work-in-process inventory in serial production lines. *Operations Research*, 36(2), 229-241.
- [2] De Meyer, A., Nakane, J., Miller, J. G., & Ferdows, K. (1989). Flexibility: The next competitive battle. The manufacturing futures survey. *Strategic Management Journal*, 10(2), 135-144.
- [3] Hunt, G. C. (1956). Sequential arrays of waiting lines. *Operations Research*, 4(6), 674-683.
- [4] Levin, D. P. (1994). Compaq storms the PC heights from its factory floor. *New York Times*, November 13.
- [5] Smunt, T. L., & Perkins, W. C. (1985). Stochastic unpaced line design: Review and further experimental results. *Journal of Operations Management*, 5(3), 351-373.