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VALIDATING THE CAPACITY PLANNING PROCESS AND FLOWLINE PRODUCT SEQUENCING THROUGH SIMULATION ANALYSIS

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ABSTRACT

This article illustrates the integration of discrete event simulation into the capacity planning process of a tier two automobile supplier. In this application, the capacity planning process is able to generate a feasible schedule for the 30% of the product line which generates 80% of the business. The schedule is “feasible” based on the ability to produce sufficient inventory to cover customer demand. The capacity planning process was unable to develop a schedule for the production of the remaining 70% of the product line or take into account shortages in customer supplied materials used in the production process. Simulation is used to validate the capacity planning process as well as generate a feasible schedule for the remaining products during the planning period as well as: evaluating the plan for customer supplied materials; identifying potential areas for improvement in the production process and determining material storage requirements for the facilities planner.

1 INTRODUCTION

In discrete parts manufacturing, the use of a manufacturing resource planning system (MRPII), requires that both production and capacity planning are integrated processes. The production and capacity planning process starts with an aggregate production and resource requirements plan and then generates the master production schedule (MPS) and rough-cut capacity plan (RCCP). At this point in the planning process, only the capacity for critical work centers has been examined. After a bill of material (BOM) explosion, the material requirements plan (MRP) is generated and the capacity of the individual work centers is validated prior to setting a shop floor schedule (Sipper and Bulfin 1997). Apart from well known limitations of the MRP approach (Watson et al. 1997), issues such as demand uncertainties and production equipment availability require a more robust method of generating and validating shop floor schedules. Although the capacity planning process may differ in continuous process industries, the validation of the capacity plan with production requirements must also be performed. The objective of this paper is to describe the capacity planning process in a company in the fabricated metal product industry and explain the use of discrete-event simulation (referred to from now on as simulation) to validate their capacity planning process.

The manufacturing process under examination is typical for industries such as stamped and fabricated metal wire products. Production is scheduled in large lot sizes due to customer demands and setup times for the processes. Individual products are scheduled onto specific flowlines where that product is completely processed. Steel coils, varying in material type, gage, and slit width are run through a continuous process which transforms a solid “wafer-like” strand of steel into a flexible, usable subcomponent in the automotive industry. The steel, which begins on a coil at the “back” of the production line, is “unwound” as it progresses through a series of straight-line continuous production processes which stretch and form the metal into an altered state which is “re-wound” onto a spool at the other end or “front” of the production process. That spool of finished material is then shipped to a tier one supplier and is assembled with other components to form a sub-assembly that is shipped to the original equipment manufacturer (OEM).

The capacity planning process determines which of the products, out of over seventy current products, should be scheduled for production on a repetitive cycle and on which flowline they should be scheduled. The products that are not explicitly scheduled will be accommodated by “open” capacity gaps on the different flowlines. The capacity plan cannot take into account the dynamics of spool availability. Spools are supplied by the customer and the amount of spools that the customer supplies are usually negotiated at the beginning of a product launch. As product is manufactured and placed on the spools, the spools are shipped to over twenty unique customers, and after the product is used in the customer production processes, the empty spools are shipped back to the manufacturer. Spools are not generic but customer specific and as such product must be placed on specific spools. In this manner the production system acts as a closed queuing network. The objective of the simulation is not only to validate the capacity plan with regards to inventory levels and customer demand but to also project the number of customer specific spools that are necessary for the system to operate efficiently.

2 BACKGROUND

Manufacturing companies face many internal and external pressures to become a more efficient in the process of creation and delivery of their products to their customers. World class customer service requires the ability to adapt to changing customer demands while still delivering the product on time. Competitive forces and the implementation of lean manufacturing practices force companies to reduce their inventories without negatively impacting customer service. Competing in this type of environment requires manufacturers to reevaluate the use of outdated systems. Over 64% of world class companies presently use planning and scheduling systems (Jusko 2000). Musselman et al. (2002) describes a simulation-based scheduling function that is integrated within Enterprise Resource Planning (ERP) systems which produces a feasible schedule through the integration with a simulation engine. Simulation-based scheduling has also been integrated into a shop floor Manufacturing Execution Systems (MES) in a semiconductor fabrication facility (Watt 1998). Although there are many commercial scheduling software packages available, developing a simulation-based scheduler provides many benefits such as lower cost than most off-the-shelf systems, allows "what-if" analyses as well as daily scheduling, and can be quickly run and rerun on a PC (Mazziotti and Horne 1997). In order for a simulation-based scheduler to be effective the knowledge system must be integrated into the simulation model. The knowledge system could be represented as a rules-based system that incorporates the experiences of personnel familiar with the production and scheduling processes (Palaniswami and Jenicke 1992). Often it is difficult to determine how production personnel make these decisions based on the information available. Most of these decisions could be characterized as allocation or production rules. Most of these rules are modeled using "if-then-else' statements in the simulation code. Robinson et al. (1998) discussed an approach that would extract decision tree logic using an expert system. The system would extract the decision rules from the different scheduling scenarios and these rules would then be integrated into the simulation model.

