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CREATING A FLEXIBLE, SIMULATION-BASED FINITE SCHEDULING TOOL

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ABSTRACT

Today's business climate for manufacturers requires low inventory, quick response systems that turn out a wide variety of products. Since many companies are reaching physical capacity constraints, finite scheduling is increasingly becoming an issue. If you are currently an engineer with simulation expertise, you may be asked to assist with an initiative to computerize your scheduling process. There are dozens of off-the-shelf scheduling tools available today, but their underlying capabilities may not meet the true needs of your system. This paper will discuss critical system characteristics that are often ignored in off-the-shelf packages yet can be accurately accommodated by creating your own simulation-based scheduler. We will review how to approach modeling and data structure issues that will commonly be encountered, while highlighting the differences from creating a standard simulation model used strictly for analysis.

1 INTRODUCTION

Over the last five to seven years, "The Textile/Clothing Technology Corporation", ([TC]^2), an industry consortium, has been charged with spreading a vision of advanced manufacturing concepts and practices that will carry the American Textile and Apparel Industries into the twenty first century. As industry leaders searched for examples of new approaches to manufacturing management, they joined forces with other industries with similar ambitions through organizations such as The Agility Forum. Collectively, these groups have defined new paradigms for business practices. It is no longer possible for companies to offer limited product lines produced in large quantities on the manufacturer's time table. "Agility - the ability to profit from rapidly changing, continually fragmenting, global markets for individualizable, customer value-based products and services" (Goldman 1996), is the new standard of excellence required to maintain a competitive advantage.

Along the journey to agility, traditional manufacturers must make many changes. In the sewn products industry, there was initially a focus on "Quick Response" and companies were encouraged to reduce plant work-in-process (WIP) levels. In order to achieve the WIP reductions, great emphasis has been placed on alternative production systems. In garment assembly plants, standard PUSH production systems with dozens of workers are being reorganized into many small, cross-functional teams. As this transformation takes place, the manual support systems that have run these processes for 50 or 100 years have become inadequate. On top of the requirement for quick turn-around, the explosion of product variety has sent engineers scrambling for new tools because they are constantly needing to reconfigure production lines. Pencil and paper methods or simple spreadsheets are insufficient to design the dynamic, team-based systems. Flexible process simulation models are now being used to quickly design the new team production systems (Mazziotti 1995).

Naturally, as the level of safety stock went down and the number of changeovers due to an expanded product mix went up, the focus for improvement shifted to plant level scheduling issues. As in many industries, most sewn products manufacturing organizations perform the scheduling and sequencing process manually or with only partial computer assistance. We will now look at how and why simulation is being used to create customized finite capacity scheduling tools.

2 FINITE SCHEDULING AND SIMULATION

There are many off-the-shelf and partially customizable scheduling software packages currently on the market. So, why choose to create your own simulation-based application? After reviewing a number of "finite capacity" software packages, we found some major problems for the textile and apparel applications that may also apply to other industries. First and foremost was the cost of such systems compared to the small profits commonly found in sewn products. But, more seriously was the realization that even these expensive tools were not capable of dealing with important system issues that were critical to creating effective production schedules.

Because of the issues shown in Table 1, [TC]2 decided that building our own simulation-based schedulers was a cost effective way to provide tools that could accurately account for the complexities and rule variations found in medium and small textile and apparel manufacturers. While the schedulers are "custom" solutions, each follows the same basic structure and content, as described below. We use the ARENA simulation product as the engine for the scheduling logic and a system of files for input and output. Our estimated cost to develop a simulation-based scheduler, ranges approximately from $15,000 to $60,000, which is significantly less than most of the off-the-shelf tools available.

Table 1: Benefits of Simulation-based Schedulers

* Accommodate different, multi-level rules for each resource
* Manage WIP limits for Kanban systems
* Handle systems with scheduling rules that involve interdependent processes
* Incorporates cyclical or progression-based rules
* Lower cost solution than most MRP add-ons or Off-the-shelf finite scheduling packages
* Faster to build than with programming language such as FORTRAN, C or C++
* Works with legacy systems through file transfer or OLE
* Allows "What-if" analysis as well as specific daily scheduling
* Can be run & rerun quickly on a PC

3 STRUCTURE AND CONTENT OF A SCHEDULING SIMULATION

An engineer, who already has a simulation package in-house, has the opportunity to develop a finite capacity scheduling tool that can be more robust and less expensive than an off-the-shelf product. But, when building such a model, it is important to take a different approach in determining the structure of the model and its input information. The standard simulation application is used strictly for analysis and contains all of the information that defines the system, products, and routings within the model constructs. Figure 1 depicts the general structure of simulation-based schedulers developed at [TC]2. Notice that input information, including: a system definition, a product definition, a list of actual customer orders, and the current status of WIP, is contained in external files. The actual simulation model reads the data into variables, contains the logic of the scheduling rules, and produces the outputs shown in the bottom boxes of Figure 1.

