Proceedings of the 1995 Winter Simulation Conference
ed. C. Alexopoulos, K. Kang, W. R. Lilegdon, and D. Goldsman

SIMULATION-BASED REAL-TIME SCHEDULING: REVIEW OF RECENT DEVELOPMENTS

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ABSTRACT

With increased usage of computer monitoring of the factory has come increased industrial and academic interest in developing more science-based real-time scheduling techniques. Simulation, best known for its application during system design or modification, is also being considered for use on day-to-day scheduling problems. This paper reviews recent developments using simulation as a tool in real-time scheduling.

1 INTRODUCTION

The problem of effectively responding to day-to-day operational disruptions on the factory floor is certainly not a new one. Machine failures, part delivery delays, and absenteeism are but a few problems that can make the best plan developed by the best production planning methodology ineffective. Companies constantly struggle to control these daily system dynamics to ensure that the right quantity or quality products continues to be produced. However, with more computerized shop floor data collection being introduced, there is a sense that more science-based techniques should be available to provide immediate decision support when such disruptions occur. Consequently, real-time scheduling, or more appropriately re-scheduling, tools are the focus of both academic and industrial developments.

Theoretically, "real-time" should mean rendering a decision immediately. Practically, the speed at which a decision is needed to be considered real-time is dependent upon system parameters such as the magnitude of part processing times and the flexibility of the system (Harmonosky and Robohn 1991). If processing times are on the order of an hour, a response in 5 minutes may pass for real-time; if processing times are on the order of a few minutes, real-time responses are probably needed in less that 1 minute. Another differentiation exists in the literature between continuous real-time scheduling, where every decision regarding which task to schedule next is made as needed as time moves forward in the physical system, and exception real-time scheduling, where a real-time scheduling decision is only made when a machine breakdown, part shortage, or the like occurs. Whether a real-time scheduling methodology can be considered as a candidate for application depends upon a particular system's definition of real-time.

There are several non-simulation based approaches to the real-time scheduling problem. Dutta (1990) presents a knowledge-based methodology to automatically take corrective action when exceptions occur. The objective in this work is to maintain the original performance, not necessarily the original schedule. Bean et al. (1991) take a different approach to exception real-time scheduling, trying to reconstruct a portion of the schedule to eventually match up with the original schedule at some future point using integer programming techniques and dynamic priority rule assignments. A more traditional approach is discussed in Kim (1990) which compares job shop dispatching rules when a job shop has alternate routings. Because many Flexible Manufacturing Systems (FMSs) have alternate routing capability and the associated need for real-time scheduling, some approaches are described in the FMS scheduling review papers of Basnet and Mize (1994) and Rachamadugu and Stecke (1994).

Since simulation has long been used as a decision support aid during system design, assessing the impact of changing system parameters upon system performance measures, it is natural to try to use it as a real-time scheduling tool. Harmonosky and Robohn (1991) present a review of real-time scheduling techniques for FMS, which includes simulations approaches. Consequently, the rest of this paper will focus upon the use of simulation in real-time scheduling since 1990.

2 SIMULATION INTERFACED WITH THE PHYSICAL SYSTEM

In most of the reported research using simulation for real-time scheduling, the simulation is assumed to be interfaced with the physical system in some manner. Figure 1 presents a typical viewpoint for the interface for exception real-time scheduling, which could be easily modified for continuous real-time scheduling. Data regarding system status updates the simulation initial conditions when a decision is needed, either on an exception basis or continually. If alternatives exist, each would be simulated and the best could be selected, or the simulation would be run to predict future problems. The research discussed in this section uses this basic interfacing theme with a few variations.

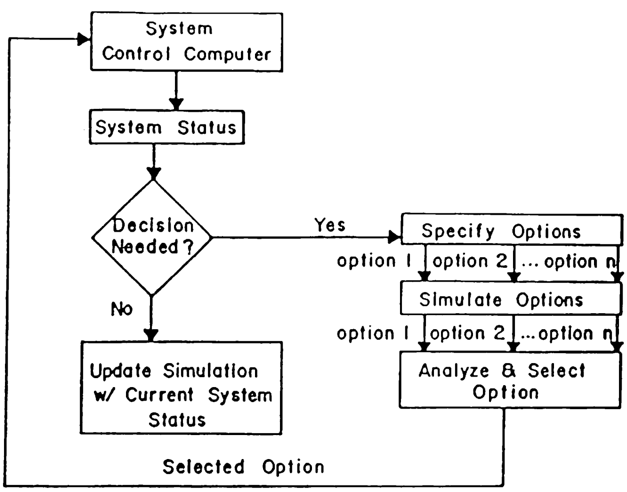

Figure 1: Interfacing Simulation with Physical System (Harmonosky 1990)

2.1 Continuous Real-Time Scheduling Approaches

Continuous real-time scheduling refers to the case where every decision regarding which task to schedule next is made as needed as time moves forward in the physical system.

