Proceedings of the 1996 Winter Simulation Conference
ed. J. M. Charnes, D. J. Morrice, D. T. Brunner, and J. J. Swain

THE USE OF SIMULATION IN THE OPTIMIZATION OF A CELLULAR MANUFACTURING SYSTEM

Stacy M. Sammons
Jeffery K. Cochran

Department of Industrial and Management Systems Engineering
Arizona State University
Tempe, AZ 85287-5906, U.S.A.

ABSTRACT

In the evaluation of a cellular manufacturing system, multiple factors should be considered, including the flow of the parts and the assignment of the workers. Simulation techniques can be effectively used in order to understand and optimize the behavior of the system. In this paper, a work cell is evaluated by means of discrete simulation using SLAM II. An optimization method is presented to determine the best alternative among proposed changes to the system. The structure of the approach allows the optimization to be performed with direction given by management. The results reveal that priority ranking of the parts, automated testing, and distributed job functions implemented together would produce the most significant improvement in the utilization of the team members.

1 INTRODUCTION

Simulation can be utilized in the manufacturing environment to predict system behavior or to conduct experiments and anticipate changes in the system before any adjustments are actually made. The model represents the system and allows for relatively easy modification and analysis. Objectives of the use of simulation to optimize a manufacturing system may include:

- Maximization of the utilization of the machinery and the workers.
- Minimization of the work-in-process in the system.
- Maximization of the production throughput of the system.

During the simulation process, many potential systems are often examined. It is beneficial to obtain the best solution in the fewest number of runs or calculations. When many design changes are being considered, it may not be feasible to run every possible combination, due to time or cost constraints. Therefore, an algorithm is needed to streamline the analysis.

Extensive research has been done on the role of simulation in cellular manufacturing. It can be used to ease the conversion from a traditional, functional layout to a work cell (Baran 1991). In addition, simulation can be used after implementation as a decision support tool to illustrate the effect of decisions on the system (Rahimifard and Newman 1995). The discussion has been primarily limited to analysis of the manufacturing system, rather than optimization. An optimum-seeking method is often used with simulation in order to determine the final preferred system from those under evaluation (Mollaghasemi and Evans 1994).

This paper describes how the flexibility offered by simulation can be utilized both to obtain savings during the decision process, and to involve management throughout the procedure of optimization. This approach is applied to a cellular manufacturing environment.

2 MODEL DEVELOPMENT

Hamilton Standard, a subsidiary of United Technologies Corporation, provides aircraft products for commercial and military applications. During the early 1990s, the company decided to pursue focused facilities with the intention of implementing continuous flow manufacturing techniques in a self-managed work team environment. The techniques implemented include the use of a cellular layout, point of use storage, and a visual pull system.

The assembly system features high performance "work teams" which are responsible for the product from the procurement of material through the shipping of completed components to the customer. The facility utilizes six work cell teams, each specializing in a different product line. A work cell is created by drawing people and equipment from their functional areas, and placing them in the same work area to reduce movement distances and allow the product to flow from one bench to another. Figure 1 shows a chart of the layout and the product flow for the work cell.

The employees at Hamilton Standard are cross-functional, capable of performing any of the functions within the team. Each team consists of six associates: one associate to purchase the materials, one associate to schedule production, one associate to receive parts, two associates to assemble and test the products, and one associate to ship the product to the customer. The team members currently work for six hours per day in their primary function, while the other two hours are used for administrative functions, such as accounting, filing paperwork, training, and attending meetings.

This paper focuses on the Outflow Safety Valve Cell Team which assembles three types of valves: a safety valve, an outflow valve, and a pressure regulating valve. The objective is to analyze the system and to optimize the utilization of the two team members who are involved in the assembly process, allowing them to accomplish other functions within the facility. The assembly of the valves can be classified as a small series production, due to the level of demand. Therefore, the focus is not on the throughput of the system. Rather, it is on the improvement of the use of work teams in the manufacturing environment.

