EXPERT SIMULATION FOR ON-LINE SCHEDULING

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ABSTRACT

In recent years, the automotive industry has realized the importance of speed of new products to market and has mounted efforts for improving it. The Expert System Scheduler (ESS) facilitates these efforts by enabling manufacturing plants to generate viable schedules under increasing constraints and demands for flexibility. The scheduler takes advantage of the Computer Integrated Manufacturing (CIM) environment by utilizing the real-time information from the factory floor for responsive scheduling.

The Expert System Scheduler uses heuristics developed by an experienced factory scheduler. It uses simulation concepts and these heuristics to generate schedules. Forward and "backward" simulation are used at different stages of the schedule generation process.

The system is used to control parts flow on the factory floor at one automated facility. This highly automated facility is a testbed for implementation of CIM concepts. The scheduler runs on a Texas Instruments (TI) Explorer II computer using software developed inhouse utilizing IntelliCorp's Knowledge Engineering Environment (KEE) shell and the LISP language. The scheduling computer is networked to the factory control computer, which actually controls the plant floor. The TI Explorer II acquires current plant floor information from the factory control system, generates a new schedule and sends it back within a short time. The configuration allows fast response to changes in requirements and plant floor conditions.

1. INTRODUCTION

The state-of-the-art in manufacturing has moved towards automation and integration. The efforts spent on bringing computer integrated manufacturing to plant floors have been motivated by the overall thrust to increase the speed of new products to market. One of the links in CIM is plant floor scheduling, which is concerned with efficiently orchestrating the plant floor to meet the customer demand and responding quickly to changes on the plant floor and changes in customer demand. The Expert System Scheduler has been developed to address this link in CIM. The scheduler utilizes real time plant information to generate plant floor schedules which honor the factory resource constraints while taking advantage of the flexibility of its components.

The scheduler uses heuristics developed by an experienced human factory scheduler for most of the decisions involved in scheduling. The expertise of the human scheduler has been built into the computerized version using the expert system approach of the discipline of artificial intelligence (AI). Simulation concepts have been used to develop the schedule and determine the decision points. As such, simulation modeling and AI techniques share many concepts, and the two disciplines can be used synergistically. Examples of some common concepts are: the ability of entities to carry attributes and change dynamically (simulation – entities/attributes or transaction/parameters versus AI – frames/slots), the ability to control the flow of entities through a model of the system (simulation – conditional probabilities versus AI – production rules), and the ability to change the model based upon state variables (simulation – language constructs based on variables versus AI – pattern invoked programs). Shannon (1984) highlights similarities and differences between conventional simulation and an AI approach. Kusiak and Chen (1988) report increasing use of simulation in development of expert systems.

ESS uses the synergy between AI techniques and simulation modeling to generate schedules for plant floors. Advanced concepts from each of the two areas are used in this endeavor. The expert system has been developed using frames and object oriented coding which provides knowledge representation flexibility. The concept of "backward" simulation, similar to the AI concept of backward chaining, is used to construct the events in the schedule. Some portions of the schedule are constructed using forward or conventional simulation.

The implementation of expert systems and simulation concepts is intertwined in ESS. However, the application of the concepts from these two areas will be treated separately for ease of presentation. The following section discusses the expert system approach and provides a flavor of the heuristics. The concept of "backward" simulation and the motive behind it are discussed in the third section. The fourth section provides some details of the implementation and the plant floor where the scheduler is currently being used. The fifth section highlights some advantages and disadvantages of using the expert simulation approach for scheduling. Finally the last section highlights the synergetic relationship between expert systems and simulation.

2. EXPERT SYSTEMS APPROACH

Traditionally, plant floor scheduling has been a difficult problem to solve. Even after decades of research, management scientists have failed to find solution approaches which can be applied in practice for job-shop scheduling (McKay, Safayeni and Buzacott, 1988). Most commercially available packages have not found generic application, because they are hard to customize to a particular plant situation and objectives. Also, some of the math-based scheduling packages require large computation times in their search for a near optimum solution. The problem lends itself well to application of an expert systems approach. In recent years, several efforts have started utilizing this approach for solving scheduling problems (Kusiak and Chen, 1988). The expertise of a human scheduler can be utilized to establish heuristic procedures which lead to schedules meeting the objectives of particular plants. The expertise is also utilized to customize the heuristics for meeting different objectives, or for providing a different set of heuristics for widely varying objectives.

