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A SIMULATION MODEL FOR PRODUCTION SCHEDULING OF A FACILITY IN A PROCESS INDUSTRY

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ABSTRACT

Production scheduling of a process industry is a formidable task. The objectives of scheduling in the facility described in this paper are to:

- satisfy demand;
- meet due dates for final products; and
- increase throughput by reducing the number of setups.

Multiple product lines of varying volume and the interaction of storage constraints with continuous flow of material create a complex relationship among these three objectives.

This paper describes a simulation-based scheduling system for finite capacity scheduling of a facility in a process industry. The primary focus is on the modeling techniques and scheduling logic used in constructing the FACTOR simulation model imbedded in this system. The construction of an MRP schedule to drive the simulation model is also discussed.

1. INTRODUCTION

The facility to be scheduled by the method described in this paper processes agricultural products in batches. The process has three stages. As a batch completes each stage, it is placed in a storage bin before starting the next stage. A batch does not necessarily remain together for the entire three stage production process. Often portions of several batches at the first or second stage are combined according to a formula into a batch at the succeeding stage. Final products are continuously fed into packaging lines that are not included in the system under study. The facility is illustrated in Figure 1.

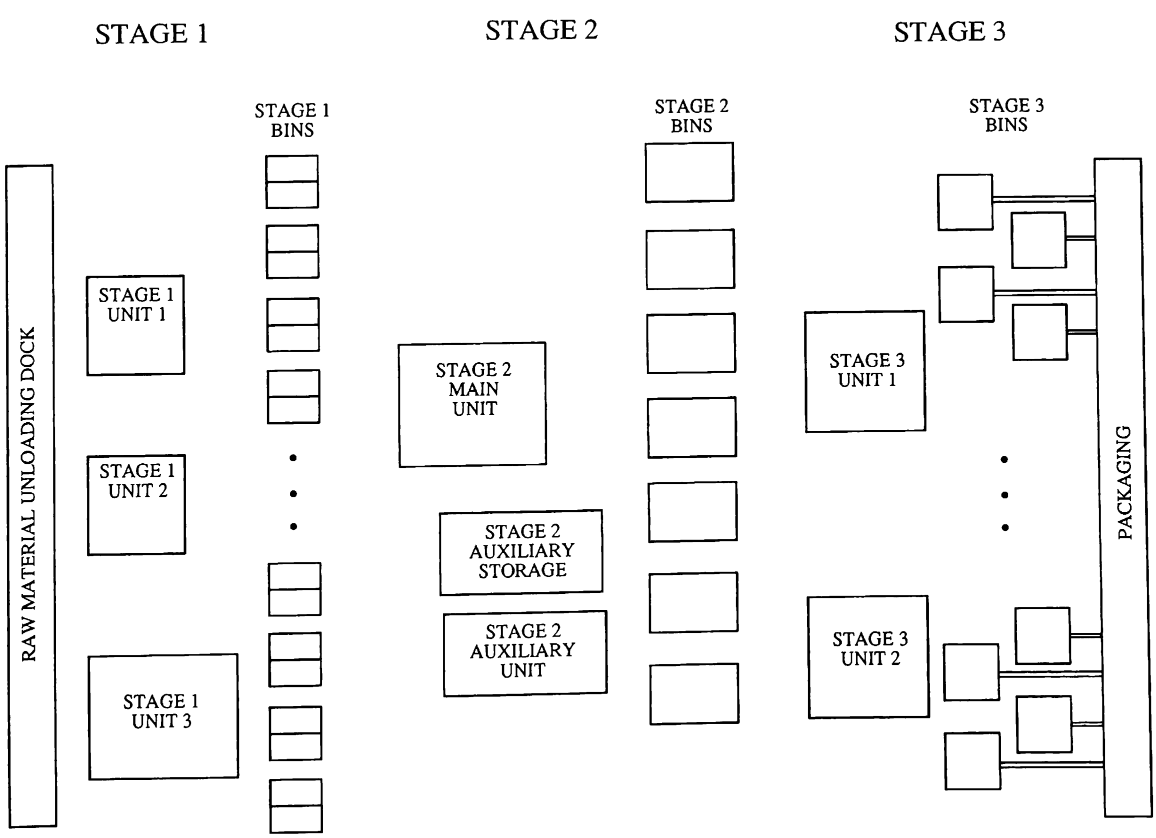

Figure 1. Facility Equipment Layout

In stage 1, raw material is processed through one of three processing units. Storage for the product of stage 1 consists of 30 bins. Bins are divided into three categories:

- pairs of bins dedicated to one product,
- single bins dedicated to one product, and
- undedicated bins.

