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 FOR CONSTRUCTION ELEMENTS MANUFACTURING

Katy Vern
Ali Gunal

Production Modeling Corporation
3 Parklane Boulevard, Suite 1006
Dearborn, MI 48126, U.S.A.

ABSTRACT

The manufacture of pre-cast concrete building elements consists of a few manufacturing steps. The process itself is simple, but the characteristics of the business are quite random. Simulation modeling is an effective tool for analyzing the difficulties of scheduling and making parts of many different specifications. Random elements include time to set-up, inspect, mix, pour cement, and form concrete. Furthermore, activities scheduled at different areas of the plant have a great impact on the facility's ability to meet delivery dates. A simulation model offers the capability to capture many of the random elements and facilitate the analyses of complicated what-if scenarios. In this paper, we describe, within confidentiality limits, a model that represents many of the interacting components of such a facility.

1 INTRODUCTION

Traditional construction techniques involve forming a building's structure at the site, using brick, wood, siding, or other materials. These techniques are manually intensive and time consuming. An alternative approach is to use pre-cast concrete building elements. These can be produced off-site at a manufacturing facility. They are then transported to the construction site for installation. These building elements offer time savings benefits over traditional structural elements because they arrive at the construction site ready for installation.

Typical building elements include pillars, columns, and wall panels. Traditionally, these elements were used mostly in commercial buildings. With the ability to create aesthetically pleasing colors and finishes, however, pre-cast concrete elements are being used in projects from home garages to schools to high-tech office buildings.

Manufacturing pre-cast concrete building elements is a relatively simple process in that there are few steps and fewer materials. The basic process is to pour cement into a form, or bed, and allow it to cure. The form is essentially a mold for the concrete. Changing the shape of the form alters the final shape of the concrete.

There are many random elements in the manufacture of construction elements. Differences in individual element size, color, and shape, constraints on resources, and randomness in production times contribute to scheduling difficulties.

Simulation is frequently applied to manufacturing facilities to improve production processes where the system has many random interacting components. The use of simulation in construction processes is not a new concept.

For example, Sawhney (1997) discusses how simulation can be used for studying construction schedules by using a petri-net modeling approach. A similar study was reported by Shi (1997) by using the activity cycle-based simulation approach. Investigation of earth moving operations, have been also investigated though the use of simulation (Hajjar and AbouRizk 1996, Ioannou and Martinez 1996). Vanegas and Opdenbosch (1994) provide a detailed methodology that incorporates visual simulation in the design process.

Given the complexity created by these interacting random elements, simulation is an appropriate tool for modeling the current and any proposed manufacturing processes. This paper focuses on the use of simulation to model the manufacture of pre-fabricated concrete building elements and to analyze complicated what-if scenarios.

Section 2 of this paper briefly describes the pre-cast building elements manufacturing process including the random elements introduced in the production process. Section 3 describes how simulation can be applied to analyze current and proposed manufacturing processes. Finally, Section 4 presents a case study of wall panel manufacturing.

2 PRE-CAST BUILDING ELEMENTS MANUFACTURING PROCESS

Manufacture of pre-fabricated concrete building elements is essentially performed in a job shop environment. That is, each element produced may be very different from all other elements. The manufacture of pre-fabricated concrete elements differs somewhat from the traditional job shop problem, however. In the traditional job shop, parts are processed by different machines. In the pre-cast job shop, however, parts are processed by the same machine (form). In essence, the "machine" has a significant set-up time required to create multiple unique parts. The parts are then batch processed through a "curing operation."

The basic steps to pre-fabricated construction element manufacturing include the following:

1. Form construction. This may include placing wooden frames for architectural openings inside the form. It may also include installing wooden bulkheads to create elements of different lengths.
2. Set-up.
3. Pull and stress supporting cables (rebar).
4. Pour cement.
5. Lay down insulation (optional).
6. Pull and stress supporting cables for second layer of concrete (if insulation installed).
7. Pour second layer of concrete (if insulation installed).
8. Cure.
9. Strip (remove element from form). This may include sawing through the concrete to create elements of varying lengths, if wooden bulkheads were not used prior to pouring concrete.
10. Apply finish.

