Proceedings of the 1998 Winter Simulation Conference
D.J. Medeiros, E.F. Watson, J.S. Carson and M.S. Manivannan, eds.

THE USE OF SIMULATION IN FACILITY LAYOUT DESIGN:
A PRACTICAL CONSULTING EXPERIENCE

Emmanuel S. Eneyo

Department of Mechanical and
Industrial Engineering
Southern Illinois University at Edwardsville
Edwardsville, Illinois 62026-1805, USA

Gertrude P. Pannirselvam

Department of Management
Southern Illinois University at Edwardsville
Edwardsville, Illinois 62026-1100, USA

ABSTRACT

This paper presents a practical undertaking to solve an industry-specific problem of facility expansion through relocation of an existing production facility to a proposed new facility. In order to remain competitive, a mid-size company located in the Midwest region of the United States required a thorough analysis of its manufacturing operations in an attempt to improve the overall productivity of its manufacturing process. A comprehensive simulation study was undertaken to determine the inherent constraints and the bottleneck operations in the manufacturing process. The relevant performance measures from the simulation outputs along with such factors as space requirements for each equipment and the expected production goal of the new facility were analyzed to present facility design alternatives for the proposed new facility. The outcome of the simulation study was well received by management and the recommendations have been implemented.

1 INTRODUCTION

Model building and analysis vis-a-vis simulation is an iterative process. The modeler often cycles through it more than once, depending on the complexity of the modeling purposes. The modeling purposes typical of a production system are performance analysis and operational control. While performance analysis is intended to understand the behavior of the system under study, operational control refers to achieving some specific or desired output from the system on the basis of the knowledge derived from performance analysis.

A commonly recommended approach to simulation modeling is to start simple and then expand. Thompson (1991) discusses the role of computer simulation in the planning, design and operational phases of any real-life project. For example, in the planning phase, computer simulation can provide an operational assessment of the existing facility through the development of an "as-is" model. By experimenting with the as-is model, the performance objectives can be examined to see if achieving those objectives is possible through modifications to the existing facility. Furthermore, the experimentation could lead to models of "conceptual scenarios" for possible new systems. Other authors, Mehta (1990) and Barbee (1996) specifically outline different steps that small-to-medium-sized companies can take in facility planning projects. The reviewed steps are geared towards streamlining the layout process.

As a queuing system, the production process under study can be characterized by some patterns of jobs arriving to the production system, following a prescribed sequence of routing to machines for service, and then departing from the system. This is a very simple way of looking at the problem initially. However, Carson (1986) and Gibson and Welgama (1993) highlight a number of issues that simulation modelers (analysts) need to address. Because of the considerable amount of time spent in tackling a real-life problem using simulation, there is an expressed interest in the literature for authors to report the knowledge gained and techniques developed for solving real-life problems. The growing need to report such simulation efforts, according to Gibson and Welgama (1993), is to prevent simulation analysts from "inventing and reinventing the wheels" in solving similar problems. This paper, therefore, describes a consulting experience where the authors used results from a process simulation to design the equipment and facility layout for a plant expansion.

2 PROBLEM DOMAIN

As consultants to the Center for Advancement of Management and Productivity at our institution, we had the opportunity to provide consulting services to several manufacturing companies including XYZ Inc. XYZ Inc. is a mid-size company located in the Midwest region of the United States. It manufactures positioning and therapeutic seating cushions for wheelchairs and mattresses for beds. Its primary customers are hospitals and people with disabilities. The cushions work on the principle of dry floatation to adjust the pressure applied on a person using the cushions.

XYZ Inc. currently has two plants (production and assembly plants) located about 30 miles apart. The production facility produces the components that are supplied to the assembly plant. Manufacturing operations at the production facility were housed on three floors due to lack of adequate space on each floor. The production process is run on three staggered shifts including 30 minutes of lunch break per shift. The components that are manufactured are conformals (cushions), valve hoses, and backs. Shipments are made from the production facility to the assembly plant three times a week. Sales have been growing rapidly for XYZ Inc. and it is currently in second place in market share. In order to remain competitive, XYZ Inc. required analysis of its manufacturing operations to improve the production process. The distance between the two plants contributed to some problems regarding quality and scheduling. XYZ Inc. decided to move the production facility closer to its assembly operations. The goal was to consolidate all its manufacturing operations in one facility with a plant-within-plant concept.

The objective of the analysis of the XYZ Inc.'s manufacturing facility was to design the layout for the operations in the proposed new facility to accommodate the production and assembly activities subject to such constraints as the future projected capacity requirements and the available floor space. The following information were required to design the facility:

(a) Capacity required for the projected future sales,
(b) Bottleneck operations of the process used to produce the primary components,
(c) Space required for each piece of equipment, and
(d) Space required to store work-in-process between operations.