By storing data in external files such as spreadsheets or databases, it is quick and easy for a user to change the scheduling scenario without affecting the integrity of the actual simulation model logic (Mazziotti 1996). Since the "users" will probably be scheduling personnel, who are most likely not simulation experts and may not be experienced computer users (Rosenwinkel and Rogers 1993), this structure provides a safeguard for the tool and expands the base of potential users because we eliminate the need for users to learn the simulation language.

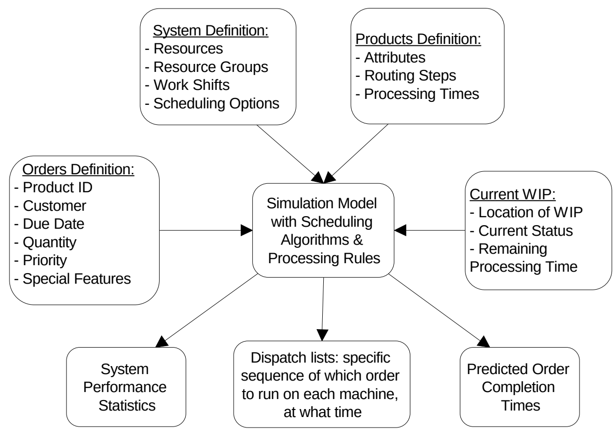

Figure 1: Structure of a Simulation Scheduling Model

3.1 System Definition

The basic concept of finite scheduling is to define the limited resources in a system and their availability, and to schedule production within those constraints. Any process simulation modeling project starts with the same step, properly defining the physical system at an appropriate level of detail. While classical "resource" constructs will be at the heart of a simulation-based scheduler, the system definition file will probably include more details such as resource groups or special resource classifications and capabilities. This type of information will facilitate more complicated resource allocation schemes and order selection processes.

3.1.1 Resources and Resource Groups

In a scheduling model, resources refer to the physical components of the system that are to be scheduled.

Resources may include machines, people, tools, and possibly material handling equipment. The manner in which resources are defined should be based on the way products flow through the process (see section 3.2.1). Consider the following questions. Do products flow through a predefined route to particular resources with absolutely no deviation? Can the product be routed to any resource that performs the appropriate operation? Are there special requirements for some orders, overlapping equipment capabilities, or product restrictions that must be followed?

If the products require one particular resource for each of the operations in their routings and there is never a deviation from the defined routing, the resources can be defined explicitly. This is the simplest of all definition scenarios, but is probably insufficient to adequately describe most systems for scheduling purposes. Generally, the product will have to make decisions about which resource to select to perform an operation.

If the products can select among equally capable resources for a given operation, the resources may be grouped together to form "resource groups". A single resource may be assigned to just one group or may belong to more than one group if it has different capabilities that are important to different products. For example, multiple resource groups can be defined for an operation when the products that flow through that operation have different requirements. Resources A, B, and C may be used interchangeably to perform operation 1 of product 1 while resources A, D, and E can be used for the same operation for product 15. Grouping the resources in this way is a feasible approach when product requirements and resource capabilities can be easily segmented.

If the system under consideration contains products and resources that have extensive limitations and restrictions, adequate resource groups may be too numerous to handle or too obscure to define. An alternative approach is to define the resources' capabilities that would be matched with product requirements in lieu of enumerating all possible resource groups. In Figure 2: "Resource Group and Capability Definition," the columns to the left of the "Description" field represent specific machine capabilities and restrictions. These weaving loom resources belong to 4 major equipment groups (which could be defined resource groups) but there are differences between the equipment of the same group. Looms have physically different dimensions, hence the "width limit." They also differ in the batch size they can produce, i.e. the "maximum roll size." We can also deduce that products are made of different materials (cotton, poly/cotton, and lycra) and not all machines can handle all materials. With this information, the scheduler could determine where to assign an order for 1800 yards of poly/cotton that is 58 inches wide.

