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MANUFACTURING MODELING USING RESQ

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ABSTRACT

Queueing networks are often used to model complex systems when the performance of the system is affected by contention for resources. Complex queueing problems occur in areas such as communication networks, computer systems, and manufacturing systems. In manufacturing processes, contention for items such as automated tools, robots, conveyors, material handling resources, and human operators greatly affect the performance of the system. The system performance can be measured in terms of production capacity or throughput, buffer requirements, work-in-process levels, and system reliability.

Modeling and simulation techniques can be used to analyze and understand the performance of manufacturing systems. They are often required to understand the effects of uncertain or random events such as tool failures and parts shortages, and to analyze the sensitivity of the system to key parameters such as buffer sizes and tool reliability parameters.

This paper presents four examples of manufacturing applications and demonstrates the uses of modeling and simulation techniques to analyze the problems. The examples presented use IBM's Research Queueing Package (RESQ), developed at the IBM Watson Research Center in Yorktown Heights, New York. RESQ is a modeling system which allows the quick construction and solution of queueing models. RESQ provides either an analytic solution or a discrete simulation capability from the same model definition. With certain constraints the model will be solved analytically; however, if the constraints are not feasible, a discrete simulation approach can be used. A major advantage with RESQ is that both solution approaches can be applied to the same model definition.

The manufacturing examples considered include:

1. A small sub-system consisting of a single tool with input and output buffers, a conveyor, and a set of transfer units. The model is solved analytically and demonstrates the effect of arrival rates upon the sub-system performance.

2. The first example is expanded to include tool downtime due to random failures. Discrete simulation is used to analyze the sensitivity of system performance to tool failures.

3. The concepts in the above examples are used to construct a model of a serial transfer line. The serial line includes multiple processing points and work-in-progress buffers between each station.

   The relationship between buffer size and system throughput is developed via simulation. Sensitivity of buffer size and throughput to tool failures is also analyzed.

4. An example of a supply and demand system in which the supply and demand rates follow random distributions. A model is constructed to analyze the relationship between the supply and demand points to determine the resulting buffer profile. The analysis also includes the expected maximum buffer size and the risk of starving the consumption point due to an empty buffer.

The intent of this paper is to demonstrate some uses and benefits of modeling and simulation in a manufacturing environment. Although RESQ is used as the modeling language, the paper provides examples of manufacturing modeling applications and is not meant to be a comprehensive RESQ tutorial.

EXAMPLE 1: SINGLE TOOL SYSTEM

The system considered in this example consists of a main conveyor, a single tool which is located off the main conveyor, and input and output work buffers for the tool.

The work units to be processed move down the conveyor and are either selected for processing at the tool or bypass the tool and move downstream. Those units selected for processing are transferred into the tool's input buffer, are processed at the tool, are placed into an output buffer, and are then transferred back onto the main conveyor. This process represents a single operation of a larger assembly process, where the work unit must visit several of these sub-systems for complete assembly. Downtime for maintenance at the tool or other portions of the system is not considered.

A RESQ model of this system is constructed by representing each element of the system, i.e. the tool, the input and output buffers, the transfer units, and the conveyor, as a unique queue. The work units flow through the queues according to the routing process described in the previous paragraph. The model is solved analytically with the following constraints:

- Each queue has a First Come - First Serve (FCFS) discipline, with an exponential service time distribution
- Each buffer has infinite capacity
- The decision to transfer into the tool or bypass the tool must be probabilistic and not a state dependent Boolean condition.

The model is used to measure the performance of the system in terms of throughput and buffer requirements. Sensitivity of the system performance with respect to job arrival rates is also performed. Although this is a relatively simple model, it can be used to determine the general performance and requirements of the system. The model can also be used as a base to analyze complex and detailed systems.

EXAMPLE 2: SINGLE TOOL SYSTEM WITH DOWNTIME

This example is an extension of the system described in Example 1. The process to be modeled is the same; however, unscheduled downtime at the tool due to failures is introduced. Tool failures may include simple tool jams that only require 2 to 3 minutes correction time, or "hard" failures in which the tool is inoperative for 2 to 3 hours. For this example, only tool jams will be considered. Hard failures can also be included with similar extensions to the model.

With the inclusion of downtime, the tool alternates between two states: "up" and "down". When the tool is up, normal processing of units is allowed. When the tool experiences a failure, normal processing is suspended until the failure is corrected. To demonstrate how tool failures can be incorporated into a RESQ model, the flow of units through the subsystem and all operations are identical with Example 1.