A schematic of the system is shown in Figure 2. The entities of the system are the valves. They enter the system after an order has been placed, the necessary parts have arrived, and the production has been scheduled. The valves must wait on a rack for a team member to become available. Then, they move from bench to bench during the assembly process. There are five benches and a testing chamber used during the process. The same team member works on the valve from start to finish. If the valve does not pass testing, rework must be done before it is tested again. Finally, the valve leaves the cell to be shipped to the customer.

Data was collected on the system to specify input parameters and probability distributions. In addition, data was collected on the performance of the system to aid in validating the model. The team maintained detailed and up-to-date information about the operation of their work cell. By working with employees of the company familiar with the overall system, it was determined that the recorded values were representative of the way the cell was currently operating.

The daily starts and exits for the cell were obtained for six months, along with the work-in-process. Histograms were used to visually ascertain the apparent theoretical distribution of the data. The Kolmogorov-Smirnov (K-S) test was used to determine whether the actual distribution was significantly different from the apparent theoretical distribution that was assumed (Friedman and Friedman 1985).

The number of daily starts for the valves was compared to an exponential distribution. For a six hour work day, a new valve enters the system with the time between creations being exponential with a mean of 324 minutes. Of the valves that are ordered, approximately 40% are safety valves, 25% are outflow valves, and 35% are pressure relief valves. The safety valve had the shortest cycle time, and the pressure relief valve

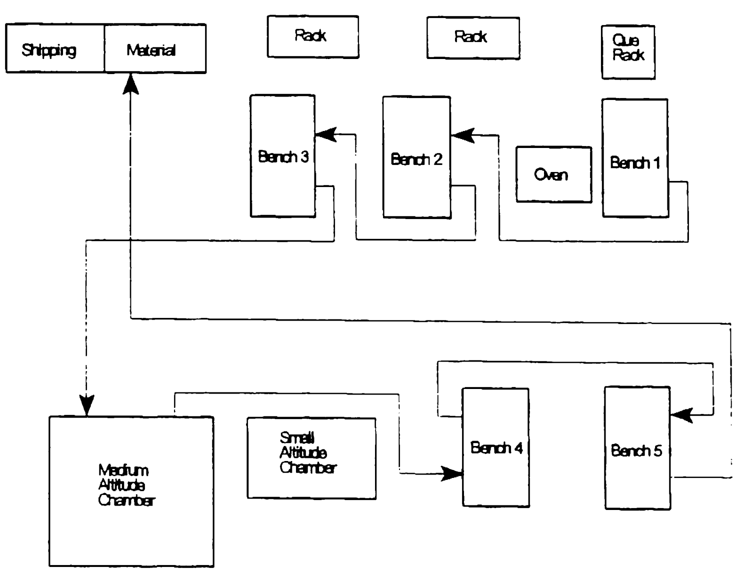

Figure 1: Product Flow for the Work Cell

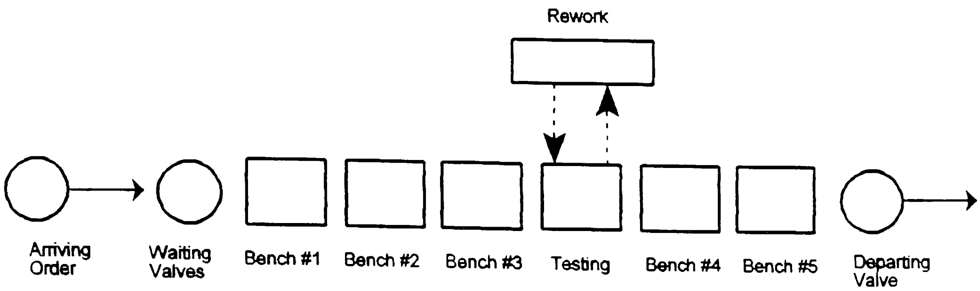

Figure 2: Schematic Diagram of Assembly and Testing Stations

measured the longest cycle time. It was necessary to determine the percentage of valves that required additional work because they did not pass the testing stage. The first time test yields demonstrated that approximately 92.5% of the valves passed testing the first time. When rework was required, the time was triangularly distributed with a minimum of 30, a mode of 50, and a maximum of 120 minutes.

