Proceedings of the 1991 Winter Simulation Conference
Barry L. Nelson, W. David Kelton, Gordon M. Clark (eds.)

MATERIAL HANDLING IN A FLEXIBLE MANUFACTURING SYSTEM PROCESSING PART FAMILIES

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ABSTRACT

The objective of this simulation study is to analyze the system performance of a six machine flexible manufacturing system cell in which a material handling system is to be incorporated. The analysis focuses on determining the production potential of the cell by grouping common parts into "families". To accomplish this, computer simulation models are developed using the SIMAN simulation language.

Initially the manufacturing cell is modeled with no material handling system to get an upper bound estimate of production output. We next explore the impact that an automatic guided vehicle (AGV) has on system performance of the manufacturing system cell. A final analysis is performed in which a conveyor system is implemented as the material handling device. The resulting performance comparison is presented in the form of confidence intervals.

Upon examination of the simulation results, our recommendation is to implement a conveyor system for material handling. Using an AGV in the flexible manufacturing cell creates a bottleneck which causes production output to dramatically decrease. Incorporating a conveyor as the material handling system does not limit the daily production output of the manufacturing cell.

1 INTRODUCTION

The first part of this paper provides a description of the flexible manufacturing cell which is modeled. The next section presents the three material handling system models developed for our analysis. The third part of the paper contains a comparison of the results obtained by the various simulation runs. Our recommendations compose the fourth section of the paper. Finally, we present a discussion on how the SIMAN simulation language simplified our model development and we offer suggestions for future efforts.

2 DESCRIPTION OF THE FLEXIBLE MANUFACTURING SYSTEM

The flexible manufacturing cell consists of six machines modeled as stations. The cell design study is abstracted from the production operation of a major manufacturer of machined gears. The number of different types of parts processed within the cell is high relative to the overall volume of production. A layout of the manufacturing cell is presented in Figure 1. This type of system has been analyzed before. For example, Cummins (1990) considers the layout aspect of a similar system using Group Technology, while Mills (1986) looks at a number of design issues related to simulation and analytic methods for analyzing cellular manufacturing. Neither author places emphasis on the material handling aspects of a case study as we do in this paper. Parts are made available to the flexible manufacturing cell when they appear at the input queue. The arrival of parts

Table 1: Families of parts and their production steps.

Family	% of Mix	Production Sequence
1	10%	1, 2, 3, 5, 6
2	15%	2, 3, 4
3	25%	5, 2, 3, 1, 4, 6
4	15%	4, 1, 2, 5, 3
5	30%	5, 2, 1, 3, 5, 6
6	5%	3, 4, 2, 1, 5, 6