Each of these steps introduces some variability into the manufacturing process. Perhaps most significant source of variation, however, is customer choice. Each customer may request pre-cast elements of different sizes with different patterns of openings, different finishes, and different colors. Further, the element's intended use impacts the depth of concrete poured as well as the number of supporting cables used. A pillar for a parking structure may need to be significantly stronger than that for a home garage wall.

This variability creates difficulties in scheduling. The time to set-up an element with many architectural features takes significantly longer than a plain unit. This must be carefully managed to maintain production. A form requiring many complex pieces and few simple ones may take so long to set-up that the concrete pour is delayed. This in turn delays the time when the building elements can be removed from the form, possibly delaying the next pour operation. Thus, each day an effort is made to balance complex pieces with simple ones so that the complex pieces are distributed over a number of production days.

In addition to the issue of the complexity of a piece, the length of the forms drives decisions. Because it takes 10 – 16 hours to cure, regardless of the lineal feet of concrete poured, efforts are made to "fill-out" a bed each day. This may result in pieces being made before they are ready for installation at the construction site. These pieces are then stored in a construction yard where they are subject to damage. In addition, inefficiencies are introduced in the form of double handling of pieces.

Figure 1 displays the general flow of material in this type of manufacturing operation.

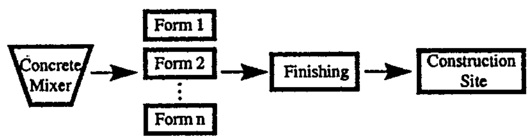

Figure 1. General flow of material pre-cast construction elements manufacturing.

3 BENEFITS OF SIMULATION

Construction elements manufacturing requires skilled manual labor to meet unique customer requirements for individual elements. Now, advances in automation, engineering processes, and production scheduling techniques have created opportunities to re-examine the process. Advanced solutions may improve the productivity; they may also require substantial capital investment. Simulation provides a tool to measure the benefits of implementing a productivity solution before investing in it. It also enables analysis of multiple types of automation and the accompanying changes in facility layout. Furthermore, simulation sometimes is the only appropriate tool for modeling complex systems with many interacting random elements. Often, spreadsheets can be used to analyze deterministic elements in a process. For example, calculating the gain in productivity from reducing cure time by one hour is relatively simple. When systems become too large or complex, however, they are difficult to analyze in this manner.

By using simulation, designers can see the impact of a change on an entire system, rather than on just one element. In complex systems with many interrelated elements, a change in one process may have unexpected consequences on another process. For example, reducing concrete cure time may result in longer waiting times for constrained resources such as cranes or yard trucks. By simulating complex processes, systems designers can see the impact of changes made before implementing them. This in turn can save money on costly automation.

Simulation can benefit manufacture of pre-cast concrete building elements by allowing the analysis of the following variables:

1. Most efficient form length

2. Alternative scheduling strategies. For example, the strategy of manufacturing pieces in the site construction order versus maximizing the use of forms.

3. Alternative crew scheduling

4. Impact on productivity by automating all or part of the production process

5. Labor distribution, layout, and material flow for an alternative process

6. Resource utilization (labor, yard trucks, cranes, etc.)

4 CASE STUDY

A construction elements manufacturer has a plant with several shops for different types of products. While some of the activities (e.g., preparing the cement, providing wood and metal fixtures) are performed by central shops, each production shop makes only certain types of products. This study started with the modeling of just one shop where some of the high-volume, high-cost building elements are manufactured.

One immediate use of this model is in investigating alternative production processes involving different levels of automation. Another issue that may be aided by simulation is the use of alternative scheduling strategies. Ideally, pieces would be manufactured just-in-time for production sites. This would reduce inventory holding costs and minimize the potential for pieces to be damaged while sitting in the storage yard or being double-handled. However, this strategy could result in few forms being filled out each day. Consequently, fewer pieces would be made and delivery dates would ultimately be missed.