Simulation has been applied to a variety of scheduling situations in different continuous process industries. Apelqvist and Lehtonen (2003), Vaidyanathan et al. (1998), and Chen and Harlock (1999) describe applications of simulation to scheduling issues in continuous process industries such as steel, coffee and textile production respectively. Ruiz-Torres and Nakatani (1998) integrated supplier and transportation elements into their simulation approach to scheduling by assigning due dates in logistic-manufacturing networks.

3 CAPACITY PLANNING PROCESS

The objective of capacity planning process is to determine the product sequence for each flowline as well as the daily production quantity necessary to meet customer demand (referred to as the daily kanban). The planning process is launched by analyzing 3-12 months of daily shipment data for all products. A Pareto analysis is performed to identify the high volume products which generated the majority of the production capacity. An initial analysis indicated that approximately 30% of the products generated 80% of the demand for production resources. The philosophy in the design of the flowline is to efficiently produce these products by scheduling their production in a repeating cycle and the remaining production demand for the low volume products will be satisfied by "open " capacity slots in the flowlines. This top 30% of the products will be referred to as the "scheduled" products since they will be put on a repeating production schedule and the bottom 70% of the products will be referred to as the "unscheduled" products since they will be produces on an intermittent basis

The next step was to determine the daily kanban for both the scheduled and unscheduled products. The daily shipment patterns for each product are analyzed to determine the daily kanban (see Figure 1). The daily kanban

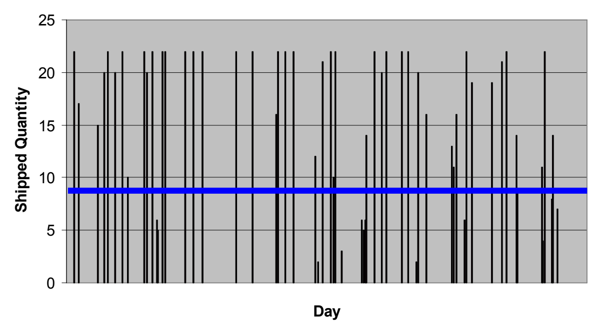

Figure 1: Daily Shipment Data for Product X

indicates the daily demand and not the daily production quantity. In Figure 1, the solid horizontal bar indicates the value of the daily kanban. The daily kanban reflects the effective quantity that must be produced on a daily basis to meet customer demands. The next step in the planning process is to determine the sequence and assignment of the scheduled products to the flowlines. During this process the number of "cycle days" is also selected. The number of cycle days represents the multiplier of the daily kanban for each scheduled product in that flowline. The selection of cycle days is not arbitrary and has a significant impact on the inventory coverage. A representative cycle (see Figure 2) shows that within the set number of cycle days four products are scheduled as well as an available slot of open capacity.

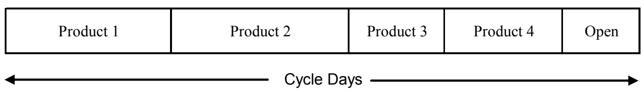

Figure 2: Representative Cycle

The available slot of open capacity is reserved for producing the non-scheduled products or 70% of the products that generate the bottom 20% of the product demand. For example, if the cycle days are set to 10 days then on Day 1, ten times the daily kanban of Product 1 is scheduled and Product 1 is not scheduled for production on the flowline again until Day 11. The focus of the capacity planning process is to ensure that there is enough gross capacity to satisfy the demand requirements for the scheduled products.

The capacity planning process is unable to address the following issues:

1. Are there enough spools in the system to meet the market demand requirements taking into account logistical considerations?
2. Are there enough open capacity slots to meet the demand for the unscheduled products?

The simulation model, using the capacity planning outputs as model inputs, is designed to provide answers to these questions.