3 ANALYSIS STRATEGY

A network model for the system was drawn as preparation for computer processing in SLAM II, Simulation Language for Alternative Modeling (Pritsker 1995). After entities are created, they are routed through probabilistic branching to specify the type of valve and the duration of the assembly operations. They wait for one of two team members to become available. Resources are used to model the team members, with the entities waiting in a file. The assembly benches are represented by activities in series. Statistics are collected on the cycle time for each of the valve types, and the entities are terminated. Statistics are also collected during the simulation on a time-persistent variable, which represents the number of entities in the system.

The main benefit of the network diagram is the ease with which it can be directly translated to SLAM code. Through the use of symbols, it allows the modeler to visualize the system and the flow of the entities. In addition, it provides a detailed picture of the organization of the model, which includes branching, the assignment of attributes to specific entities, and the collection of variables used for analysis.

It was necessary to establish that the computer program was executing as intended through model verification. A trace was performed to aid in the verification. This provides further detail about a specific time in the simulation. Additionally, a manual process of reviewing data inputs and outputs was done, ensuring that no significant discrepancies existed between expected and observed performance.

The process of establishing that a desired accuracy existed between the simulation model and the real system involved a comparison of the model output with the data that was obtained for the assembly system. Validation shows that the system can be represented by the model that was developed. The cycle times for the valves, the number of valves that were assembled in a given time period, and the average number of valves that were in the cell showed that the model represented the process in the work cell at Hamilton Standard. The organization of the model is directly comparable with the system's structure, and the model only has enough complexity to portray the important characteristics of the real system.

The process of establishing the experimental conditions for using the model consisted of developing an efficient experimental design to explain the relationship between the simulation response and the controllable variables and to make each simulation so that the most information could be obtained from the data. The utilization of the resources was affected by the work hours of the team members and the time between arrivals of the valves, among many other factors.

The initial conditions were established by using a pilot run to estimate a state which was representative of the long-term behavior of the system. Several runs were needed in order to accurately assess the system, due to normal variation. The use of a few long runs as opposed to many short runs generally produces a better estimate of the steady state mean, minimizing bias. Therefore, the simulation was run for six months with six hour work days.

4 APPLICATION OF THE MODEL

The simulation model was executed with the determined conditions to obtain output values for the system. The average cycle times for the three valves were the following: 257 minutes for the safety valve, 475 for the outflow valve, and 612 minutes for the pressure relief valve. Additional measures of performance included the total number of observations, the number of entities in the system, the time spent waiting for a resource, and the utilization of the resources. The average values from the results of the simulation runs are summarized in Table 1 for the original system.

An average of 142 valves were assembled in six months with a waiting time of 269 minutes. An average of 2.3 valves were in the work cell, either located at a bench or waiting for a resource. The utilization was approximately 72% for each team member. A value above 85% is usually considered high when variability is involved in the system.

Table 1: "As Is" Performance Measures

	Average Value
Throughput (parts / six months)	142
Work-In-Process (parts)	2.3
Waiting Time (minutes)	269
Utilization (% for team members)	143

The model was used to predict performance of the system. Design changes were made to the model, within realistic constraints, in order to attempt to improve the utilization of the team members. The first change was to establish a priority ranking in the file, rather than relying on the default, First-In First-Out (FIFO) ranking. A Low-Value-First (LVF) ranking was used on the attribute representing the type of valve. This ensured that the safety valve, the valve with the lowest cycle time, was placed first in the file, followed by the outflow valve and then the pressure relief valve.

The next change referred to the testing procedure used at Hamilton Standard. They were considering the use of fully automated test equipment, run entirely by computer. The duration of the activity for testing was adjusted to eliminate the variance involved.