The expert for this system was a plant floor scheduler with 20 years of experience in the field. He was very articulate in formulating the scheduling heuristics which took important plant floor issues into account. He was an excellent abstract thinker and capable of generalizing from specific situations to abstract application. His experience also guided the development to concentrate on prevalent situations on plant floors, rather than for all possible situations. His expertise was also used in evaluating the schedules generated using the heuristics. He guided the developers through iterations of evaluation and modification of heuristics until they met the requirements.

The heuristics are used for the following decisions:

- Part dispatching, that is, which part order will be scheduled next from the candidate part orders. A part order is defined as an order for certain quantity of a particular part type. The quantity may be determined based on customer orders and batch sizing considerations.

- Machine selection, that is, which machine among the candidate machines will be used to process the selected part order.

- Interval selection, that is, which time interval in the window of time being considered on the selected machine is most suitable to process the selected part order. One of the trade-offs in this particular situation is setup versus Just-In-Time.

- Secondary resource constraints, that is, when to consider the constraints of labor, tooling, purchased parts, gages etc.

- Supporting events consideration, that is, when to schedule preventive maintenance, service parts and safety stock replenishment production.

The types of specific information which can be incorporated using knowledge-based technology is illustrated in choosing the machine for the next operation on a batch of parts. When multiple machines are available the following selection criteria are used :

1. The scheduler determines the ideal completion time for the batch of parts.

2. A window of time in which the operation on that batch can be scheduled is determined for each eligible machine. All machines which can perform the operation to be scheduled are eligible for consideration. The window is dependent on the process time for the operation and various user controlled parameters.

3. Each machine is checked for a block of idle time within the window which is large enough to schedule at least x% of the operation and any associated setups. "x" is machine and operation dependent.

Expert system technology facilitates the handling of complex reasoning. This is illustrated with the following heuristic which is used in conjunction with backward simulation (Barber, Burridge and Osterfeld, 1988a):

1. If there are intervals which will completely contain the run time (the time required to perform the operation and the setups), the interval which would yield the most synchronous schedule over all primary machines is chosen. Some consideration is also given to the secondary goal of setup minimization.

2. If there is no complete fit of the total run time (process + setup), but a partial fit of some minimum percentage exists, all preceding operations on the chosen machine are shifted earlier in time to make room for the one which needs to be scheduled. This results in having to shift all the affected operations across all the machines which precede those shifted on the machine being scheduled. The recursion techniques in LISP handle this quite well.

3. If no fit of any kind is found, the window is shifted earlier in time and another iteration is done.

4. In following the precepts of Just-In-Time, arrival of components is scheduled at the assembly cell on an as needed basis. For example, if an assembly requires three batches of a given component, the first arrives when assembly begins, the second arrives 1/3 through assembly, and the third arrives 2/3 through the process.

The primary objective of the heuristics is to meet customer demand. Secondary objectives may be setup minimization and work-in-process minimization. Tuning parameters are available to the user to generate schedules closer to objectives in his/her environment.

3. SIMULATION CONCEPTS

Simulation concepts have been implemented using object oriented programming. A model of the plant floor is developed using frames to represent parts, machines and operations (processes) (Barber, Burridge and Osterfeld, 1988b) :

- Associated with each part is a process plan which identifies the sequence of operations or processes to be performed on that part. The part class is further subdivided into assemblies and component parts. Assemblies identify how many of what components are required for assembly operation.

- Machines eligible to perform operations are identified by each operation.

- Associated with the operations are the setup and process times required for each part on which the operation can be performed.