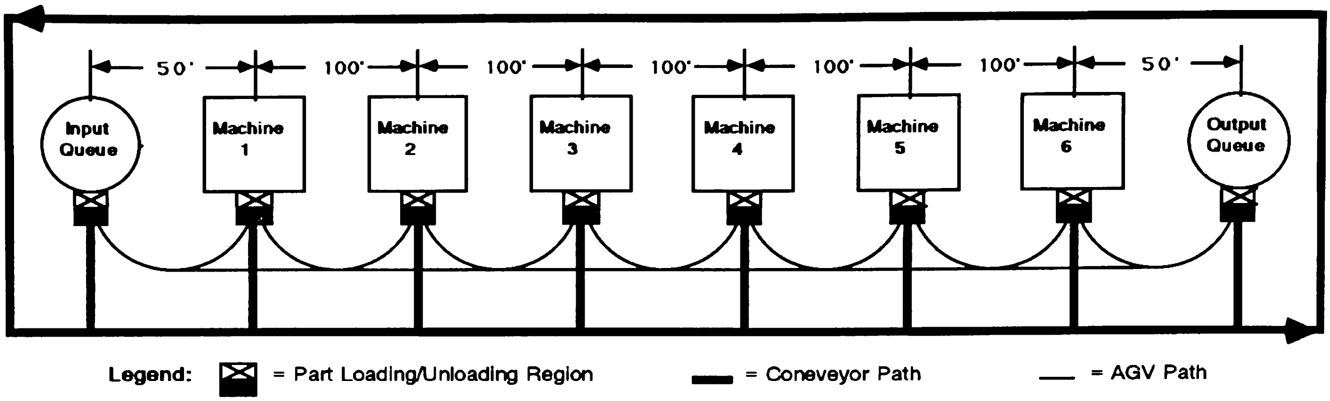

Figure 1: Layout of the flexible manufacturing cell. The proposed paths for the AGV and conveyor system are indicated in the cell layout. Spacing is given in feet.

to the input queue occurs at intervals of between 20 and 22 minutes, uniformly distributed. All distribution fitting calculations used in this paper follow accepted statistical techniques (Cochran and Cheng 1990). Based on discussion with management, the queue capacity at each machine was not to be considered as a constraint in our model.

The families of parts produced by the cell and their production steps are summarized in Table 1. The part classifications follow the work of Opitz (1970) and Opitz and Weindahl (1971). A classification is necessary for this system since the total number of parts may exceed 1,000.

Production times have been determined from groupings of historical data. This data was obtained from process planning sheets for the machines and parts modeled. Table 2 summarizes the mean values and associated sample standard deviations of production times based on family type and work station.

The scheduling of part production is only restricted by the part mix percentages (presented in Table 1). These mix percentages are based on units produced, not on production time. The only constraint given by management is that the percentages by family should fall within 20% of the target during any reasonable monitoring period.

Table 2: Mean and standard deviation of processing time for each part by machine in the manufacturing cell. The distribution of processing times has been shown to follow the normal distribution.

Part Family	Station 1	2	3	4	5	6
1	10,1.5	15,2.25	20,3	-	16,2.4	24,3.6
2	-	23,3.75	30,4.5	21,3.15	-	-
3	17,2.55	30,4.5	18,2.7	16,2.4	21,3.15	29,4.35
4	6,.9	6,.9	12,1.8	12,1.8	12,1.8	-
5	24,3.6	24,3.6	15,2.5	-	15,2.5	20,3
6	9,1.35	8,1.2	10,1.5	10,3	14,2.1	29,4.35

Our objective in determining system performance is to:

- Maximize the production output of the manufacturing cell.
- Meet the production mix percentage targets.
- Minimize the average time a part spends in the manufacturing cell.
- Do not constrain production throughput by implementation of an automated material handling system.

Validation of the simulation models and their associated output was accomplished by seeking the appraisal of experts. As presented by Cochran (1987), this approach is an available technique for testing the validity of a simulation model.

3 MODEL DEVELOPMENT

3.1 Production Potential Without an Explicit Material Handling Device

The initial simulation model of the flexible manufacturing cell uses a general distribution for modeling part movement. This allows for throughput determination that is not restricted by a material handling device. Various part release strategies are implemented to determine maximum throughput. The results of the baseline model are used for assessing the impact of material handling systems.

Historical data indicates that between 3.0

and 6.5 minutes, uniformly distributed, is required to load or unload a part from a machine. General part movement between machines takes between 3.0 and 6.5 minutes, uniformly distributed.

The output was analyzed using the method of batch means with a batch size of 24 hours. Steady-state behavior was reached within 24 hours and analysis consists of 20 batches (20 batches x 24 hours x 60 minutes = 28,880 minutes). Determination of steady-state conditions, autocorrelation and run length are accomplished by standard means of analysis (Law and Kelton 1991).

The results of this simulation model indicate that the most optimistic production output of the flexible manufacturing facility is approximately 68 parts per day.