The final design change involved the reallocation of resources. Rather than having each team member follow every step of the assembly process, they were divided. The objective was to maintain relatively equal utilization for the two employees, while separating their job functions. The first choice was to have one team member assemble only at the first three benches, and the second team member to test and finish the assembly. However, this was not effective because the job duties were unequal and the system backed up waiting for the first team member.

The model was adjusted so that the first team member was dedicated to the first two benches. The second team member was responsible for the remaining assembly and testing functions. This system was successful in providing an equal amount of work for the two employees. It has the advantage over the original distributed system of allowing the associates to concentrate on only a part of the assembly process, so that their experience level may improve at a faster rate.

Optimization can be accomplished with different methods. The most obvious method is enumeration, which consists of running every possible combination of the changes to the system. There are M^N combinations, where N is the number of modifications and M is the number of alternatives considered within each modification. In this case, there are eight combinations. The results for the utilization are shown in Figure 3 for each of the simulations. The utilization values are included with 95% confidence intervals representing the high and low values.

A more efficient method is shown in Figure 4, Figure 5, and Figure 6, which uses pattern search optimization. For three design changes, this method can be illustrated graphically by a cube. The front face represents the system with team members performing all of the assembly functions, while the back face represents the system with team members dedicated to specific functions.

The original system is represented by the box for FIFO priority, manual testing, and distributed functions. Starting with the original system, the adjacent boxes are simulated and compared to the original system. The best alternative is selected, and then the boxes adjacent to this new system are simulated. This is continued until the optimum is reached. The benefit is that there is only a need to run the model for alternatives that are next to each successive optimum.

Although this method only eliminated the need for one run in locating the optimum in this case; it would be more of an advantage for models with extensive design changes. Additionally, it allows management to be involved in each step. Management can direct the search and provide knowledge of other constraints that may affect the process. They can streamline the process and direct it to the areas that are most relevant. In this way, the pattern search optimization method takes advantage of past knowledge and experience.

5 CONCLUSIONS

A one-tailed hypothesis test was used to determine if the modifications made statistically significant improvements to the utilization. The three modifications of priority ranking in the file, priority ranking with automated testing, and priority ranking with automated testing and dedicated functions showed statistically significant improvements in lowering the utilization of the team members. The best value for the utilization