3.1.2 Resource Availability

The system definition file must also include the exact availability of the resources in order to avoid scheduling production during off-shift hours or planned downtimes such as preventative maintenance. To simplify the amount of information required, consider how much difference there is in the hours that resources are available. If the whole plant follows a single schedule, only one definition is required. If each resource functions on a different time-table, it may be necessary to specify a calendar (pattern of availability) for each one. Often it will be possible to define only a few calendars and add a parameter for each resource that references the appropriate calendar.

System Definition File
1536 = Simulation Start Time in Hrs
1 = number of days to schedule

Material Types:
1 = 100% cotton
2 = 50/50 poly/cotton
3 = lycra

A Group = set of identical machines

				Processing Capabilities				
Group	# Machs Active	Mach Type	Description	Max Width	Speed Factor	Max Roll Size (yds)	Material Type 1	Material Type 2
1	3	1	Saurer	66	5	500	1	0
2	15	1	Saurer	72	-5	500	1	2
3	5	2	GTM	80	0	1000	2	0
4	2	2	GTM	85	5	1000	1	2
5	4	3	Air Jet	100	0	2000	1	0
6	40	3	Air Jet	120	2	2000	2	3
7	6	1	Saurer	45	0	500	3	0

Figure 2: Resource Group and Capability Definition

3.1.3 Setups and Changeovers

In addition to standard processing durations, setup and changeover times are important to finite scheduling and must be defined in an appropriate format. If the setup time is resource specific only, (the same delay will be used for any product processed at a particular resource), defining the time on a per resource or resource group basis is sufficient. However, if the setup times are resource and product specific, a "from product… to product…" matrix should be constructed for each resource. This format will provide the functionality required to model sequence dependent changeovers, which are common in dyeing processes in the textile and food processing industries. For example, the cleaning time of dye vessels is dependent upon the direction of color progression; if the next product to be processed is a darker color, only a minor setup is incurred, however if the next color is lighter than the previous product, the cleaning time is much longer and represents a major setup.

3.2 Product Definition

The second input file, "Products Definition", should contain all applicable information that makes a product unique or that may be used in sequencing decisions. This information must includes the product's routing steps, the standard processing time per operation, and may include information about operational batch sizes and transportation batch sizes. This reference file should contain information for each product for which orders *may* be received (see Table 2).

Table 2: Products Definition

STYLE #	STYLE ID	DESCRIPTION	# COLORS
1	1010	T-Shirts	2
2	1020	Golf Shirts	8
3	1030	Camp Shorts	4
4	1040	Uniform Pants	4

3.2.1 Routing

Product routings must be specified in order for the simulation scheduler to correctly sequence the orders through the process. The routing must define the sequential set of steps (tasks or operations) that must be accomplished to complete the product. Along with each step, the routing must define what resource(s) are required to complete the task. This may be specified by 1) identifying the exact resource a product requires for each operation, 2) identifying the resource group from which any resource may be selected (see Table 3), or 3) listing the processing requirements for each operation. The way in which resources are specified is directly related to the complexity of the products' processing requirements and the capabilities of the resources (see section 3.1.1). Option 3 means that the exact routing is not predefined, but the logic of the simulation model will determine the specific resources to use as an order progresses through the system. This type of decision-making and flexible routing is a feature that can be incorporate in simulation models but may not be offered with heuristic tools.

Table 3: Product Routing Steps

STYLE #	ROUTE STEP	PROCESS TIME (MIN)	UNIT/ BATCH	RES. GROUP
1	1	0.6	Batch	Cut-1
1	2	2.95	Unit	Sew-1
2	1	0.8	Batch	Cut-1
2	2	9.2	Unit	Sew-2
3	1	1.35	Batch	Cut-1
3	2	15.66	Unit	Sew-3
4	1	1.7	Batch	Cut-1
4	2	13.9	Unit	Sew-4

3.2.2 Processing Time

The processing time for each of the product's operations is required and the basis by which the time was derived (unit versus batch) should be denoted. If the operation is a unit process, the time specified should be applied to each unit of the order or lot. If the operation is a batch process, the time indicated should be applied to the batch as a whole, regardless of the quantity, provided the order quantity is an appropriate size (see section 3.2.3). Alternatively, it may be more appropriate to define the speed of the equipment, perhaps in feet per minute or inches per second. This would be a way to allow the model to calculate the exact delay time based on the attributes (size) of the order.