Stage 2 is the bottleneck in the operation. It has a main processing unit and an auxiliary processing unit for those products requiring a two-phase process. Several stage 1 products from stage 1 bins may be mixed in the main processing unit to form a stage 2 batch. The quantity of each stage 1 product required may not be equal to an entire stage 1 bin. For this reason, partially filled stage 1 bins may occur. There are two intermediate storage bins between the main unit and the auxiliary unit. The intermediate storage is required because the first phase is normally much faster than the second, and once the first phase is done, the main unit can start another batch. Since stage 2 batches are usually much larger than stage 1 batches, the storage for the final product of this stage consists of only six nondedicated bins and one dedicated bin.

Stage 3 has two identical processing units. The final products are released from these units into storage bins, all except two of which are dedicated to a specific final product. The two bins not dedicated to a specific final product are reserved for one of two disjoint families of products. Final products are continuously removed from these bins at a rate that remains constant over a shift.

2. PRODUCTION CONSTRAINTS

The main production constraints in this facility are

- capacity for storage of products between stages, and
- capacity of the processing units at stage 2.

Storage constraints impose the operating requirement that both component materials for a product and storage for the product be available before the processing at that stage can begin. Storage bins are not abundant, limiting the output obtainable from the process. To complicate matters, storage bins may be dedicated to specific products, as in the case of high-volume products. Bins may also be dedicated to products whose properties are such that a storage bin requires a lengthy or expensive cleaning process before it can be used for another product. In other cases, such as low-volume products, storage bins are undedicated and may contain a different product at each filling. Except in special cases of high-volume storage bins or storage bins which can hold double batches of a product, a bin must be completely empty before it can be refilled.

The main processing unit at stage 2 must run almost continually to satisfy demand. Double batching at the second stage increases throughput because the second batch shares a processing unit setup, eliminating the need for nonproductive changeover. However, indiscriminate use of double batching can cause due dates to be missed and demand at packaging to go unsatisfied.

The combination of these two constraints makes it imperative that the right products be produced at the right time. This paper describes the techniques used to generate schedules for this facility.

3. SCHEDULE GENERATION PROCESS

The process of generating a schedule for this facility follows these four steps:

1. creation of a simple MRP schedule for each stage of production based on the demand from packaging and the bill of materials;
2. translation of the simple MRP schedule into input data to drive the simulation;
3. execution of the simulation; and
4. generation of detailed production schedules from the simulation data.

This paper focuses on the creation of the MRP schedule and the construction of the simulation model.

The creation of the simple MRP schedule is particularly interesting because of the interaction of continuous flows with batch processes and the "pull" of demand from packaging. The algorithm for creating this schedule is described in section 4. A stand-alone program is used for this purpose.

The simulation model exhausts the demand specified in the simple MRP schedule in order to generate detailed production schedules for each resource and storage bin. The detailed schedules produced by the simulation model are achievable because of the "realism" built into the model [Pritsker 1989]. Realism comes from the modeling constructs and extensions, which encompass the continuous aspects of the system, the storage constraints, the finite capacity of processing units, and operating requirements pertaining to space and material availability. Section 5 focuses on the modeling of the manufacturing system and its constraints. Realism also comes from the ability of the model to mimic the decision-making process and provide information similar to that used in the actual manufacturing operation. In this facility, the model enhances the decision-making process by allowing stages of production to communicate and coordinate with one another. Incorporation of coordination across stages into the scheduling logic is the key to producing viable production schedules and is discussed in Section 6. The simulation model is built on the framework of FACTOR but is supplemented with tailored logic for modeling system constraints and implementing the scheduling logic.

4. THE SIMPLE MRP SCHEDULE

Demand from packaging drives the scheduling system by creating a "pull" on products of the three stages of production. Stage 3 products must complete before they are demanded by the packaging lines. The starting time for a stage 3 product imposes a completion time on its ingredients which are stage 2 products. Similarly, the starting time of a stage 2 product imposes a completion time on some stage 1 products. To generate the simple MRP schedule, demand at packaging is projected back to each of the three stages of production and the times at which batches must complete are determined. These times are referred to as absolute due dates.

