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THE ROLE OF SIMULATION IN ADVANCED PLANNING AND SCHEDULING

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ABSTRACT

The tasks of planning and scheduling in manufacturing have evolved from simplistic Material Requirements Planning systems to today's sophisticated Advanced Planning and Scheduling systems. While planning is concerned with the long-range determination of what needs to be manufactured, typically over a relatively long time period, scheduling is the task of deciding how that manufacturing is to be accomplished, typically over a relatively short time period. Simulation is well suited to the scheduling task since it can handle as much detail as is necessary to capture the subtleties of the manufacturing process. It is desirable for a simulation-based scheduling function to be integrated with an Enterprise Resource Planning system, which maintains the system data suitable for driving a simulation of the current system load and thereby producing a feasible schedule. This paper describes such an integrated system and the role of simulation within it.

1 INTRODUCTION

Today's manufacturers face intense competition to deliver on time. Providing excellent customer service often means being prepared to offer a variety of product options, accept last-minute changes, and respond rapidly to orders for build-to-order and configure-to-order products. At the same time companies are attempting to follow the principles of lean manufacturing to avoid the expense of high inventories (Womack and Jones 1996). These pressures make efficient production planning not just desirable but critical to continued survival.

Modern Enterprise Resource Planning (ERP) systems contain all the data necessary for detailed production planning. This includes product information, such as bills of material and routing of parts through the manufacturing process. It includes system information such as equipment, manpower, and shift schedules. It also includes status information such as the current order book, work in process, inventory levels, and released purchase orders. This is what is needed for an Advanced Planning and Scheduling (APS) function to determine how to efficiently plan a plant's operations and to replan quickly and accurately based on changing requirements.

2 MRP AND SIMULATION

The traditional Material Requirements Planning (MRP) function in an ERP system concerns itself with determining the amount of product to be made in a given time period. This is based on the demand for end items in that period, the component items which must go into that demand, and the lead time required to produce each component and end item. A major flaw in such an approach, of course, is that limits on manufacturing capacity are not considered (Musselman and Uzsoy 2001b). Actual lead times usually vary considerably from the fixed lead times assumed by MRP when a system is highly utilized and dynamic.

In order to determine whether or not an infinite capacity plan such as produced by MRP is actually feasible, simulation can be used to determine whether the start times generated by the plan will actually allow the manufacturing orders to be completed by their due dates. The integration of simulation with manufacturing planning systems became feasible in the 1980's as computing power increased to support production control systems, shop floor data collection systems and database management systems. FACTOR, one of the first commercially available simulation-based schedulers, provided a complete set of data transfer functions to support integration with any production data system (McFarland 1987). Soon thereafter General Motors integrated simulation with both a factory control system and artificial intelligence techniques (Jain et. al. 1990).

While simulation is capable of producing a highly realistic manufacturing schedule, the task of "correcting" the infeasibilities of an MRP plan in capacity-constrained environments is quite daunting. Through the years the authors have been involved in many successful applications of such, but the data requirements to maintain a realistic model consistent with the plan and the business process expertise needed to effectively execute it have made these successes costly and difficult to perpetuate. What is needed is a better starting point from which to schedule – which leads to APS systems.

3 ADVANCED PLANNING AND SCHEDULING

An APS system uses variants of the planning and scheduling approaches described above in an integrated way. A planner module which pays some attention to capacity constraints produces a "schedulable" plan. This plan then feeds a scheduler module, which produces a detailed list of operations showing how capacity will be used and returns this information to the planning function for use in the next planning period. The data regarding current and planned operations can also be used to provide realistic estimates of the ability to meet a new customer order request. This integration of planning, scheduling, and order promising is described in this section.

The APS system used as an example here is Frontstep APS, which is integrated with Frontstep's SyteLine and GEAC's System21 ERP systems (Frontstep, Inc. 2001). Its function is to coordinate material and capacity planning in order to fulfill the demands being placed on the manufacturing system. It does this using three key processes: advanced planning, advanced scheduling, and order promising.

3.1 Advanced Planning

The role of planning in APS is to determine what demands on the production system will be met over a given planning horizon. The input to the planning process includes information on manufacturing capacity and demand data. Demands may be of several types: customer orders, forecasts, transfer orders (i.e., orders from other plants), released jobs, or replenishments of safety stock. Manufacturing system data includes bills of material, workcenter availability, part routings through workcenters, and inventory (both on-hand and scheduled for delivery). The output from the planning process is a feasible plan, which provides release and completion times for every demand. Like MRP before it, APS takes into account the availability of materials. Unlike MRP, it also takes into account the capacity of workcenters to process the material and satisfy demands.