While we were cognizant of the plant-within-plant concept, both parties recognized that our primary responsibility, at this stage, is on the segment of the proposed new facility allotted for the production operations.

3 METHODOLOGY

The consulting opportunity was initiated with a written proposal on the role we can play to assist the company, how we plan to approach the problem and a list of possible deliverables and time lines. As with most simulation studies, we clearly identify the following four phases: (1) data collection and analysis, (2) simulation modeling for the existing production system, (3) simulation analysis of capacity expansion options, and (4) layout developments of the proposed new facility, as the proper procedure for solving the facility design problem. We, however, noted that the second and third phases of our task significantly entails three segments namely: model building and validation, output analysis, and experimentation for capacity expansion scenarios for the proposed new facility. Figure 1 provides a schematic representation of the project steps.

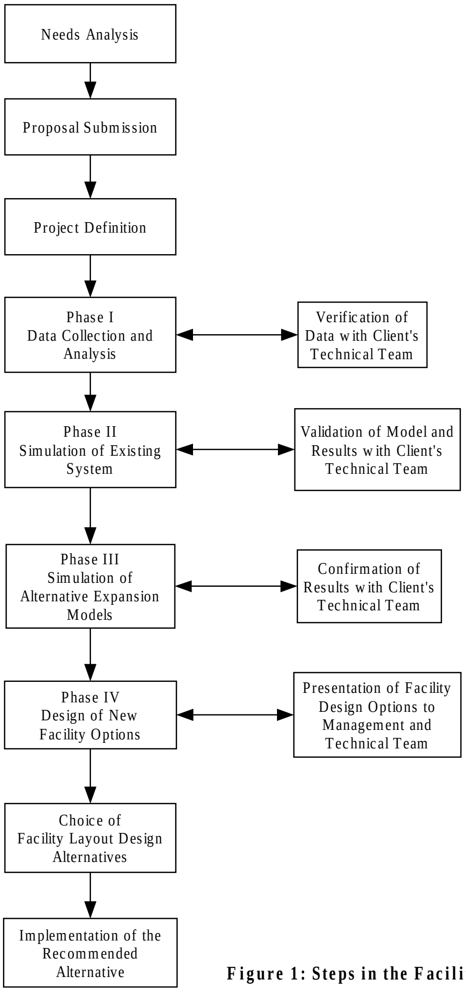

Figure 1: Steps in the Facility Design Project

Upon the acceptance of our proposal, a meeting was scheduled for us to meet with the management in charge of the facility project. In the meeting, we requested that we would like to work with a team of technical personnel who will maintain a line of communication with us regarding such matters as technical questions that we may have, assumptions, verification, and validation of the modeling effort. Our request was not only granted, but the client was very emphatic on keeping to deadlines as promised in the proposal. Furthermore, there was a general agreement that we will make a formal presentation of our findings (in written and oral forms) to management after each phase of our investigation.

3.1 Data Collection and Analysis

We visited the production plant a number of times and with the assistance of the client's technical team, we gathered data pertaining to the current production flow, process operations, processing times, resources, and plant layout. Our preliminary analysis of the collected data revealed some inconsistencies about processing times. We then requested several plant visits to perform a time study of the production operations. We carefully analyzed the historical data in conjunction with our time study estimates and summarized the results in the form of a flow chart, modeling assumptions, processing times, and production floor plans. An executive summary report of our findings was presented to management for information and review prior to a scheduled meeting for a formal presentation. Upon review and discussions at the meeting, necessary corrections were made to some of the modeling assumptions. This was particularly very important, because subsequent stages of the project, to a greater extent, relied on the given data set and assumptions.

3.2 Simulation Modeling of the Existing Production System

3.2.1 Model Building and Validation

The objectives of phase 2 of the production project were (1) develop a simulation model for the current process, and (2) analyze the results of the simulation to identify bottlenecks. Our goal was to model the process as close to reality as possible. This was exactly the case. The process times used in the simulation model were based on the data gathered in phase 1. For most of the effort-related tasks, an attempt was made to fit proper distributions to the data collected. A subset of the results are graphically illustrated as Figure 2. In modeling the production process, based on the verified assumptions, a number of areas require very complex decision control rules. For example, there are five possible batching alternatives for the heat drying ovens conformals only; conformals and backs; conformals and valve hoses; conformal, valve hoses and backs; backs and valve hoses). However, the simulation model was limited to the first three options that are most commonly used in the existing production process. The computer modeling was done using AWESIM simulation software.