The absolute due date for the first batch of any final product occurs when the initial inventory is projected to be depleted by demand at packaging. The time of depletion depends on the continuous removal rate and the initial quantity on hand. Absolute due dates of succeeding batches are computed recursively by adding a batch amount to inventory on its absolute due date and calculating the next time of depletion from the removal rate.

To obtain absolute due dates for products of preceding stages, the processing time of the current stage is subtracted from the absolute due date to give the latest date that the product can start. The components of each batch from the preceding stage are found in the bill of materials. The start date of the product of the current stage becomes the absolute due date for its components. The list of components with start dates constitutes a demand for products of the preceding stage. Observe that the items in this list are not necessarily full batches. Although this is a discrete demand instead of a continuous demand, as is the case at the final stage, the absolute due dates may still be computed by determining when inventory will be depleted, adding a batch quantity to inventory and repeating.

5. THE SIMULATION MODEL

The simulation model is built on the framework of the standard components of the FACTOR base system. The standard model components and their relationships are illustrated in Figure 2. Orders, generated from the simple MRP schedule, are placed for parts which represent raw materials, intermediate products and finished products. In this application each order contains one load which corresponds to a batch of product. The jobsteps of a single-phase process plan are shown in Figure 3. Resources represent finite capacity processing units. Materials represent the bins in which products are stored.

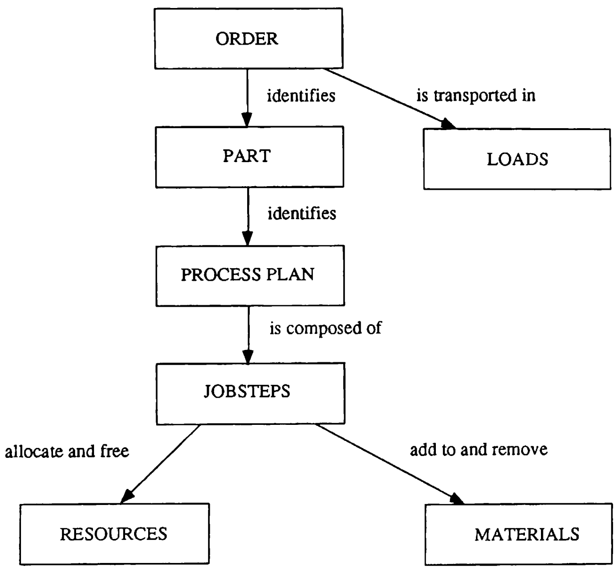

Figure 2. Fundamental FACTOR Model Components

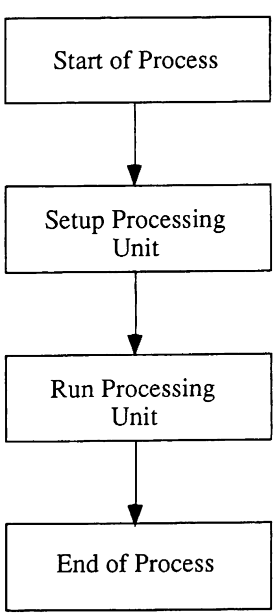

Figure 3. Single-Phase Process Plan

The details of the modeling of storage constraints and operating requirements pertaining to availability of space, intermediate products and raw materials follow.

5.1 Modeling of Storage

Standard FACTOR materials are used in this application to model storage bins dedicated to specific products. The capacity of the material (i.e., available space to store product) is the sum of the capacities of the individual bins dedicated to a particular product. The capacity of a single bin, for scheduling purposes, is equal to the standard batch size of the product.

A set of bins dedicated to a product is modeled by a single material. This is possible because a product is removed from one bin only, with no additions to that bin until the bin is empty. Moreover, it can be assumed that there is at most one partially filled bin. The number of full, partially filled and empty bins dedicated to a material can be determined by dividing the quantity on hand by the standard batch size.

The set of undedicated bins at each stage in the process is also represented by a single material. In order to model the individual undedicated bins, an auxiliary list has been added to each material record in the database. In the case of materials representing dedicated storage bins, the list remains empty. For materials representing sets of undedicated bins, the list is populated with entities specifying the bin identifier, the product currently stored in the bin, the quantity in the bin and the quantities of space and materials reserved in the bin.

5.2 Space, Intermediate Product and Raw Material Requirements

Two tailored jobsteps were created to model operating requirements pertaining to availability of space, raw materials and intermediate products. These are:

- start-of-process jobstep, and
- end-of-process jobstep.