A final issue is that of crew scheduling; planning the start and stop times for each crew at each operation for each one of the forms is a task that can benefit from analyzing the long-term behavior of the processes. This task is complicated by the fact that there is a high level of absenteeism among the shop workers. When one or more of the crew members are absent, the operations still continue but at a slower pace, sometimes resulting in canceled pouring operations. By working set-up and stripping crews on all shifts, there would never be a missed pour. More skilled labor would be required, however, to be able to accomplish both major tasks at all times.

Consequently, the objectives of the study were to investigate the following:

1. Alternative production methods with varying degrees of automation.

2. Alternative scheduling strategies. For example, the strategy of manufacturing pieces in the site construction order versus maximizing the use of forms.

3. Alternative crew scheduling (e.g., working stripping crews on both shifts).

Another objective of the study was to create a model with sufficient animation to facilitate a visual communication tool in analyzing the system.

4.1 System Description

The manufacturing activity actually begins when the production drawings are created. Each afternoon, production personnel examine available production drawings and develop a pouring strategy for the next day. The strategy is influenced by many factors. Amongst others, these include the required site delivery date, the need to fill out a form, and production piece complexity.

Two goals drive the push to fill out a form. One is the desire to avoid wasting materials. Cables (rebar) must be pulled across the form, regardless of the lineal feet of wall panels produced. Thus, if cement is poured in only half of a form, the other half of cables are wasted, along with the time spent to pull and stress them. A second push comes from the demand for the products. To meet demand, the facility, as currently designed, must operate at near capacity. Thus, unfilled forms may result in missed delivery dates. In addition to attempting to completely fill a form, production personnel must balance piece complexity. The general layout of the manufacturing facility is displayed in Figure 2.

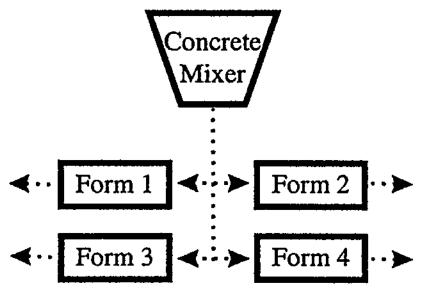

Figure 2. General layout of the manufacturing facility (not to scale).

Four basic types products exist. Certain types of products are always routed to one of the forms. Each day, Forms 1 and 2 are set-up, poured, and stripped. Space constraints dictate that Forms 3 and 4 are set-up, poured, and stripped on alternating days. The table below outlines the differences between the forms.

Table 1. Form differences

Forms 1 and 2	**Forms 3 and 4**
Types 1 and 2	Types 3 and 4
10 – 12 hour cure time	14 – 16 hour cure time
Elements are separated wooden bulkheads	Elements are created by sawing concrete of different lengths

Production crews start at staggered times in the morning. During the first two hours, all personnel devote themselves to setting up Form 1. After that, some personnel leave Form 1 to begin setting up Form 2. They are joined by crew members who start at a later time. Production crews work until the concrete is poured. Thus, their workday varies in length. Because the concrete takes so long to cure, stripping crews do not start work until late night.

4.2 The Model

A model of the manufacturing system was developed using the ProModel simulation software. There were several challenges in conceptualizing the model. First of all, this facility shares the support of certain central processes with other facilities on the same site. Consequently, any delays in those supporting activities create a chain-reacting series of delays within this facility. Those external delays include time spent waiting for materials, quality control inspectors, and resources such as yard trucks. Therefore, there was a need for adequately and realistically representing the delays due those external factors. Following a brainstorming session, the project team decided to represent these delays as random durations in the current model. This approach, however, required some data collection efforts for characterizing the distribution of such delays.

The delays due to the operations within the facility included crane downtime, crew absenteeism, and concrete cure time. The team developed a simple form to collect data on these delays. In addition, production data was collected over a period of time. In this way, variation in production time included the impact of crew absenteeism.

Another modeling challenge was capturing the variety of the elements that can be poured to each form. This problem was overcome by analyzing the data from the central data processing system. There were sufficient data to characterize the distributions of the number of elements made in each from in each day for the past several years. The data also supported the analyses of the distributions of the total length and the amount of concrete poured to each form. By using such data, the model also captured the essence of the scheduling decisions made prior to setting up each form.