Each cycle of the existing production process is started with twenty production carts. Nineteen of these production carts are of the conformal type, while the remaining one cart is reserved for either the valve hoses or the backs depending on the market demand. Thus, for each production cycle, the scheduling can either be [19, 0, 1] or [19, 1, 0] for conformals, valve hoses and backs respectively. Each conformal cart consists of two racks and the single cart for valve hoses or backs is also considered as a rack. At different stages of production process, the system entities are in terms of racks or the end-components (conformals, valve hoses, and backs) as opposed to carts. In course of the simulation experiment, we examined the effect of the different scheduling patterns of backs and valve hoses. We noted that the scheduling pattern of backs and valve hoses affects the throughput and system time. However, the output analysis discussed below is based on the pattern where backs and valve hoses are produced in alternate cycles.

3.2.2 Output Analysis - Part 1

In principle, we considered the existing production system to be non-terminating because it is operated on a 24-hour cycle of continuous operations. Given some other logical constraints peculiar to this production system, it became evident that the method of independent replications is more suitable for obtaining results for output analysis. The simulation was thus replicated for 20 weekly production cycles.

As noted in the introduction, this phase of the output analysis is all about understanding the behavior of the system by means of some specific performance measures such as throughput, system time, waiting time, queue length, and utilization. For an in-depth analysis, data on these performance measures were collected at various stages of the production process and summarized in tabular form to enable us infer potential bottleneck and constrained operations. A careful analysis of the data, taking into account, (1) length of queue before the operation, (2) average waiting time before the operation, and (3) utilization of the process, reveals that there were three bottleneck operations.

In presenting our findings to management, we noted that in making capacity changes to the three identified bottleneck operations, proper tradeoffs analysis should be considered for effective outcome. It was also suggested that the impact of the scheduling pattern of backs and valve hoses in the bottleneck analysis should be examined thoroughly in the final phase of the project. Management's favorable response to the presentation was evident in their forward expectation of the final phase of the project.

