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SIMULATION OF MANUFACTURING SYSTEMS

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ABSTRACT

This paper discusses how simulation is used to design new manufacturing systems and to improve the performance of existing ones. Topics to be discussed include: manufacturing issues addressed by simulation, simulation software for manufacturing applications, techniques for building valid and credible models, and statistical considerations. A comprehensive example will be given in the conference presentation.

1 INTRODUCTION

One of the largest application areas for simulation modeling is that of manufacturing systems, with the first uses dating back to at least the early 1960's. In this paper we present an overview of the use of simulation in the design and analysis of manufacturing systems. Detailed discussions of simulation, in general, may be found in Banks, Carson, and Nelson (1996) and Law and Kelton (1999). A practical discussion of the steps in a sound simulation study is given in Law and McComas (1990). This paper is a synopsis of a three-day short course with the same title as this paper, which the first author has given more than fifty times since 1985.

2 MANUFACTURING ISSUES ADDRESSED BY SIMULATION

The following are some of the specific issues that simulation is used to address in manufacturing:

<u>The need for and the quantity of equipment and personnel</u>

- Number, type, and layout of machines for a particular objective
- Requirements for transporters, conveyors, and other support equipment (e.g., pallets and fixtures)
- Location and size of inventory buffers
- Evaluation of a change in product volume or mix
- Evaluation of the effect of a new piece of equipment on an existing manufacturing system
- Evaluation of capital investments
- Labor-requirements planning
- Number of shifts

<u>Performance evaluation</u>

- Throughput analysis
- Time-in-system analysis
- Bottleneck analysis

<u>Evaluation of operational procedures</u>

- Production scheduling
- Inventory policies
- Control strategies [e.g., for an automated guided vehicle system (AGVS)]
- Reliability analysis (e.g., effect of preventive maintenance)
- Quality-control policies

The following are some of performance measures commonly estimated by simulation:

- Throughput
- Time in system for parts
- Times parts spend in queues
- Queue sizes
- Timeliness of deliveries
- Utilization of equipment or personnel

3 SIMULATION SOFTWARE FOR MANUFACTURING APPLICATIONS

Historically, simulation packages were classified to be of two major types, namely, simulation languages and applications-oriented simulators. Simulation languages were general in nature and model development was done by writing code. Simulation languages provided, in general, a great deal of modeling flexibility, but were often difficult to use. On the other hand, applications-oriented simulators were oriented specifically toward a particular class of applications and a model was developed by using graphics, dialog boxes, and pull-down menus. Simulators were sometimes easier to learn and use, but might not have been flexible enough for some problems.

However, in recent years vendors of simulation languages have attempted to make their software easier to use by employing a graphical model-building approach. A typical scenario might be to have a palette of model-building icons located on one side of the computer screen. The icons are selected from the palette with a mouse and placed on the work area. The icons are then connected to indicate the flow of entities through the system of interest. Finally, one double-clicks on an icon to bring up a dialog box where detail is added. On the other hand, vendors of simulators have attempted to make their software more flexible by allowing programming in certain model locations using an internal pseudo-language. In at least one simulator, it is now possible to modify existing modeling constructs and to create new ones. Thus, the distinction between simulation languages and simulators has really become blurred.

Based on the above discussion, we will now say that there are two types of simulation packages. A *general-purpose simulation package* can be used for any application, but might have special features for certain ones (e.g., for manufacturing or process reengineering). Examples of general-purpose simulation packages are Arena, AweSim, Extend, GPSS/H, Micro Saint, MODSIM III, SIMPLE++, SIMUL8, SLX, and Taylor Enterprise Dynamics Developer. On the other hand, an *applications-oriented simulation package* is designed to be used for a certain class of applications such as manufacturing, health care, or call centers. Examples of manufacturing-oriented simulators are Arena Packaging Edition, AutoMod, AutoSched, Extend + MFG, ProModel, QUEST, Taylor Enterprise Dynamics Logistics Suite, and WITNESS.

A much more detailed discussion of the topics in this section may be found in Chapter 3 of Law and Kelton (1999).