The use of simulation for searching for job shop scheduling rules is well known (Hershauer and Ebert 1974, Kiran and Smith 1984, plus Moore and Wilson 1967, are all good overviews). We employed many of their strategies in determining our results. By running different combinations of machine part selection rules, we determined that the following rule maximizes throughput:

- Machine 1 - select first part from waiting area
- Machine 2 - select the part with the lowest processing time
- Machine 3 - select first part from waiting area
- Machine 4 - select first part from waiting area
- Machine 5 - select first part from waiting area
- Machine 6 - select first part from waiting area

Not only does this strategy obtain the most optimistic production output, it also maintains the requirement regarding production mix.

Our analysis indicates that machine 2 is the first to limit system throughput. At our production level, it is in use 100% of the time.

3.2 Production Impact of AGV Installation

This simulation model is the second in our study. Its purpose is to determine the impact of an automated material handling vehicle on the production potential of the manufacturing cell.

The material handling system consists of a single automated guided vehicle (AGV) which is capable of transporting one part at a time. The AGV moves at an average speed of 183 feet per minute. Between 45 and 75 seconds, uniformly distributed, is required to load or remove a part from the AGV. The AGV is allocated on a first-in, first-out strategy, based on a request for transport.

The model of this system is a modification of the initial simulation, but now an AGV system is incorporated. This model uses the same product release procedure and machine part selection rules that determine maximum output in the initial study. This allows us to statistically quantify the impact the AGV system has on system performance.

The simulation was run at steady-state for 5.5 batches. Each batch was a day. Total elapsed simulation time was 7,920 minutes (5.5 batches x 24 hours x 60 minutes = 7,920 minutes). Note that this model could not be run for 20 days as was done in the previous study, for the simulation soon exceeds the allowable number of parts (i.e. entities) in the manufacturing cell. This is due to the large number of parts waiting for transport by the AGV. The throughput level of 68 parts per day can clearly not be supported with a limited AGV material handling system.

Analysis shows that using an AGV as the material handling device causes output to be reduced to 43 parts per day. Initially we hypothesized that cell output would decrease as a function of the additional burden of the limited material handling resource, but not with such dramatic results.

The analysis indicates that the AGV is a bottleneck for the flexible manufacturing cell. There are on average a large number of parts waiting for transport by the AGV. Currently AGV utilization is 100%. The addition of a second AGV is a logical solution to the problem of excessive utilization, but due to cost inefficiences it was not considered as a viable alternative.

3.3 Production Impact of Conveyor Installation

This model of the flexible manufacturing cell implements a non-accumulation conveyor system in place of the AGV.

The model for this system is again a modification of the initial simulation model. To be able to determine the impact of the conveyor system on system performance, this model incorporates the same product release procedure and part selection rules that determined maximum output in the previous studies.

The conveyor-based material handling system consists of a single, uni-directional, closed-loop, non-accumulating conveyor. The conveyor moves in the direction indicated in Figure 1. Since the conveyor moves in one direction, a move from machine 4 to machine 3 will require traversing the loop from 4-5-6-OQ-IQ-1-2-3.

The conveyor is designed to move at a speed of 60 feet per minute. Each part requires between 45 and 75 seconds, uniformly distributed, to be loaded onto or unloaded from the conveyor.

Cells on the conveyor are 4 feet wide. This allows any part family to be placed into a single conveyor cell and still allow 6 inches of freedom between parts.

The simulation of the conveyor system was run for 20 batches as in the initial study. As previously noted, a run length of this size allows for steady-state results to be analyzed.

Using a conveyor as the material handling system results in production output of approximately 68 parts per day. Production potential obtained by this material handling system is equal to that determined in the initial simulation model.

In terms of different types of conveying systems, a non-accumulating conveyor is all that needs to be considered. An accumulating conveyor system is a more expensive alternative, but will not increase output from the manufacturing cell. Our initial simulation study indicates that the production output from the facility is a maximum of 68 parts per day. With a non-accumulating conveyor, we achieve this potential. As in the initial study, the production output is first limited by machine number 2.

4 COMPARISON OF RESULTS

The average number of each family type produced per day are summarized in Figure 2 and Table 3. Based on 24 hour averages, the production potential associated with the conveyor system is equal to that of the model implemented with a general material handling time distribution. The

Table 3: Average 24 hour production output of the flexible manufacturing cell.