Krishnamurthi and Vasudevan (1993) present a framework for a domain-based on-line simulation, which they suggest could be used as a general purpose decision support system. The objective is to create something general to all problems within a specific domain where the simulation is continuously monitoring the real system so that it always reflects current system state. Their framework consists of several modules: a simulation module, a simulation control module, static and dynamic databases, a data acquisition module, and a customization module.

A prototype is developed for the domain of a single queue with multiple parallel servers. The objective is to determine the number of parallel servers to minimize queue length and waiting time as system conditions change over time. The prototype uses Turbo C to pass data between computers, the SIMAN simulation language and the CLIPS expert system as a knowledge base to check if a prior decision exists that can be used without a new simulation. The time saved by the developed prototype system was 30% of the time taken by an off-line simulation process.

Smith et al. (1994) use simulation as a task generator in addition to an analysis and evaluation tool. A simulation of the physical system acts as a decision maker determining what task must occur next and sends that task to the execution software for the system. Using simulation as a shop floor control mechanism was developed as part of a larger joint project, RapidCIM, with Texas A&M University, Penn State University, and Systems Modeling Corporation. This project's overall objective is to reduce the time required to develop fully functional shop floor control systems for flexible discrete parts manufacturing. Consequently, the control logic developed and used for the simulation becomes the physical system's control system, reducing time between the simulation analysis phase and physical system implementation.

Special features of the Arena/SIMAN simulation language are used to enable direct interfacing with physical system data and to enable switching the simulation between off-line analysis mode and on-line task generator mode. The reported control system is developed for Texas A&M's Computer Aided Manufacturing lab and Penn State's CIM lab where it provides direct continuous control of shop activities. Currently, the system does not evaluate several alternative tasks at each decision point. However, the authors do suggest that it could be used to evaluate multiple alternatives by making a copy of the simulation that can be initialized with the current physical system state and run into the future.

Duffie and Prabhu (1994) present a heterarchical manufacturing system that uses simulation to evaluate local schedules that are continually developed by local controllers. The system has loosely coupled, highly autonomous entities having minimal global information. All entities develop their own local schedule and "cooperate" to meet global goals. The local and global merits of these local schedules are evaluated by a simulation that is developed by modifying the physical systems control software.

This direct link of the simulation with the actual shop floor control software is similar to the concept in Smith et al. (1994). However, in Duffie and Prabhu (1994) the scheduler may suggest alternative local schedules that the simulation must evaluate. The simulation is initialized with real system status before each run and goes forward in time for 12 parts to be scheduled. The global merit determined by the simulation provides feedback to entities allowing them to select their best local scheduling alternative. The authors suggest that developing efficient distributed discrete event simulation for heterarchical systems could provide faster schedule evaluation, making it a more attractive application in real-time.

2.2 Exception Real-Time Scheduling Approaches

Exception real-time scheduling refers to the case where a real-time scheduling decision is only made when a disruption occurs, such as a machine breakdown or part shortage.

The concept of using a simulation combined with a knowledge base has been reported in several papers. In Manivannan and Banks (1991) and Manivannan and Banks (1992), a framework is presented for a real-time control system that integrates data collection, a knowledge base and simulation. In Manivannan and Banks (1991), they use an event/time synchronization module that links a simulation model to the real system by modifying the events and times stored in the event calendar based on temporal data for the corresponding event times in the real system. The knowledge base stores results of simulation evaluations of alternatives each time a decision is made, which is then searched at subsequent decision points for a match to reduce response time, similar to Krishnamurthi and Vasudevan (1993). They state that the system is implemented at Georgia Tech for an AGV system using SIMAN/Cinema and a knowledge base in common LISP. The Manivannan and Banks (1992) paper uses a similar framework, but it does not use an event/time synchronization module to have the simulation reflect current shop status. Also, the knowledge base is used to determine if the entire shop or just a portion needs to be simulated and initializes a copy of the SIMAN model for each alternative. An example of how the framework would be applied to a small FMS is included.

A knowledge base is also used in Katz and Manivannan (1993) to determine when the simulation should be invoked for real-time decision making based on what they term "soft" exceptions, ones that may be hard to notice. At specific point in time, system performance measures are evaluated, such as queue sizes, and if they are outside of a specified tolerance range, this soft exception triggers the need for a real-time response. They synchronize the simulation with the real system in a two-step process which updates the simulation with current system status and invokes the knowledge base to determine why state variables disagree. They suggest that the proper synchronization is necessary and the time interval between checks for soft exceptions must be carefully chosen.