The RESQ model from Example 1 is extended by defining two types of jobs to be processed by the tool. The first job type represents normal work units to be processed and routed through the system as in Example 1. A second job type is used to represent the arrival of an unscheduled failure at the tool. The failure job visits the tool according to a failure frequency distribution and remains in process according to a repair time distribution. This process models the "down" and "up" states of the tool. The tool queue is also modified from a FCFS queue to a priority queue, with the failure job having priority over normal jobs.

The system performance measurements are the same as in Example 1; however the degradation in performance due to tool downtime is also measured. Sensitivity of the system to the frequency and duration of failures is also analyzed. A simulation approach is required due to the priority queue discipline at the tool.

EXAMPLE 3: SERIAL TRANSFER LINE

The concepts presented in Examples 1 and 2 are used as a basis for modeling a multiple operation assembly process, commonly referred to as a serial transfer line. The transfer line consists of several tools connected in series by a fixed conveyor, with work-in-process (WIP) buffers between tools. Each unit of work must be processed at each tool in sequence. Units waiting to be processed accumulate in the WIP buffer prior to the tool and are removed for processing on a first come - first serve basis.

Accumulation of work in the WIP buffers occurs primarily due to unscheduled downtime at the tools. In the case of hard failures or extremely frequent short failures, WIP buffers may become full, thereby forcing an upstream tool to stop operation only because it has no room for its output. Therefore, in a system with limited buffer capacity, a single tool failure can cascade and quickly force the entire process to stop.

The throughput of this type of transfer line is therefore critically dependent on the sizes of the WIP buffers as well as the tool failure characteristics. Systems which experience frequent failures of short duration require a certain level of WIP buffer to avoid the cascading effect. A RESQ model is developed to represent this system, again using concepts similar to those of the previous examples. Additionally, the WIP buffers are included as queues with finite capacity. Sensitivity of throughput to buffer size and failure parameters is also presented.

EXAMPLE 4: SUPPLY AND DEMAND BUFFER SYSTEM

Another problem frequently encountered in the design of manufacturing systems is the determination of buffer sizes between operating points in a system. A case of special interest occurs between a process point that supplies components and a corresponding process point which consumes the components. This is a common occurrence in an assembly process where products manufactured on one line are feed directly into another process for additional assembly.

Since both assembly processes contain production variations due to random tool failures, the contents of the buffer between the two processes changes with time. It is desirable in this type of system to avoid the extreme cases, that is, the condition of a completely empty buffer or completely full buffer. An empty buffer starves the demand point and forces it to stop production. A full buffer forces the supplying line to shut down because there is no room in which to place its output.

The design of the system therefore involves an effort to simultaneously meet the following objectives:

1. Minimize the risk of starving the demand point
2. Minimize the buffer inventory.

Obviously a buffer with extremely large capacity which is always full will satisfy the first objective; however this solution is infeasible due to the inventory costs. The problem involves determining the minimum buffer contents which provides an acceptable risk of starving the demand point.

A combination of a RESQ model and supplemental statistical analysis is used to determine the appropriate buffer strategy. The RESQ model consists of a supply point which creates units according to a specified random distribution, a demand point which consumes units according to its distribution, and a buffer. The supply distribution is expressed as the time between outputs, or inter-production times, from the supply point. Similarly, the demand distribution is defined as the time between demands for an assembly. These distributions may be empirically derived, or may be estimated by the modeler. In this example, they are based upon additional, independent detailed modeling of the respective assembly processes.

A profile of the buffer contents versus time is developed and used to analyze both the risk of starving the demand point and the expected maximum buffer contents. This combination of discrete modeling via RESQ supplemented with statistical analysis of the simulation results is an effective way to quickly determine the appropriate buffer strategy.

SUMMARY

This report has demonstrated the uses and benefits of modeling and simulation techniques for analyzing manufacturing systems. It has also illustrated the use of IBM's Research Queueing Package (RESQ) to model manufacturing processes. The samples presented can be expanded and incorporated into larger models to analyze complete manufacturing systems. With RESQ, these models can be constructed and analyzed in a timely manner.

The Operations Research Department at IBM Lexington has used RESQ to model several manufacturing systems with excellent results; therefore, they recommend using RESQ.

In general, analytical solutions cannot be obtained due to the limiting assumptions that must be made. However, RESQ simulation models are easily constructed and analyzed, and can include details such as tool failures and buffer constraints.

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