The concept of "backward" simulation is used to construct the schedules. The concept has existed in a simple form in scheduling literature under the name "backward scheduling". In the library of AI techniques, a somewhat similar concept of backward chaining is used. Backward chaining works by starting from a goal state and working backwards to the initial state using production rules whose outcomes are goal state or sub-goal states. In AI literature, the backward chaining usually does not include modeling passage of time. In backward simulation, the idea is to start with the goal state, and then simulate passage of time backwards to the initial state. In a plant floor scheduling context, the goal state is the end of horizon with all customer demands satisfied with production as close to due dates as possible. The events are simulated backwards, starting from the last operation of a part to its first operation.

The major motivation of using backward simulation comes from the thrust to implement the Just-In-Time philosophy. It is difficult to determine the release time for an order on the plant floor using forward scheduling or conventional forward simulation for complex scenarios. Several iterations will be required to determine correct release times for the hundreds of orders processed by a practical sized department on the plant floor. Queuing theory relations provide approximations to determine service times in simple multi-server networks, but few approximations are available for practical situations with multiple resource constraints and multiple routings. Even otherwise, the queuing theory approximations provide mean values which will not predict the release times of the orders as accurately as backward simulation.

The backward simulation considers known or deterministic machine unavailabilities similar to forward simulation. These known unavailabilities may be due to shift timings, current breakdowns or tool tryouts. Random machine breakdowns are not considered explicitly during scheduling, though some slack may be included to account for their occurrence. The ability to quickly generate schedules together with the ability to access real-time information allow generating new schedules in response to such machine breakdowns.

The use of backward simulation does require care in implementation of traditional dispatching rules. For example, while simulating backwards in time the job with the latest due date will be selected first to get the effect of the traditional dispatching rule "earliest due date first". Similarly, the job with the longest process time will be selected first to get the effect of shortest process time rule. As such, the traditional dispatching rules are not being used in ESS, though some of the heuristics are due dates based.

At times, a plant may receive orders which it cannot satisfy by the due dates desired by the customer due to capacity constraints. In conventional or forward simulation, this situation will be reflected by orders being completed later than their due dates. Backward simulation leads to order release times which are earlier than the beginning of the scheduling horizon in such a situation. The system will indicate that to meet the customer orders at the desired due dates the orders should have been released sometime in the past. In such a case, the requirements may be adjusted or some of the orders will be made late. The new release times in such cases are calculated by intelligently shifting the schedule forward in time, making use of idle time intervals on machines, until it becomes feasible.

Once the customer orders have been scheduled, the remaining capacity is utilized by scheduling safety stock replenishments and low priority orders. Both the safety stock replenishments and low priority production orders are scheduled using forward simulation. These are placed within the idle time intervals left on the machines due to excess capacity. The schedule is also adjusted for scheduling preventive maintenance events and for honoring constraints of expected material receipts, labor, tooling etc.

4. APPLICATION

The Expert System Scheduler has been developed using the package KEE, which is a product of IntelliCorp. The simulation concepts and rules have been coded using LISP. The scheduler is currently resident on TI Explorer II hardware.

The system is being used at a highly automated facility involved in automotive component production. The plant floor is controlled through a Factory Control System (FCS) which resides on a Stratus 2000 computer. The factory floor status information is maintained by the FCS. In addition, the FCS contains current data on customer orders and on the expected material receipts. All this information is sent through a computer network to the TI Explorer II whenever the situation warrants a new schedule. The Expert System Scheduler is used to generate a new schedule within a short time, and the schedule is sent back to the FCS for execution. The FCS sends appropriate commands to the plant floor cell controllers for implementing the schedule. The information flows to and from ESS are shown in figure 1.

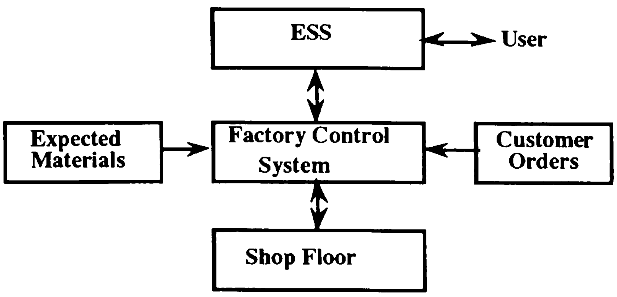

Figure 1: Information flows to and from ESS.