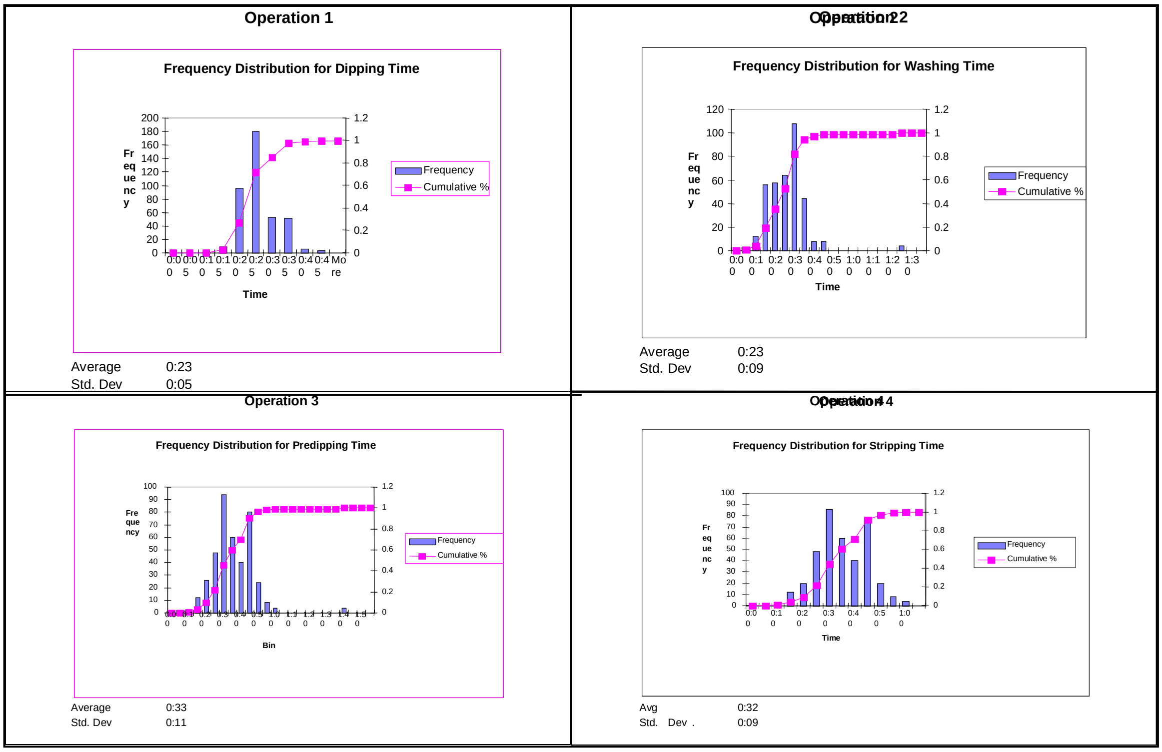

Figure 2: Distribution of Activity Times

3.3 Simulation Analysis of Capacity Expansion

3.3.1 Model Embellishment and Validation

Using the results from phases 1 and 2, and the suggested changes by the client's technical team, we conducted a simulation experiment to study alternative scenarios that will satisfy the expected production goal of the proposed new facility. Because of market demand, the focus of this phase was slightly shifted to the dominant component - conformals (vis-à-vis cushions). Also, there was some interest on the part of management to explore the option of shortening the 7-day workweek to a possible 5-day workweek. Our modeling effort at this stage was geared towards embellishing the already developed model to achieve some flexibility in experimenting with several scenarios.

3.3.2 Output Analysis - Part 2

This phase of the output analysis is all about operational control which aims at achieving some specific or desired output from the production system on the basis of the knowledge derived from performance analysis. In course of experimenting with conceptual scenarios of attaining the expected production goal of 170,000 conformals per year, it became evident that the throughput is sensitive to the number of production carts the system is started with. An in-depth analysis revealed that the minimum expected production goal of 170,000 conformals per year will not be realized with the existing 19 production carts. This result is true for both the 5-day and 7-day workweek schedules. Furthermore, we observed that there is no appreciable change in the throughput when the number of production carts exceeded 35. We also observed that there is no significant difference in the system times between the two principal scenarios and among their feasible alternatives.

Examination of the resource utilization, waiting lines, and wait times showed consistency in the values of the various parameters between the two competing schedules. There was no strong evidence for bottleneck operations when production is initiated with 25 or 30 production carts. However, when the production process was initiated with 35 carts, we observed one of the critical workstation emerged as the bottleneck operation. The utilization of the key operations ranges from 50% to 88% in the case of the 30 production carts.

Our presentation to management at the end of this phase addressed two parts. The first part explained the modeling effort, the analysis, and the recommendations. The principal recommendations are (1) for the 5-day workweek we recommended two feasible alternatives of going with either 30 or 35 production carts; and (2) for the 7-day workweek we recommended three feasible alternatives of going with 25 or 30 or 35 production carts. The second part of the presentation shed some light on the importance of the simulation results in achieving an effective layout design

While the alternative of initiating production with 30 carts appears to be the favorable candidate for the proposed facility, the choice between the two competing schedules would require an economic analysis for an objective cost-benefit tradeoff. On the other hand, the choice of 35 production carts would require an additional unit of a critical resource to enhance the performance of the proposed new facility. In conclusion, the reported throughput (conformals) for the prescribed configuration is up by about 11% compared to the result obtained in phase 2. The average system time decreases from 195 minutes to 170 minutes. This is about 13% improvement for the proposed facility. Similar trends were also observed in the utilization performance. The increased system capacity is equally a factor for the improved performance.

3.4 Facility Layout Design

Facility layout problems occur in both the design of new facilities and redesign of existing ones. In this case, we are faced with a manufacturing layout problem of a proposed new facility. The exercise involves determining the location of machines, workstations, and other facilities to achieve the following objectives:

(a) minimize material-handling costs,
(b) facilitate the traffic flow,
(c) provide a safe workplace for employees and thereby increase employee morale,
(d) minimize the risk of injury to personnel and damage to property, and where necessary
(e) provide for supervision and face-to-face communication.

With the above stated objectives in mind, the actual process of designing the layout to achieve the expected output of the proposed new facility is a function of (1) the size of the work area, (2) the sizes of the equipment, and (3) the work-in-process inventory at various workstations. While the size of the work area is a constant parameter, the other two factors are variable parameters that are driven by the input process of the production system. The size of the equipment has a direct correlation to the number of possible resources that can be accommodated. The same thing is true with work-in-process inventory having a direct relationship with queue length. The number of resources and the maximum queue length are products of the simulation model. Therefore, the facility layout design was fashioned along the recommended feasible alternatives discussed in Section 3.3.2. The outlined objectives become a useful guide for the layout designer in sketching out the corresponding floor plans for the feasible alternatives.

In a sense, we used the parameters of the feasible alternatives to develop appropriate layouts for the proposed new facility, given the prescribed space constraints. Our suggested layout design, based on the recommended 30 production carts, generates a throughput that exceeds the target production goal by 50%.