Family Type	No Material Handling system	AGV System	Conveyor System
1	6.85	4.18	6.85
2	11.65	8.90	11.60
3	15.75	10.18	15.85
4	10.70	6.18	10.75
5	20.65	11.63	20.55
6	2.65	2.00	2.65
Total	68.25	43.07	68.25

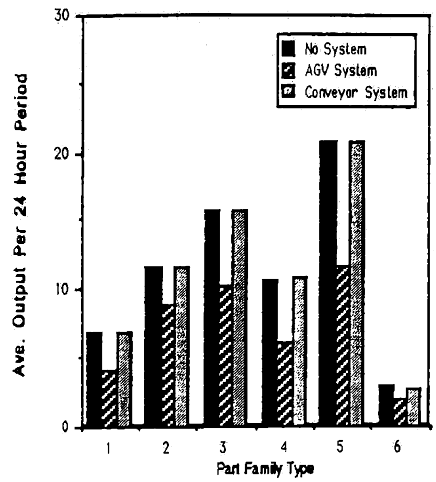

Figure 2: Average production output for a statistically typical 24 hour period. Results are given for the number of each part family type produced by the three simulation models. Note that the conveyor system is equivalent to the system with no material handling device.

second study indicates that with an AGV, the manufacturing facility outputs an average of 43 parts per day. The production capability of the AGV system is but 63% (43/68) of what is obtained by means of the conveyor.

In Table 4, 95% confidence intervals for the average time a part spends in the manufacturing facility are presented. Figure 3 indicates that the average processing time for a part is between 4 and 5 hours. The addition of a conveyor (as the material handling system) increases the average processing time to be between 5 and 6.5 hours. With an AGV, it takes an average of between 32 and 36 hours to process a part through the manufacturing cell, but this time value is growing unbounded. Depending on the family type, the processing time associated with an AGV incorporated into the system is increased by 5 to 12 times.

The variation for processing times of each family type are summarized in Table 5. The AGV dramatically increases the variability associated with the mean processing time. There are variation increases upwards of 30 times by using a single AGV as the material handling device. The variation of times for the conveyor system is minimized when compared to the initial simulation model and in certain instances it is less.

Table 4: 95% confidence intervals for the average time (in minutes) that a part is in the manufacturing cell. The table provides the average processing time for each specific family type plus the time associated with an average part.

Part Type	No Material Handling System	AGV System	Conveyor System
1	(184, 196)	(1361, 2093)	(193, 205)
2	(135, 271)	(1224, 1566)	(165, 184)
3	(404, 606)	(2152, 2650)	(521, 803)
4	(136, 144)	(1759, 2385)	(231, 239)
5	(235, 255)	(2126, 2602)	(331, 355)
6	(195, 215)	(1527, 2673)	(287, 306)
Average	(247, 301)	(1942, 2182)	(320, 389)

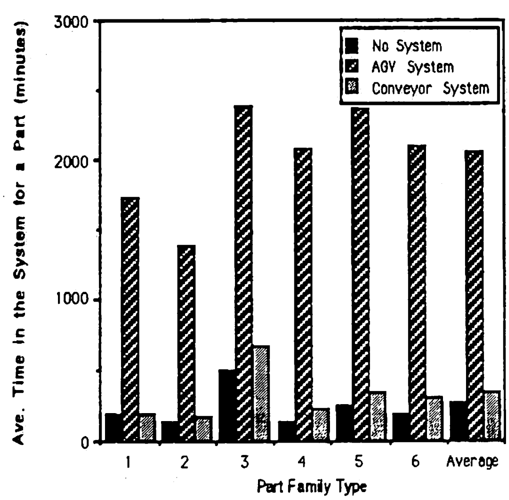

Figure 3: Average time for a part family type to be in the manufacturing cell. Results are summarized for each of the three simulation models.