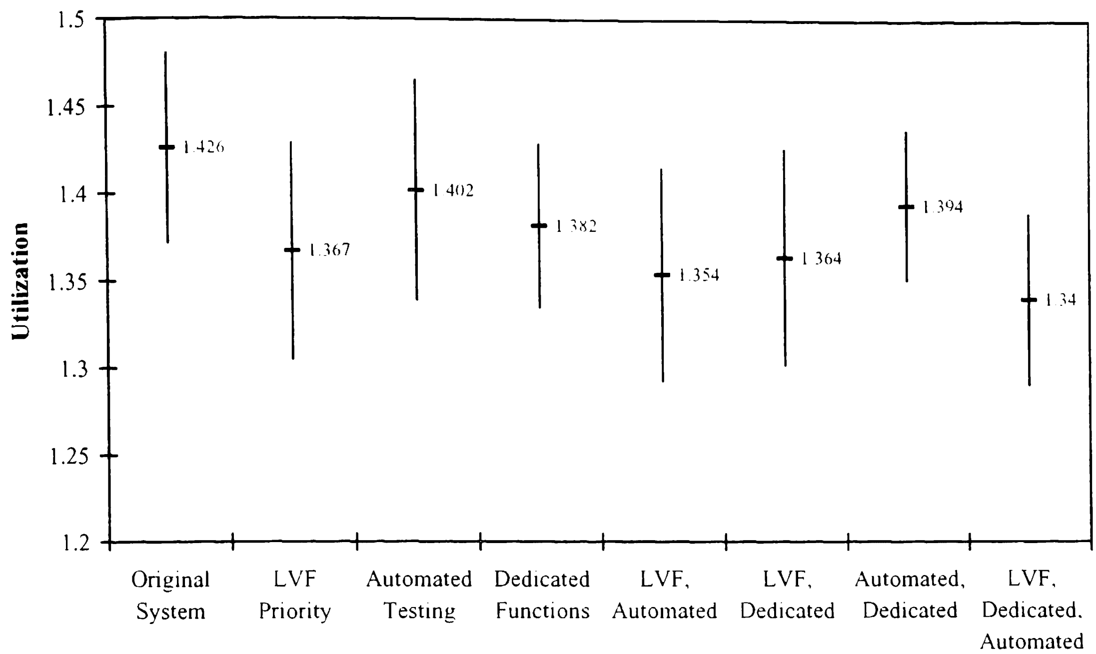

Figure 3: Effect of Design Changes on Utilization

	Manual	Automated	Manual	Automated
FIFO	**1.426**	1.402	1.382	
LVF	1.367			
	Distributed		Dedicated	

Figure 4: Simulated Alternatives - Step 1

	Manual	Automated	Manual	Automated
FIFO	1.426			
LVF	**1.367**	1.354	1.364	
	Distributed		Dedicated	

Figure 5: Simulated Alternatives - Step 2

	Manual	Automated	Manual	Automated
FIFO		1.402		
LVF	1.367	**1.354**		1.340
	Distributed		Dedicated	

Figure 6: Simulated Alternatives - Step 3

occurred when all three modifications were made to the process.

Simulation was an effective tool for this analysis in anticipating changes in the work cell. It gave an evaluation of the system in terms of a performance measure, and allowed for easy modification and optimization of the system. The results for this process were as expected, and the pattern search optimization effectively demonstrated the significance of the design changes on the manufacturing cell.

Hamilton Standard is considering the establishment of additional facilities with work teams. The results of simulation are relevant to the process of learning how to effectively manage teams in a manufacturing environment.

REFERENCES

Baron, J. J. 1991. Tips on Tackling GT-Based Cells. *Manufacturing Engineering* 106:46-49.

Friedman, L. W. and Friedman, H. H. 1985. The Probability Distribution as a Performance Criterion When Comparing Alternative Systems. *Simulation*, 262-264.

Mollaghasemi, M. and Evans, G. W. 1994. Multicriteria Design of Manufacturing Systems Through Simulation Optimization. *IEEE Transactions on Systems, Man, and Cybernetics* 24:1407-1411.

Pritsker, A. 1995. *Introduction to Simulation and SLAMII* John Wiley & Sons, New York.

Rahimifard, S. and Newman, S. T. 1995. The Role of Simulation in Operational Planning and Control of Flexible Machining Cells. In *Proceedings of the 1995 Winter Simulation Conference*, ed. C. Alexopoulos, K. Kang, W. R. Lilegdon, and D. Goldsman, 793-798.

AUTHOR BIOGRAPHIES

STACY M. SAMMONS is a graduate student in the Department of Industrial and Management Systems Engineering at Arizona State University. Her primary focus is in management of technology and information systems. In addition, she is attending the American Graduate School of International Management, and she received a B.S. degree in aerospace engineering from the University of Arizona in 1995. She is a licensed Engineer-In-Training in the state of Arizona.

JEFFERY K. COCHRAN is an associate professor of Industrial and Management Systems Engineering at Arizona State University, where he is also a director of the Systems Simulations Laboratory. Dr. Cochran was educated at Purdue University (BSE 73, MSNE 76, MSIE 82, PhD 84). His industrial experience includes positions at Battelle Northwest Laboratory, Los Alamos National Laboratory, and NASA's Laboratory for Applications of Remote Sensing. Professor Cochran has directed research projects for the National Science Foundation's I/UCRC for Manufacturing and Automation, the National Institute of Standards and Technology, and the Institute for Manufacturing and Automation Research. His primary research interests are simulation modeling and analysis, computer integrated manufacturing, operations research, and artificial intelligence. Dr. Cochran is the author of over fifty scholarly publications, and is a Professional Engineer.