This planning process is order-centric, focusing on the demand for end items and determining how much demand can be met in a given time period. Exactly how that demand will be met, in terms of specific assignments of jobs to workcenters and their sequencing, is left to the scheduling function. It is in fact often desirable for a plan to be somewhat tentative, since it covers a planning horizon subject to disruptions. Forecasts may not be accurate. Deliveries may be delayed. Equipment may fail. Unexpected rush orders may be received. Therefore planning is not expected to be highly detailed. Individual machines may be aggregated into a workcenter with no determination of which will be used by a specific order. Setup times may be averaged since sequencing at this time is premature. Buffer times may be defined, especially prior to processing on bottleneck machines, to allow for possible disruptions. The end result is a "schedulable" plan.

3.1.1 Planning Logic

Each end item order to be planned has a promise date, which was determined through an order promise function. The logic of the planner algorithm operates on each order in turn, as follows:

- Start backward from the promise date and reserve the workcenter capacity and material required for each operation. If the material required is a manufactured component, then it too is planned backward from the point at which it is required. If at the end of this pass the start date is on or after the beginning of the planning horizon, proceed to the next order.
- If the backward pass fails, meaning that the resulting start date would be in the past, reserve capacity and material forward from the planning start date. If the resulting completion date is within the planning horizon (even though after the promise date) this order is planned.
- If both the backward and forward passes fail, then the order is not included in the planning period.

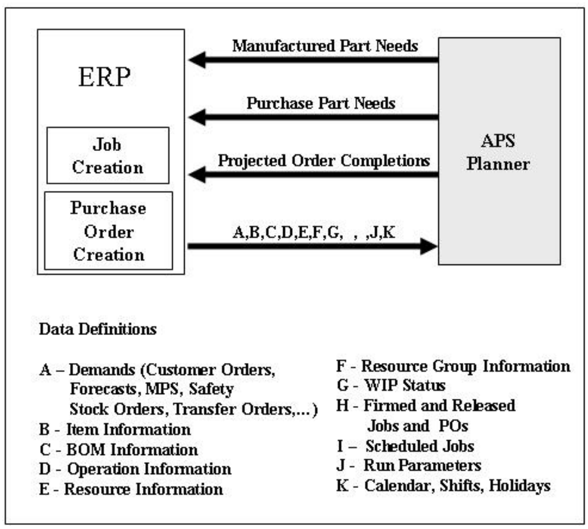

Figure 1: APS Planner Data Flow

The end result of the above process is a "feasible" plan. Figure 1 shows the input and output flows between the ERP system and the planning function.

3.2 Advanced Scheduling

The role of the scheduler module in APS is to produce a detailed list of operations specifying which orders are to be worked on at which workcenters and at what times. The input to this module includes all demands to be satisfied, including the internal orders added by the planner module when an end item required a component to be manufactured. It includes the current material inventory levels as well as planned deliveries of purchased materials. It also includes the same manufacturing system data as that provided to the planner module but uses a more detailed representation of that data. Detailed information used by the scheduler module that is not pertinent to the planner module includes

- Variable run times based on the machine and operator actually assigned
- Rules for selecting machines and operators based on skill sets and quality requirements
- Variable setup times based on the previous and next part characteristics such as part type, family, color, width, etc.
- Rules for sequencing jobs at workcenters, based on minimizing setup and other factors
- Allowable shift overruns
- Rules for selecting from a list of prioritized jobs based on due date, slack, cost and other factors.

The result is an accurate representation of what to expect on the shop floor in the immediate future. While the planner module typically considers demand on the system over a few weeks or months, the scheduler module will typically work with a much shorter time frame such as a shift, a day, or a week (Pritsker and Snyder 1994). The usefulness of a detailed schedule degenerates quickly as time passes, since disruptions on the shop floor or changes to the order mix may require significant adjustments. For this reason a simulation used for generating a schedule is usually deterministic. If a random event occurs (i.e., machine failure, arrival of a rush order, or a missed delivery date by a supplier) then a new schedule can quickly be generated and its impact evaluated. This will be illustrated shortly.

3.2.1 Scheduling Logic Using Simulation

While the APS planning function is order-centric, the APS scheduling function is event-driven. Given a set of orders and associated start dates, the scheduler algorithm begins by generating a calendar, that is, a time-ordered list containing the first scheduled operation for each order. As each operation is able to acquire the workcenter capacity and materials it requires, the calendar is updated to reflect the time at which the operation will end.