Kim and Kim (1994) also use a soft exception concept, in addition to breakdowns and the like, to trigger real-time decisions. Soft exceptions are detected based on a monitoring period. They simulate several alternatives when an exception occurs using a deterministic simulation, which does not consider future breakdowns or rush jobs but is updated with the current state of the system. An experiment varying the length of the monitoring period and the size of the performance tolerance for soft exception detection is discussed. Periodic monitoring had a statistically significant effect on improving the mean flowtime and mean tardiness. Results suggest that mid-range monitoring period lengths and tolerances are best.

The previously discussed work assumed a discrete manufacturing environment. A continuous flow manufacturing system is considered in McConnell and Medeiros (1992). They suggest that continuous flow environments may be better suited to using simulation as a real-time scheduling tool because fewer events occur necessitating such decisions. They compared using a model of the entire system, a hierarchical model having different models for different decision types, and a Nelder-Mead optimization model on a test system. Using SIMAN on a VAXStation 3100 and evaluating several alternatives for each decision, the optimization model was fastest at 1 to 2 minutes and the hierarchical model was slowest at 1 to 4 minutes. This suggests that investigating the coupling of simulation with an optimization procedure may be worthwhile to reduce decision response time and make a better decision.

2.3 Some Specific Issues

In any attempt to use simulation as a real-time scheduling tool, the issues of how to initialize the simulation to current shop status when a decision is needed and how to determine an appropriate look-ahead window length and parameters must be considered. Gaafar and Shaik (1993) discuss the initialization issue suggesting an integrated bar code-based data acquisition system to detect problems and initialize the simulation to current shop status. The system automatically initializes a SIMAN model to current shop floor status by updating specific fields in the experimental file.

The look-ahead window length for simulations evaluating several alternatives at a real-time decision point has a direct impact upon potential real-time application of simulation. Longer run lengths should provide statistically better output, but that makes decision response time longer. Harmonosky and Robohn (1995) investigate how physical system parameters affect the amount of time it takes to perform the simulations given a specific level of precision for statistical accuracy of the simulation output. The objective is to start to develop the profile of a system that would be a good candidate for real-time simulation. ANOVA was used with a nested experimental design having 2 different manufacturing systems modeled with 3 replications per model at each design point and using cpu time as the dependent factor. Their results suggest that the profile of a system that would be amenable to simulation as a real-time tool would be a system with longer average processing time, a WIP performance measure and some flow shop type characteristics, since run cpu time was shorter with these parameters.

The issue of what simulation assumptions are made during the look-ahead horizon is considered in Harmonosky (1993) an Houser (1992). Specifically, a deterministic look-ahead horizon, meaning that no further system disruptions occur during real-time simulation runs, and stochastic look-ahead horizon are compared. At issue is whether there is a significant difference in the amount of cpu time required to perform simulation runs and whether the type of horizon affects which alternative is selected. Simulation runs using the stochastic look-ahead required a statistically significant longer time. When evaluating two different alternatives, it was found that in a majority of cases the alternative chosen was the same for both types of look ahead horizons.

Bosak (1993) extended this study by including more alternatives to be evaluated at a decision point. He found that a majority of the cases had a different alternative selected for the deterministic and stochastic look-ahead horizon. This suggests that results regarding the effect of the type of look-ahead horizon may be affected by the complexity of the system and the number of alternatives. Also, this work did not thoroughly examine the cases where different alternatives were selected to evaluate whether a significant difference in long-term system performance would occur with the different alternatives. Research is currently underway to consider this issue and to consider whether there is a significant difference in alternative selection assuming an event-based stopping rule (e.g. until the next predicted breakdown) versus a relative precision stopping rule.

3 COMMERCIAL DEVELOPMENTS

Interest in real-time scheduling is high in industry. Several commercial products are trying to meet industry's demand by using simulation.

Pritsker Corporation has two products that might be considered. FACTOR/AIM may be considered more of a design simulation; however data can be downloaded from a database, such as current shop status, and alternatives could then be evaluated. The resulting schedule decision could be integrated with other information systems via a spreadsheet. This product requires a user well-versed in simulation. FACTOR Production Manager uses simulation and an optimal scheduling procedure. It is a client/server operation that automatically initializes/updates a simulation by interfacing with existing information systems, e.g. MRP, order entry file. If a shop floor disruption occurs, the simulation accesses the shop floor data needed, runs forward in time, and produces an exception report showing jobs that will miss their due date. The speed depends upon the size of the existing information systems that must be searched for data and the number of parts that are affected by a disruption. Current research is in the areas of continually comparing actual shop floor performance versus predicted, incorporating new optimization methodologies, and better melding of the optimization algorithm output with what is realistically possible on the shop floor via simulation analysis (Dukett 1995).