4 DEVELOPING VALID AND CREDIBLE SIMULATION MODELS

A simulation model is a surrogate for actually experimenting with a manufacturing system, which is often infeasible or not cost-effective. Thus, it is important for a simulation analyst to determine whether the simulation model is an accurate representation of the system being studied, i.e., whether the model is *valid*. It is also important for the model to be *credible*; otherwise, the results may never be used in the decision-making process, even if the model is "valid."

The following are some important ideas/techniques for deciding the appropriate level of model detail (one of the most difficult issues when modeling a complex system), for validating a simulation model, and for developing a model with high credibility:

- State *definitively* the issues to be addressed and the performance measures for evaluating a system design at the beginning of the study.
- Collect information on the system layout and operating procedures based on conversations with "subject-matter experts" (SMEs).
- Delineate all information and data summaries in an "assumptions document," which becomes the major documentation for the model.
- Interact with the manager (or decision-maker) on a regular basis to make sure that the correct problem is being solved and to increase model credibility.
- Perform a structured walk-through (before any programming is performed) of the conceptual simulation model as embodied in the assumptions document before an audience of SMEs, managers, etc.
- Use sensitivity analyses [see Chapter 5 of Law and Kelton (1999)] to determine important model factors, which have to be modeled carefully.
- Simulate the existing manufacturing system (if there is one) and compare model performance measures (e.g., throughput and average time in system) to the comparable measures from the actual system.

5 STATISTICAL ISSUES IN SIMULATING MANUFACTURING SYSTEMS

Since random samples from input probability distributions "drive" a simulation model of a manufacturing system through time, basic simulation output data (e.g., times in system of parts) or an estimated performance measure computed from them (e.g., average time in system from the entire simulation run) are also random. Therefore, it is important to model system randomness correctly and also to design and analyze simulation experiments in a proper manner. These topics are briefly discussed in this section.

5.1 Modeling System Randomness

The following are some sources of randomness in simulated manufacturing systems:

- Arrivals of orders, parts, or raw materials
- Processing, assembly, or inspection times
- Machine times to failure
- Machine repair times
- Loading/unloading times
- Setup times

In general, each source of system randomness needs to be modeled by an *appropriate* probability distribution, not what is perceived to be the mean value. Note that sources of randomness encountered in practice are rarely normally distributed. A detailed discussion of simulation input modeling is given in Chapter 6 of Law and Kelton (1999).

5.2 Design and Analysis of Simulation Experiments

Because of the random nature of simulation input, a simulation run produces a *statistical estimate* of the (true) performance measure not the measure itself. In order for an estimate to be statistically precise (have a small variance) and free of bias, the analyst must specify for each system design of interest appropriate choices for the following:

- Length of each simulation run
- Number of independent simulation runs
- Length of the warmup period, if one is appropriate

We recommend always making at least three to five independent runs for each system design, and using the average of the estimated performance measures from the individual runs as the overall estimate of the performance measure. (Independent runs means using different random numbers for each run, starting each run in the same initial state, and resetting the model's statistical counters back to "zero" at the beginning of each run.) This overall estimate should be more statistically precise than the estimated performance measure from one run. Note that independent runs (as compared to one very long run) are required to obtain legitimate and *simple* variance estimates and confidence intervals.

For most simulation studies of manufacturing systems, we are interested in the long-run (or steady-state) behavior of the system, i.e., its behavior when operating in a "normal" manner. On the other hand, simulations of these kinds of systems generally begin with the system in an empty and idle state. This results in the output data from the beginning of the simulation run not being representative of the desired "normal" behavior of the system. Therefore, simulations are often run for a certain amount of time, the *warmup period*, before the output data are actually used to estimate the desired performance measure. Use of the warmup-period data would bias the estimated performance measure.

A comprehensive treatment of simulation output-data analysis can be found in Chapter 9 of Law and Kelton (1999).

6 SIMULATION ANALYSIS OF A MANUFACTURING SYSTEM

In the actual conference presentation, we will give a detailed analysis of a manufacturing system. We will address the following issues:

- Evaluating different machine and forklift-truck resource levels
- Sizing of work-in-process buffers
- Determining the impact of random machine downtimes
- Determining the effect of different logic for the forklift trucks

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