3.2.3 Operation Batch Size

Batch sizes refer to the number of units of a product that are processed either sequentially without interruption or simultaneously for a given operation. Batch sizes can be expressed in terms of a minimum and a maximum number of units to process for an operation. Logic should be included to determine if the quantity of units in an order is below the minimum or above the maximum batch size for the operation. In the case of the order quantity being below the minimum, logic should be executed that would group orders for like products until the minimum is satisfied. Should the order quantity be above the maximum, determine the number of sub-batches required and split the original order accordingly. This information will be necessary in order to apply the processing time (see section 3.2.2) correctly if there are batch operations in the manufacturing process.

3.2.4 Transportation Batch Size

The transportation batch size specifies the number of units that must be completed by the current operation before the product is transported to the next operation. If the product is transported in the same batch through all operations, the batch size can be specified once per product. However, the quantity may be different for each operation, in which case it must be defined for each operation in the routing. This information is required to determine when a group of products will be available to proceed to the next routing step.

3.3 Customer Orders and Work-In-Process

Simulation has traditionally been used for planning and design activities and used substantially less for the implementation and daily operation of a system (Thompson 1994). Not surprisingly, the standard techniques of modeling entity arrivals and initial system conditions are not valid approaches when developing a daily scheduling tool. An important aspect of a simulation-based finite scheduler is that it must use actual demand (customer orders) and work-in-process (WIP) information, not arrival/demand data estimated from statistical distributions. Statistical distributions only characterize what this data *could* be and not the reality of what it is on a specific day. By using the structure in Figure 1, it is possible to interface with MRP systems or sales order processing systems to obtain the active customer orders file. The important data elements of customer orders generally include: product identification, order identification, customer, production lot number, quantity, due date, and priority. This information is used in the simulation logic as parameters in sequencing decisions. If the system has many restrictions based on order characteristics, it is important to read in those characteristics as attributes of each order. In the weaving example shown in the resources definition, we would need to define the width of the fabric, the size of the order (roll length) and the fiber content in order to match up the machine restrictions.

The standard simulation approach to dealing with initial conditions is to start a run with the system "empty and idle" and allow it to continue for a warm-up period until a steady-state is reached. Steady-state conditions are of no concern to daily scheduling and planning operations. Rather, it is the actual state of the system at a specific moment in time that is of interest. The current state of the system is defined by reading in the WIP file that identifies the current location of each order and the remaining processing time at its current operation. It is required that the model be initialized to the actual current state of the system because each sequencing decision can depend on the current WIP status and resource availability. WIP information may be collected and input by hand prior to running the scheduler, or, preferably, is available through a WIP tracking system that can download the information directly to the file that will be read by the model.

3.4 Other Data Issues

There are a number of other factors that will probably be required to accurately schedule a system. The following two examples discuss other functionality that can be achieved with a simulation-based scheduler. The information to incorporate these features may be system or product specific and should be located accordingly in the definition files.

3.4.1 Work-In-Process Limits

Specifying desired minimum and maximum WIP limits is optional, but should be included if controlling in-process inventory is a concern in generating a schedule. These limits may be defined in terms of the number of units or the time value of the work waiting to be processed. Limiting the amount of WIP is important when there are physical space limitations for in-process storage and staging. From a management perspective, it is also important to minimize the financial investment required to maintain inventories. WIP limits would normally be included in the system definition file for each resource or resource group, but may also be defined with the product routings if it is product and operation specific.

Since queuing and current inventory levels can only be determined with a simulation that steps through time, Kanban systems with WIP limits are prime candidates for simulation-based schedulers. Heuristic-based schedulers are not able to schedule an operation based on the backlog of work at a downstream process because they cannot calculate the details of time-based system dynamics.

3.4.2 Inventory Levels

Finished goods and raw materials inventory levels should be specified if they are a consideration in the scheduling process. This information is most often used to determine if a product needs to be manufactured to fill an order and if the materials necessary to make the product are available. In many facilities these functions are performed by MRP systems. However, the simulation scheduler can perform these tasks if the information is available and an MRP system is not in place. In the absence of an MRP system, these tasks must still be performed and are often done so by hand. The advantage of the scheduling simulator is that it can automate the manual process of pre-processing, grouping, and releasing orders. This information is product specific and should be included in the product definition file or can be read in as a separate file that only contains current inventory levels.

4 MODELING ISSUES

Since the simulation model is the scheduling engine, it will be necessary to define the decision logic that will be used to assign orders to resources. It is important to be as flexible as possible in developing the model so the scheduler can continue to be used as system priorities change. As discussed above, it is useful to have attributes and capabilities that can be used as parameters of generic decision processes. With this structure, the specific values of the attributes can change without requiring programming changes.