A friendly user-interface is very important for acceptance of an expert system by the users (O'Keefe, Belton and Ball, 1986). ESS uses a very user-friendly mouse driven interface. The schedule is presented to the user in the form of a Gantt chart as shown in figure 2. The figure shows the schedule for an 8-hour period for a small department on a plant floor. The user has an option to mouse-click on an operation and get more details as shown in the figure. The user can scroll the Gantt chart up and down if there are more than 24 machines, and right and left to look across the scheduling horizon. Successive operation of one particular batch of parts can be highlighted to follow its flow through the machines. In the figure the flow of a batch of parts of type '46gb' is highlighted.

The user can have the system generate the schedule step by step and follow its construction, or run all the steps together. The Gantt chart interface has been found very useful by the users, as it gives them an understanding as to how the schedule is built and the overall performance. It also gives the user a quick means of evaluating the quality of schedule.

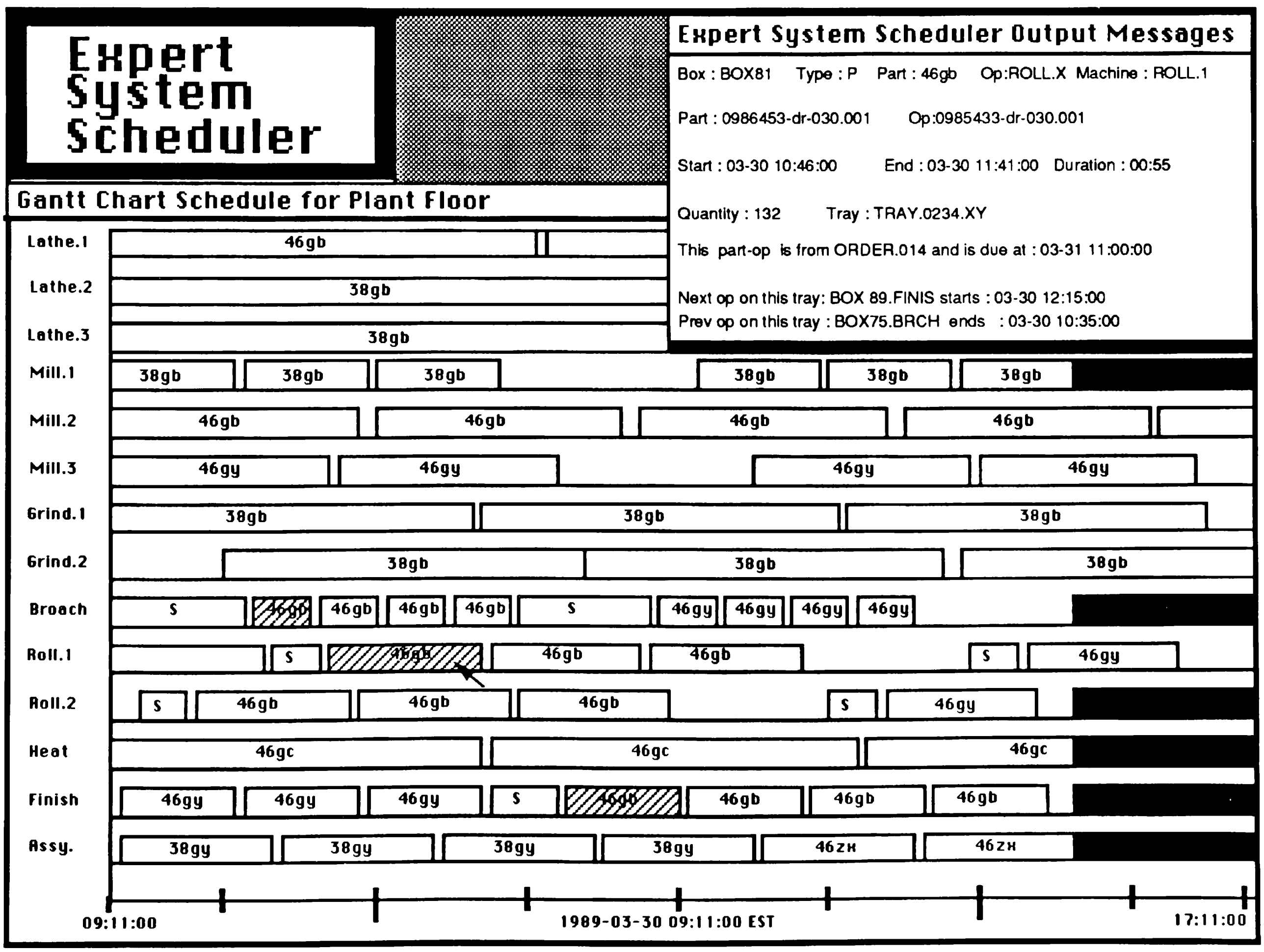

Figure 2: Sample schedule display generated by ESS.

Aside from the highly automated facility, where the scheduler has been controlling the production for several months, the scheduler has been evaluated by modeling and generating schedules for several factories which are not so highly automated. The evaluations have helped develop the heuristics for generic application.

5. ADVANTAGES/DISADVANTAGES

There are some disadvantages associated with these systems. There are few people with expertise in expert system building tools and techniques, proficiency in LISP, experience in scheduling and simulation, and extensive manufacturing backgrounds. Knowledge acquisition for expert systems requires special skills. Developers of these early systems need to be selected carefully, and given extensive training. Although prices are coming down, hardware (LISP machines) and software are still expensive. Consulting by AI companies is very expensive. Additional issues are expected to surface as the system is implemented in multiple sites.

The backward simulation approach can be used effectively for generating schedules. However, it cannot be used to examine the effect of random events. If robustness of a schedule is to be evaluated, it will have to be simulated in a traditional manner with random events incorporated. The fast response of the scheduler reduces the concern about the robustness of the schedule to a large extent.