4 SUMMARY AND CONCLUSIONS

The primary problem academicians face when working on projects in the industry is difficulty in communication. We tend to use technical terms and jargons related to the topic and software used which may mean nothing to managers in industry. This problem in communication sometimes leads to managers not appreciating the results and a reluctance to accept the recommendations. The other issue that leads to failure (or at least the inability to meet the goals) is the limited amount of time and effort on the part of the client. Problems cannot be thoroughly analyzed and solutions may not be effective if the client managers and engineers are not closely involved with the project.

Communication and client involvement were ensured in this project through the formation of a technical team within XYZ Inc. at the beginning of the project. The purpose of this team was (1) to monitor the progress of the project, (2) to monitor the accuracy of the findings, and (3) to provide the authors with all the necessary data and information. The authors were in constant touch with the team throughout the tenure of the project. The team members' insight and help were very valuable in analyzing and confirming the data and validating the simulation models.

It became very clear in the beginning of the project that the support from the technical team depended on how clearly we explained out part of the work. As a result of this, it was essential for us to express all the findings and conclusions in a form that reflected the business they were in and the terminology that was familiar to them. For example, our primary concern in the project was our explanation for the choices made for future capacity changes. Although the team was familiar with the concept of bottlenecks, we had to make sure that we summarized and presented the results from the simulation software in a manner that was comprehendible to them. In identifying the bottlenecks the queue lengths and average waiting times at each process was used to explain how the waiting time at the bottlenecks affect the throughput for the whole production line.

Close contact with the technical team also meant that the client was constantly aware of the progress of the project. Deadlines were set early for each phase at the beginning of the project and these dates were constantly monitored. In the few instances when it was expected that the dates would be missed both parties were made cognizant of the problem early enough to adjust the work and due dates. On each instance the reason for the delay was clearly explained and understood.

The above described consulting project was a satisfying experience for the authors since their efforts were greatly appreciated by the client and the authors' recommendations have been implemented. Furthermore, XYZ, Inc. has requested the authors' involvement in the planning and designing activities to move the assembly operations to the new facility. The client was able to appreciate the results of the project because they were closely involved with the project and there was an open line of communication. They also realized that they were providing a valuable service to the academic community by providing us access to a wealth of examples that we could take back to our classes and share with our colleagues. While we wish we were able to discuss the details more specifically with the reader, the proprietary nature of the production process precludes us from doing so. We do appreciate XYZ, Inc. willingness to allow us to share some parts of our experience with our academic and consulting colleagues.

ACKNOWLEDGMENT

This work was supported in part by the Center for the Advancement of Management and Productivity (CAMP) at Southern Illinois University at Edwardsville under the direction of Mr. Jim Mager.

REFERENCES

Barbee, Gene, (1996), "The Best Laid Plans - Part 1," *Bobbin*, Vol. 37, No. 11, pp. 99-101.

Carson, John S., (1986), "Simulation Series, Part 2:Convincing Users of Modeler's Validity Is Challenging Aspect of Modeler's Job," *Industrial Engineering*, Vol. 18, No. 6, pp. 74-85.

Gibson, Peter and Welgama, Palitha S., (1993), "Simulation Methodology in Facilities Design: Knowledge From a Practical Application," *Industrial Engineering*, Vol. 25, No. 9, pp. 52-58.

Thompson, Michael, (1991), Simulation: From Start to Finish," *Automation*, Vol. 38, No. 11, pp. 26-28.

AUTHOR BIOGRAPHIES

EMMANUEL S. ENEYO is an Associate Professor of Industrial Engineering at Southern Illinois University at Edwardsville. He received his BSISE and MSISE from the University of Southern California and a Ph.D. degree in Industrial Engineering from Purdue University. He has four years of industrial work experience with Bechtel Power Corporation, Rockwell International, and Rohr Industries, Inc. prior to his entering into the doctoral program. He also has over six years of consulting experience. His current teaching and research interests are in the areas of engineering economics, methods design and work measurement, production planning and control, simulation modeling, neural networks, and knowledge-based expert systems in engineering applications. Dr. Eneyo is a senior member of IIE, SME, and CASA of SME, and a member of Alpha Pi Mu, Tau Beta Pi, INFORMS, and the American Society for Engineering Education (ASEE).

GERTRUDE P. PANNIRSELVAM is an Assistant Professor of Operations Management at Southern Illinois University at Edwardsville. She holds a B.Tech from Madras University, an MBA from the University of New Hampshire, and a Ph.D. in Business Administration from Arizona State University. Her current research interests include quality management, operations strategy, and scheduling. Dr. Pannirselvam is a member of the Decision Sciences Institute (DSI), Production and Operations Management Society (POMS), and the Institute for Operations Research and Management Science (INFORMS).