Each order moves through its route over time, with its completion date dependent on the dynamics of the system. Which specific machine will it be allocated at a given operation? How long will it have to wait for other orders at the same machine? What will the setup time be? Answers to these questions cannot be planned ahead of time, but rather unfold dynamically as orders move through the system over time. The end result is a detailed schedule.

Figure 2 shows the input and output flows between the ERP system and the scheduling function. Figure 3 illustrates that the scheduled jobs dictated by the scheduler module and purchase orders released by the ERP system are returned to the planner module for the next planning run. It is this "put-back" that allows the APS Planner to continue to produce realistic plans while honoring the APS schedules.

The entire planning and scheduling process is tightly integrated, but not automatic. As described earlier, the

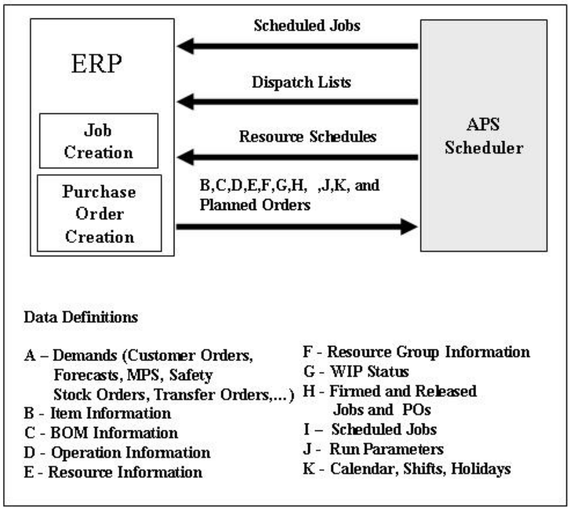

Figure 2:. APS Scheduler Data Flow

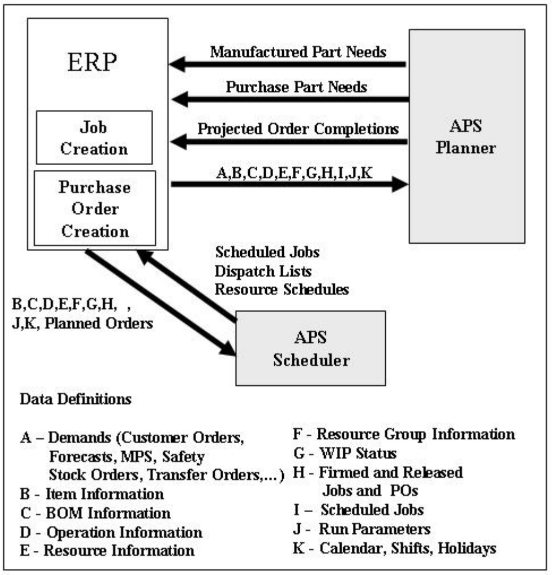

Figure 3: Closing the Planner/Scheduler Loop

APS Planner produces planned manufacturing orders and planned purchase orders. These are based on actual customer orders and, optionally, on forecasts and other estimates. A (human) production planner now may use these recommendations to release jobs to the shop floor and to create purchase orders. The APS Scheduler is then run, and uses these planned and released jobs to assign workcenter capacity and inventory. Only the released job assignments are then fixed within the APS Planner to create new recommended plans.

3.2.2 Comparing Alternative Schedules

A feasible schedule may not be a desirable schedule. If too many orders are not "schedulable," for example, there are a number of things that might be tried to temporarily increase the capacity of the system. Perhaps an extra shift could be added for a key workcenter. Temporary help might be brought in if labor is the bottleneck. One or more operations might be outsourced. A major benefit of simulation has always been the ability to investigate variations on a system without disturbing its operation. This benefit has been brought to APS by providing the ability to copy the ERP data and experiment with changing one or more parameters and comparing the results with the original.

The APS Analyzer screen shown in Figure 4, for example, provides access to two alternative versions of a production system that assembles, paints, and inspects production system bikes. Figure 5 illustrates a graphical version of a resource schedule for this system using one workcenter for each operation (Alternative 0). The planner module has determined that the start date for order 9911-0003D should be at 2:30 p.m. on Thursday, November 7. The scheduler module has projected that the completion date will then be 1 hour prior to the promise date.