The following were measures of system performance:

- Number of wall panels completed on a daily basis for each form and total daily over all forms
- The total length of panels completed on a daily basis for each form and total daily over all forms
- The percent of time spent on internal delays
- The percent of time spent on external delays

Data from the previous year's production fed the input parameters for the baseline model data. This data was used to develop empirical distributions. The inputs to the simulation model were contained in an Excel Spreadsheet and read by the model. These included the following:

- The empirical distributions of the number of each type of product made in each form daily
- The empirical distribution of the total length of the elements made in each form daily
- The distribution of cure times for each form

5 RESULTS AND CONCLUSIONS

The model was used making analyses on several different scenarios of production methods. In one case, the impact of improving concrete deliveries to the forms was studied. In one scenario the system was modeled as it existed, in second scenario, assumptions were made on the delivery performance of an improved system.

Simulations over a year of production showed that if the delivery performance were improved as suggested in second scenario, the plant would be able make roughly 400 more wall panels on an annual basis. This difference corresponded to an improvement over 9% in annual throughput. This is achieved by restructuring the facilities and production process to reduce external delays attributed to time waiting on materials. This translates into a savings of approximately $119,000 per year in terms of production costs.

Although a construction elements plant utilizes some processes that could be viewed as different from traditional manufacturing processes, the nature of the production operation is similar. The underlying concepts of planning products and making them are the same. Such similarities make it possible to apply the same principles of designing and running a manufacturing facility. Simulation proves to be a very flexible and powerful tool for analyzing the operations of such systems, as the present study finds.

REFERENCES

Anil Sawhney (1997), Petri Net Based Simulation of Construction Schedules, *Proceedings of the 1997 Winter Simulation Conference*, Ed..S. Andodottir, K. J. Healy, D. H. Withers, B. L. Nelson, pp. 1111-1118.

Jingsheng Shi (1997), A Conceptual Activity Cycle-Based Simulation Modeling Method, *Proceedings of the 1997 Winter Simulation Conference*, Ed. S. Andodottir, K. J. Healy, D. H. Withers, B. L. Nelson, pp. 1127-1133.

Dany Hajjar and Simaan AbouRizk (1996) Building a Special Purposes Simulation Tool for Earth Moving Operations, *Proceedings of the 1996 Winter Simulation Conference*, Ed. J. M. Charles, D. J. Morrice, D. T. Brunner, J. J. Swain, pp. 1313-1320.

Photios G. Ioannou and Julio C. Martinez (1996), Simulation of Complex Construction Processes, *Proceedings of the 1996 Winter Simulation Conference*, Ed. J. M. Charles, D. J. Morrice, D. T. Brunner, J. J. Swain, pp. 1321-1328.

Jorge A. Vanegas and Augusto Opdenbosch (1994) Using Simulation and Visualization technologies to Strengthen the Design/Construction Interface, *Proceedings of the 1994 Winter Simulation Conference*, Ed. J. D. Tew, S. Manivannan, D. A. Sadowski, A. F. Seila, pp. 1137-1144.

AUTHOR BIOGRAPHIES

KATY VERN is a Senior Applications Engineer at Production Modeling Corporation. She received her B. S. and M.S. Industrial and Operations Engineering from The University of Michigan. AT PMC, she develops software applications, including simulation models, databases, and Visual Basic applications. Prior to joining PMC, she worked as an industrial engineer in an automotive manufacturing plant. She also performed ergonomics consulting in the railroad industry. She is a member of IIE.

ALI GUNAL is a Senior Consultant at Production Modeling Corporation (PMC), an Industrial Engineering services firm servicing the manufacturing industry nationally and internationally. He received his Ph. D. degree in Industrial Engineering from Texas Tech University in 1991. Prior to joining to PMC, he worked as an Operations Research Specialist for State of Washington. At PMC, he is involved in consulting services for the analysis, design, and operation of manufacturing systems using simulation and other Industrial Engineering tools. He is familiar with several simulation systems including AutoMod, Arena, Quest, Robcad, and Igrip. He is a member of APICS and SME.