Systems Modeling Corporation has features in the ARENA simulation package that help support using simulation in real-time by providing an easier link/interface with the real system. The simulation clock can be synchronized to real-time and hooks are built in to send and receive messages from other equipment. Also, communication between ARENA and another computer is supported; some standards are included but they could be customized. These features are used at Texas A&M and Penn State (see Smith et al. 1994). Another product, PREACTOR, is currently a stand alone scheduling package. However, upcoming versions will move toward integrating PREACTOR with ARENA (Sturrock 1995).

4 CONCLUDING REMARKS

Science-based real-time scheduling techniques are certainly needed. Simulation with its look-ahead and what-if capabilities has good potential in this area. The work reviewed in this paper included continuous and exception real-time scheduling, incorporating knowledge bases with simulation, issues related to goodness of the approach, and commercial developments.

It is encouraging that some of the implementation issues highlighted by Harmonosky (1990), Rogers and Flanagan (1991), and Rogers and Gordon (1994) are being considered and addressed by commercial developments, particularly the issue of interfacing the real-system and simulation. However, other issues remain, both academic and industrial. Although the time to run a simulation is drastically reduced by the high speeds of today's PCs, the time (and ability) to access the needed shop floor data and supporting system data which may be resident in existing company information systems is often not insignificant. Also, we need to make reasonably good statistical analysis of simulation outputs for decision alternatives by appropriately determining look-ahead window parameters and run lengths, number of replications, stopping rule determination, etc.

Although the academic-based work reviewed here has been tested using hypothetical simulated systems or in a laboratory setting, this work needs to be implemented and tested on some "real-world" systems. Opportunity exists for more academic and industrial partnerships to continue pushing the potentiai of simulation as a real-time tool.

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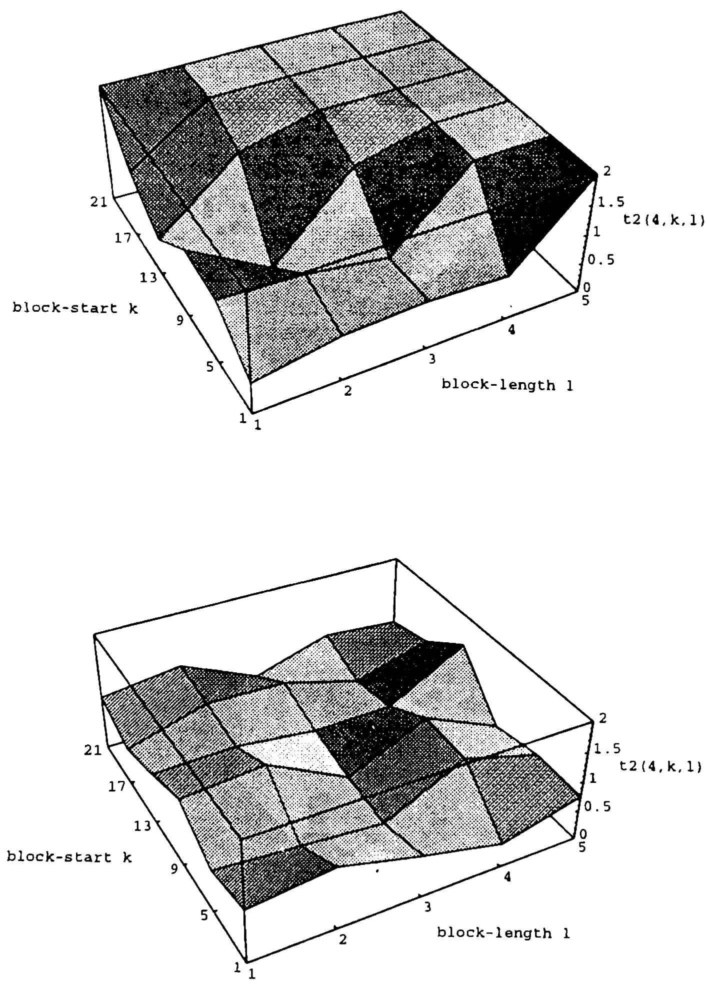
Analysis Methodology



Performance of a random number generator, from "Inversive Pseudorandom Number Generators: Concepts, Results, and Links," by Peter Hellekalek.