Unfortunately, on November 5 a shipment of component parts did not arrive. All orders requiring the component are starved and thereby made late. The new projected date of order 9911-0003D shown in Figure 6, for example,

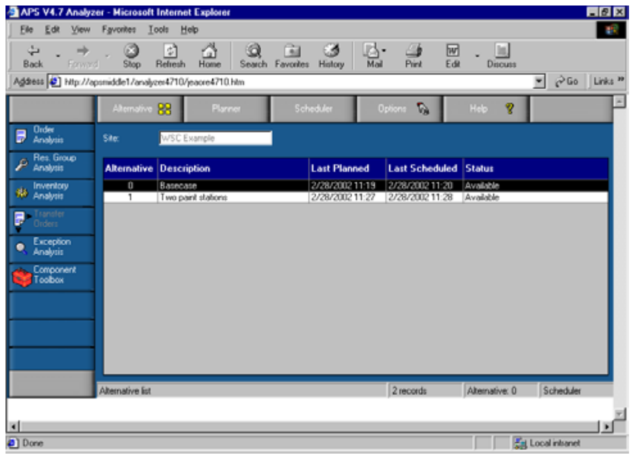

Figure 4: APS Analyzer Screen

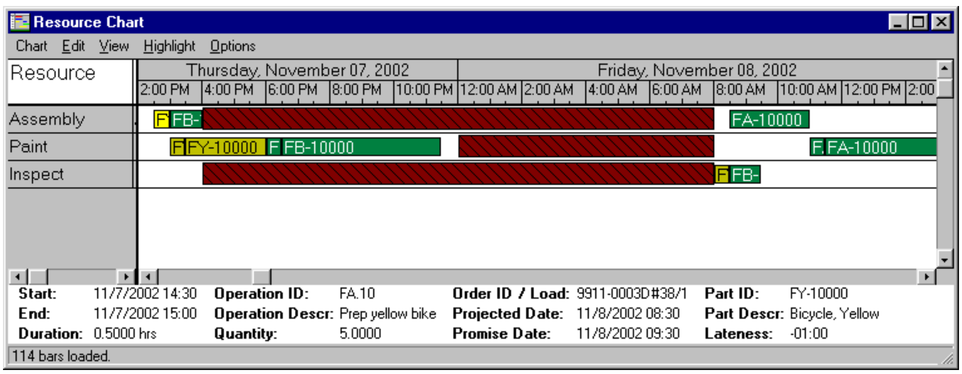

Figure 5: Resource Analysis Gantt Chart, Alternative 0.

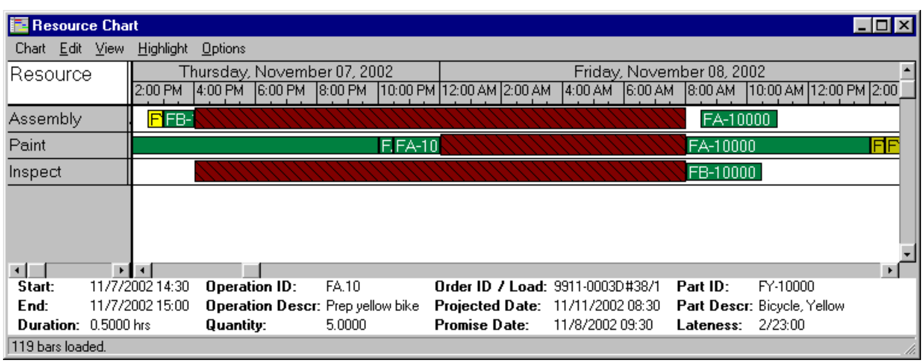

Figure 6: Delayed Delivery

is nearly 3 days late. One alternative which might reduce the lateness of this and other orders is the temporary addition of a second paint station. Selecting the Component Toolbox from the APS Analyzer screen allows the user to modify the system components shown in Figure 7.

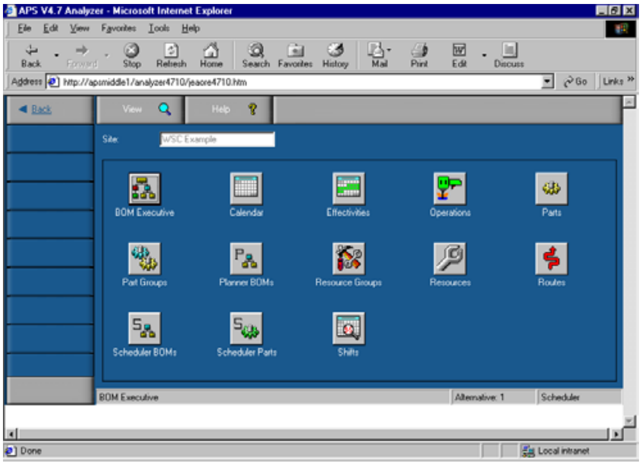

Figure 7: APS Component Toolbox

Adding a copy of the Paint resource, Paint2, and making it a second member of the Resource Group Painting will allow two bikes instead of one to be painted at a time. Figure 8 illustrates the new schedule, in which order 9911-0003D is once again projected to be one hour early. This is only one of many options that might be tried.