The basic element of sequencing decisions are queue ranking rules. These are priority schemes that sort the orders waiting for a particular resource. Queue ranking rules typically correspond to order and product attributes such as product identification, customer identification, due date, priority, or processing time.

Scheduling options refer to more sophisticated methods that define how to select the next order to process from a group of potential orders. It is possible to construct multi-level decision rules based on multiple criteria that will filter the potential orders to be scheduled. It is possible to select an order with the earliest due date that uses the same tool as the last product processed (to avoid a setup). Another scheduling option would be to schedule an upstream process based on the needs of processes located further downstream (Thompson 1994). For instance, cutting operations in the sewn products industry may select the next order based on determining the lowest WIP level at downstream sewing centers. The objective would be for a cutting resource to process some required level of demand while avoiding starvation at sewing, yet minimizing WIP build-up. Another selection process may define first, second and third choice order characteristics. This would require searching the pending queue for the first choice, second choice and so on until a match is found.

In selecting the order to process, it is very common to come across more than one order that meets the criteria. Here it is important to define tie-breaking mechanisms. Most searching mechanisms in simulation languages select the first item to satisfy the search conditions. By changing the tie-breaking mechanism from one simulation run to another, it is possible to generate multiple schedules (solutions) for the same scenario (Rosenwinkel and Rogers 1993). This is a way to build pseudo-optimization into a simulation-based scheduler.

In summary, by constructing a simulation model to generate a finite schedule it is possible to define ranking rules and scheduling options that are unique for each specific area of a system. Order sequencing decisions can consider current system conditions and can compare all pending orders because all orders are tracked simultaneously.

5 APPLICATIONS FOR THE SCHEDULING MODEL

A simulation-based scheduling model may be used for a number of purposes. In addition to generating daily production schedules, it can serve as a tool for handling exceptions in the production plan and as a long-range planning and analysis tool. This added utility of a simulation scheduling model cannot be found in heuristic-based schedulers.

5.1 Short -Term Sequencing

A simulation application used for daily scheduling should be executed predominantly in a deterministic mode using standard processing times, actual customer orders, and current system conditions based on WIP data and resource availability. The purpose of a scheduling simulator is to determine the exact sequence of specific customer orders to be scheduled for each resource while taking into account all the constraints of the system. Slack factors used in the scheduling process being modeled may be included, but additional variability and potential resource breakdown should not be incorporated. It is not realistic to include unpredictable events and impose their consequences on the daily schedule until the event actually happens.

5.2 Exception Scheduling

While the normal planning process may generate a schedule for the next day or the next week, the simulation can be re-run at any time to accommodate disruptions such as major machine breakdowns or part shortages (Harmonosky 1995). In this way, the model will be used for exception-based rescheduling that will address the “what now” questions that arise when unanticipated events occur. Typical “what now” questions include the following. Is an order going to be late because of the new circumstances? Do I need to contact the customer to negotiate a new due date? Do I need to add overtime to the schedule or should I activate alternative resources? A simulation-based scheduler can provide the feedback necessary to answer these questions quickly and accurately.

5.3 Long - Range Planning

A scheduling simulator can also be a valuable long-range planning tool if logic is built in that provides the option to read specific order data from external files *or* generate demand within the model using statistical distributions. The scheduler should be executed in the stochastic mode for long-range planning. The random events not explicitly generated in the deterministic mode should now be turned on in the model and randomly varying processing times should be used. The simulator can test system robustness to demand fluctuations, experiment with long range sales forecasts and product mix, determine if the system capacity is sufficient for projected future demand, and perform "what if" analyses common to mainstream simulation studies.

SUMMARY

Process Simulation languages can effectively be used to create finite capacity scheduling applications. Since scheduling models will be used as daily business tools, it is important to design the model to be flexible. Using external files to define the current state of the system and the orders that must be scheduled, will achieve this flexibility and will make it easier for non-simulation-experts to safely use the tool. Because a simulation steps through time while keeping track of all orders (entities) in a system, such a scheduler will be able to make comparative decisions based on actual system conditions. It will also be possible to have different scheduling rules in different areas of the system instead of the single, global procedure used in heuristic schedulers. By taking the issues mentioned above into consideration, it is possible to create a robust, custom scheduler that is less expensive than an off-the-shelf tool.

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