5 CASE STUDY RECOMMENDATION

The simulation study demonstrates that production output of the flexible manufacturing cell is maintained by using a conveyor as the material handling device. With the conveyor, the manufacturing cell has an average output of 68 parts per day. The time a part spends in the manufacturing cell is dramatically reduced. Not only is the aver-

Table 5: 95% confidence intervals for the standard deviation of time (in minutes) that a part is in the manufacturing cell. The table provides the variation of processing time for each specific part family type plus the time associated with an average part.

Part Type	No Material Handling System	AGV System	Conveyor System
1	(31, 39)	(655, 1199)	(31, 40)
2	(480, 576)	(497, 744)	(67, 80)
3	(844, 987)	(785, 1440)	(1183, 1383)
4	(26, 31)	(725, 1182)	(30, 36)
5	(101, 116)	(813, 1156)	(115, 312)
6	(247, 301)	(596, 1498)	(39, 48)
Average	(490, 528)	(862, 1033)	(621, 669)

age time reduced, but the associated variability of this time is greatly decreased when compared to an AGV system. In addition, the production mix targets are satisfied.

To achieve maximum production output, the optimum part selection rule for a machine has been determined to be:

- Machine 1 - select first part from waiting area
- Machine 2 - select the part with the lowest processing time
- Machine 3 - select first part from waiting area
- Machine 4 - select first part from waiting area
- Machine 5 - select first part from waiting area
- Machine 6 - select first part from waiting area

Utilizing the conveyor system in the facility causes the average time a part spends in the system to be between 5 and 6.5 hours. This compares well to the AGV system in which the average time ranges between 32 and 36 hours. The cycle time for the manufacturing facility is around 5.5 hours with a conveyor system. Cycle times by family type are summarized in the previous section. Analysis indicates that the time between when a part enters and leaves the manufacturing cell is around 4 to 11 times less when a conveyor is used to transport parts versus an AGV.

The AGV is a bottleneck for the manufacturing facility. Using this type of material handling device causes production output to dramatically drop.

Before a decision is made to go with the conveyor system, remember that such a system lacks flexibility. There is great expense involved in changing the layout of a conveyor system if the station set-up is modified.

If it can be reasoned that the current station set-up will remain relatively unchanged, our recommendation is to implement a non-accumulating conveyor system for material handing. This conclusion is based on the fact that with a conveyor system, system performance in maximized. That is, production output is maximized, long-term percentage mixes are met, and the average time a part spends in the manufacturing cell is minimized.

6 COMMENTS ON MODELING METHODOLOGY

The models for the simulation study of the flexible manufacturing system were developed in System Modeling Corporation's SIMAN (Pegden, et al. 1990) simulation language, Version 4.0.

SIMAN is a combined discrete-continuous simulation analysis language which contains a number of features that make it particularly useful for modeling manufacturing systems. Among these are the ability to create macro or indexed models, the transport function, the convey function, the output processor for analyzing model output, plus the separation of the model into the distinct experimental and modeling frames.

Our initial simulation consisted of modeling the manufacturing cell and "optimizing" production output. This required us to develop an initial model in which the manufacturing cell was modeled using the station concept in SIMAN. This model was run and analyzed by the output processor to compute confidence intervals for the results. In attempting to increase production output from the manufacturing cell, modifications were only required of the experimental frame, where parameters and selection rules were varied.

The development of the two simulation models containing an automated guided vehicle system and a conveyor are simple modifications to the initial model. In each, due to the indexed stations approach and the differentiation between the experimental and model frames, the addition of the material handling system was accomplished quite easily.

Our experience has shown that the SIMAN simulation language allows for easy comparison of material handling alternatives. We believe that this type of analysis is best accomplished by a combination of SIMAN with standardized routines (Lin and Cochran 1989). Since so many studies of flexible manufacturing systems cells have been performed, their development should be standardized (Cochran, et al. 1991) and ultimately automated using artificial intelligence techniques (Cochran and Mackulak 1987).

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