Advantages of an expert system based scheduler include the incorporation of heuristics to tailor a scheduler to a particular business site. The scheduler can be easily customized to allow for operation peculiarities, business plans, operation goals, specific customers and order mix. Model based reasoning allows utilization of heuristics aimed at achieving the goals of synchronous scheduling, setup minimization, and machine dedication under changing factory conditions.

The ability to prototype rapidly is a benefit resulting from the use of an expert system shell. Some of the specific features which support the rapid construction of systems are the developer interface tools, inheritance, the provisions for structuring knowledge, modularity, and the ease of incremental development. Specifically, incremental development facilitates the understanding of a complex and ill-structured problem like factory scheduling. A limited module can be quickly developed for simulation testing to determine which additional factors need to be incorporated into the model.

Another advantage this technology offers is that the knowledge representation scheme is relatively generic. The frame based knowledge representation structure provided by the expert system tool eases the integration of the various knowledge bases developed for this phase of the project.

The interactive Gantt chart is a very valuable tool for both understanding new scheduling techniques and debugging the generated schedules. Understanding is gained of the scheduling algorithms and the performance of the schedule through the graphical representation of relationships between batches on one machine and across machines. The graphical display makes it easier to spot inconsistencies or irregularities in a schedule.

This technology offers unusual flexibility for change. An expert system based scheduler can be easily customized to a particular application. Heuristics, or rules, can be incorporated to cover conditions at specific sites.

Perhaps one of the biggest advantages is the user acceptance of the schedule. The user can understand and believe in the system. The data on which the schedule is based is easily accessible and in an understandable form.

6. CONCLUSION

The application described here utilizes advanced concepts in AI and simulation modeling, together with the latest in computer hardware and graphics for effective real-time control of the plant floor. Though this application has been developed independently, development of such a system was hypothesized by Shannon in 1984. This application proves that the disciplines of AI and simulation modeling can be used synergistically for a practical purpose.

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