The start-of-process jobstep checks the availability of raw materials or products of a preceding stage required to make the product of the current stage, the availability of storage space for the product of the current stage, and the availability of the processing unit at the current stage (or possibly current phase of the current stage). The requirements for raw materials or products of a preceding stage are obtained from custom database records containing the bill of materials. If the storage space is undedicated, the list of bins associated with this space must be searched in order to find an empty bin with no space reservations. If the processing unit, storage space and raw materials or products of a preceding stage are all available, the space and materials or products are reserved.

The start-of-process jobstep has continuous modeling capabilities for the purpose of accurately determining when storage bins containing raw materials or products of a preceding stage become empty. This is necessary since a product of the current stage usually requires quantities not equal to the bin size of the preceding stage. The following example should clarify this concept. A stage 1 product has 11,000 lbs. of inventory on hand in two bins. Since each bin has a capacity of 10,000 lbs., there are 10,000 lbs. in one bin and 1000 lbs. in the second bin. The formula for the stage 2 product requires 2000 lbs. of this stage 1 product. Given a stage 2 processing time of 2 hours and assuming a uniform removal rate over the time of processing, it is determined that the bin containing 1000 lbs. will be empty one hour into the stage 2 processing time. At that time the quantity on hand is decremented by 1000 lbs., making 10,000 lbs of capacity, which is one bin, available for space reservations.

The end-of-process jobstep contains logic to remove raw material and intermediate products reserved but not removed by a start-of-process jobstep and to add the product of the current stage or phase to storage reserved by a start-of-process jobstep. It resets the reservations for raw materials, intermediate products and storage. It has the capability to selectively reset some reservations and retain others depending on the point at which the jobstep occurs in the process plan.

6. SCHEDULING LOGIC

The scheduling logic for the simulation model was designed to meet the scheduling objectives while adhering to the production constraints of this facility. These objectives are to:

- satisfy demand;
- meet due dates for final products; and
- increase throughput by reducing the number of setups.

Evaluation of the production system with respect to the scheduling objectives indicates that meeting the objectives is contingent on the operating strategy for the bottleneck. Improper sequencing at this processing unit can result in the late delivery of final products through inefficient use of setups and storage bins. Additionally, sequencing at the bottleneck is constrained by the availability of stage 1 products. For this reason, the stage 1 scheduling logic must consider process dependencies.

The ability of stage 3 processing to satisfy demand is heavily dependent on the sequencing at stages 1 and 2. Sequencing by earliest due date is adequate for stage 3 and therefore, will not be discussed further.

6.1 The Main Processing Unit at Stage 2

Sequencing logic for the main processing unit of stage 2 must consider that the setup time is lengthy when clean-up is required between batches of different products and that storage space subsequent to this process is very limited.

Initially this queue is sequenced by least dynamic slack. Dynamic slack is defined as the time to due date less the estimated processing time for an order. Least dynamic slack ordering gives some treatment to the objective of meeting due dates and accounts for processing time, but does not address throughput issues or storage constraints.

The throughput issues and storage constraints are introduced into the scheduling logic by performing a series of tests on the queue ordered by least dynamic slack. The queue may be reordered based on these two tests:

- storage availability test, and
- double batching test.

The storage availability test determines if there will be storage space available within an acceptable time window for the stage 3 product consuming the stage 2 product under consideration. This test ensures that the limited stage 2 storage will not be locked up with products that will not be processed at stage 3 in the near future.

If an order passes the storage availability test, then the double batching test is made. The double batching test determines if it is feasible to pull forward an additional order for the same product to gain a throughput advantage. An order is not pulled forward if there are remaining orders with a dynamic slack less than a specified threshold or if storage space is not available for the second order.

Dynamic slack sequencing with these tests balances the objective of increasing throughput with the objective of meeting due dates provided the stage 1 products are available. The following section discusses the complementary nature of the stage 1 and stage 2 scheduling logic.

6.2 The Stage 1 Processing Units

The stage 1 processing units supply the ingredients consumed during stage 2 processing. Therefore, the stage 1 processing units must be synchronized with the stage 2 operating strategy in order to avoid idle time at the bottleneck. A "pull" concept is employed to achieve this synchronization.

The sequencing of the stage 1 processing units is based on a list constructed from a copy of the current stage 2 main unit queue and the bill of materials for each stage 2 product in the queue. This list is modified according to the need for a stage 1 product. Need is established from the following criteria for each stage 1 product on the list:

1. the current inventory position;
2. the reservation status;
3. quantities marked for other entries on the list;
4. the in process quantity; and
5. the available storage space.