Bear in mind that running an advanced scheduling function may not be necessary to satisfy the needs of the shop floor. The main difference between advanced planning and advanced scheduling is not necessarily the detail reported but rather the effect that sequencing has on production. If the sequence in which orders are to be processed at each workcenter does not significantly affect the throughput, then a detailed schedule may not be required (Musselman and Uzsoy 2001a). The advanced scheduling function can be critical, however, for systems in which setup times between products are significant.

3.3 Order Promising

The use of APS enables a supplier to realistically answer the customer question "When can I get N units of Product X?" Or the related question, "How much of Product X can I get by date Y?" With a realistic representation of the current status of a manufacturing site, it is straightforward to reproduce the effect of adding the customer's order to the mix and be able to make a realistic promise. This process is referred to as CTP, or capable-to-promise. Since CTP uses both available inventory and production capacity to determine a date at which an order can be promised, it differs significantly from simpler available-to-promise (ATP) functions which consider only uncommitted inventory as available to satisfy the demand.

If there is only one plant which can satisfy a customer's demand, then only one promising system need be consulted to obtain a realistic promise date. If, on the other hand, other participants in the supply chain need to be considered, then it becomes necessary to connect to them as well. This can be done using the Internet. Given each participant's response, the "best" promise date from among a variety of sources can be obtained.

Figure 9 illustrates a scenario in which a customer inquires about the ability of a supplier to fill an order. There are multiple sites in the supply chain which can supply the item in question, and the promise date supplied by each is dependent on the information available. A "point promiser" site provides a date based on available inventory and planned supplies, while a "capacity promiser" site estimates this date based on production rates as well as available inventory and planned supplies. The best information is available at an APS site, which knows, based on available inventory and workcenter capacity, exactly when and how the order can be filled. This wealth of information comes at the expense of setting up a good information system, of course, which is why the supply chain function allows the inclusion of sites which might not be in a position to maintain APS-quality data for CTP.

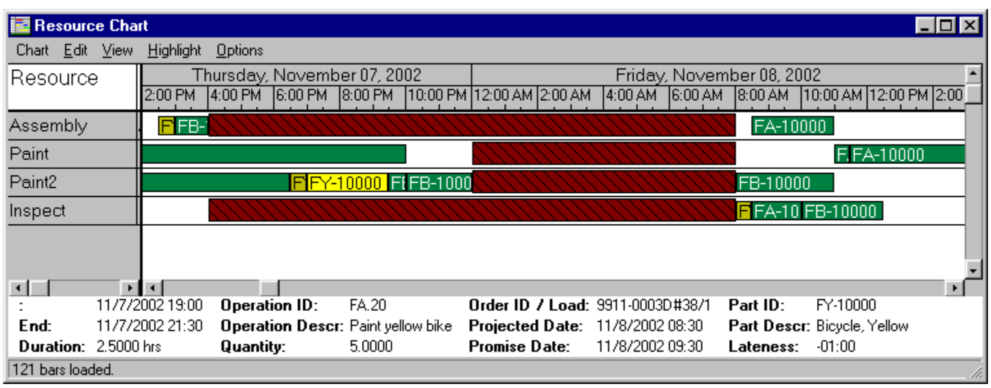

Figure 8: Resource Gantt Chart, Alternative 1

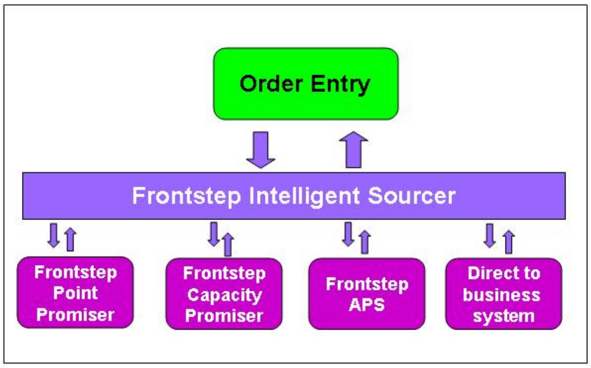

Figure 9: Order Promising Across Multiple Sites

4 CONCLUSION

The ability of an APS system to realistically project order completion times as well as the utilization of capacity and materials is critical in today's competitive manufacturing world. Combining APS planning technology with enterprise management processes can improve customer service and on-time delivery, reduce expediting, overtime and inventory, and increase throughput and profit. Simulation's scheduling role in such a system is key due in large part to its ability to faithfully replicate the real world. Its value is further enhanced when fully integrated with advanced planning and order promising.

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