The following example should clarify this concept. Suppose the first product on the stage 2 main processing unit queue is A, and product A is made up of stage 1 products A1 and A2. Products A1 and A2 are both given a rank of 1 on the list since they are associated with the first stage 2 product planned to be processed. Once constructed, the stage 1 ranked list is traversed from low rank to high rank, and each entry is tested according to the above criteria. Since A1 is the first on the list, suppose its requirement is for 1000 lbs. Additionally assume that there are 1250 lbs in inventory with no reservations, none marked for another entry in the list, and no A1 in process. This implies that no need exists for A1, since the requirement is satisfied by available inventory. To avoid double counting, 1000 lbs. of A1 are marked for this A1 entry. This process of searching the list continues until an entry with need is found. Once a product with need is found, storage space is examined. If storage is available, then the queue for the stage 1 processing units is searched for this product's order with the earliest due date. This order is moved to the head of the queue.

The coordination of the two stages greatly increases the efficiency of the process. The likelihood of idling the bottleneck is reduced, increasing the ability of the process to satisfy demand.

7. SCHEDULING SYSTEM OUTPUT

The primary outputs of the scheduling system are the Order Summary Report and the Processing Unit Schedules.

The Order Summary Report is one of the best indicators of schedule viability because it specifies the predicted completion date and subsequent earliness/lateness of every order for each of the three stages of the manufacturing process. The report can also isolate only late orders or orders expected to complete later than a specified lateness threshold. Therefore, this report provides the data necessary to determine if the scenario under evaluation achieves the objectives relating to due date performance without the effort of creating more detailed operational reports. More than one iteration of the scheduling process may be required to obtain a scenario which is satisfactory with respect to due date performance.

Once an acceptable scenario is obtained, Processing Unit Schedules are generated for each processing unit in the manufacturing system. These schedules provide the operator or process controller with the predicted start time and completion time of each batch which must be processed by the unit. The Processing Unit Schedules are operational reports of the events which must occur on the manufacturing floor to produce orders on-time with good throughput and processing unit efficiency.

8. SCHEDULING SYSTEM BENEFITS

The simulation-based scheduling system implemented in this facility provides many significant improvements over the previous production scheduling methods. First and foremost, the scheduling system produces achievable production schedules. Achievable schedules are the result of a realistic model of the manufacturing process. The "realism" comes through the modeling constructs and extensions, which encompass the continuous aspects of the system, the storage constraints in each stage of the process, the finite capacity of the processing equipment, and the inclusion of process dependencies.

The ability of the scheduling model to manage process dependencies is the key to scheduling viability. The scheduling system coordinates the activities of the various operating departments and ensures that they are working together. Under the simulation based system, the stage 1 process controller knows that implementation of his schedule directly impacts the ability of stage 2 to produce its product. Under previous methods, however, the stage 2 process schedule had limited ties to the stage 1 process, which resulted in many interventions and overrides on the shop floor. A lack of coordination also occurred between stage 2 and stage 3. Since a coordinated approach to scheduling the various stages of the process has been implemented, interventions and overrides have become the exception rather than the rule.

Additionally, decisions in a simulation-based scheduling system are dynamic and based on predicted events. For example, the scheduling logic for the stage 1 processing units (described in section 6.2) depends on inventory position which changes over time. Thus, a decision made under conditions of ample inventory may differ greatly from a decision made under conditions of insufficient inventory. This has noticeable implications from a sequencing perspective, among which is improved accuracy in scheduling.

Finally, the simulation-based scheduling system is flexible. The system under study is dynamic. Process changes are constantly implemented in an attempt to improve the performance of the manufacturing system. As process changes are implemented, the model can be modified accordingly without major changes to the overall scheduling system. In other words, the scheduling system is designed to fit the production environment rather than the production environment being tailored to fit the scheduling system.

9. SUMMARY

Simulation-based, finite-capacity scheduling systems have been successfully implemented in the manufacture of discrete parts. This application illustrates the viability of such systems for scheduling process industries. It demonstrates the adaptability of simulation modeling to the production constraints and continuous flows of materials found in process industries. Finally, it provides an example of scheduling logic vital to producing an achievable schedule that coordinates the operation processing units with each other and with storage constraints.

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