4 SIMULATION MODEL

4.1 Model Design

The simulation model is designed to track spools and products as they travel through the system. The basic process is for a batch of customer spools that are assigned to a specific product to be sent to the appropriate flowline when production begins, the spools are loaded with the product and sent to finished goods inventory (FGI). Products are shipped from FGI to the appropriate customer location when the shipment order is received. After the customer has used the product on the spool in their production process, the empty spool is shipped back to the manufacturer (See Figure 3).

The model requires five modules to supply all the input data required to perform the simulation experiment (see Figure 4):

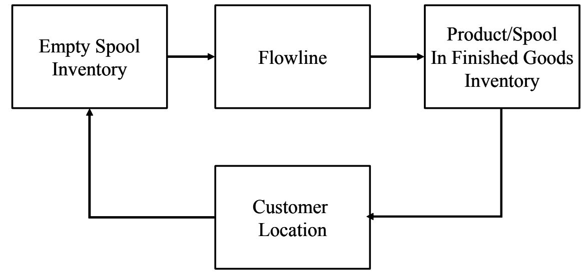

Figure 3: Spool Flow through System

1. Capacity Planning Output: The information provided in this module includes the scheduled cycle days and product sequence for each flowline. The scheduled hours, including weekend/overtime that is designed for each flowline is also provided. This information aids in determining the amount of "open capacity" at the end of the cycle that is available for producing the unscheduled products. The daily kanban level for each product is sent to the simulation model from this module.
2. Product Specific Data: Data required to process the spools on the flowline, such as setup and spool change times; production rates; customer/spool associations; and flowlines capable of producing the product are generated from this module.
3. Spool Inventory Data: The location of spools in the system and whether or not they contain product is supplied to the model as part of the initialization logic in the model.
4. MRP Shipment Data: The dates and amount of product shipments to customers is input as the market demand data.
5. User Specific Data: The user has ability to customize the simulation experiment by changing certain requirements in the model. One such requirement is the percentage of spools required to start the production run. The user has the ability to accommodate spool shortages by allowing the model to start a production run with less than the full complement of spools. The user can also override the process capacity plan outputs by changing daily kanban and cycle days as well as run rates. Another capability for the user is to allow the simulation model to use non-customer specific spools (discussed further in Section 4.2).

4.2 Spool Management

Spool management is a critical issue in this process. Customer spools are dedicated to specific customers. There are typically less than five products for each customer. Customers will supply a fixed amount of spools to the manufacturer at the beginning of a product launch. When

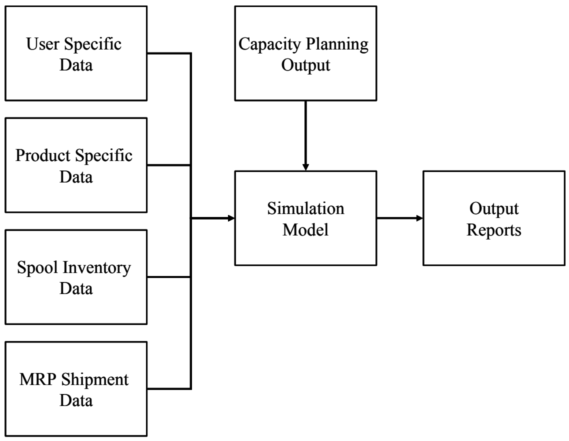

Figure 4: Simulation Model Data Flow

production is short of spools the product cannot be manufactured or shipped to a specific customer. In order to buffer temporary shortages, the manufacturer owns "generic" spools which can be used to supplement any customer spool deficiencies. Production control attempts to use any customer spools prior to depleting the inventory of generic spools but they also don't want to abort a production run of a product if they know that more customer spools will be arriving during the production run. The user allows the model to set a "start" percentage to determine if enough spools are available to start the production run (see Figure 5).

The simulation model will execute the above logic in an effort to produce all scheduled products on each flowline. In the situation where a product cannot be started due to lack of spools, the logic will attempt to run that scheduled product at the end of the flowline sequence if spools become available.

4.3 Unscheduled Products

After all the scheduled products have been processed, the simulation logic starts to evaluate whether any unscheduled products can be run in the slots of open capacity that are available until the beginning of the next cycle. The logic will then look forward 28 days to see whether any unscheduled products, that are capable of running on that flowline, have shipments scheduled. The shipments are prioritized by earliest due date (EDD) and then with each due date by the rank of business that specific product represents. Instead of using a daily kanban values, these production runs are set up in a make-to-order approach, producing only what is required to satisfy the specific order. At a point which there is either no orders of unscheduled product to fill or not enough shift time left to produce the orders, the logic for that flowline waits until the beginning of the next cycle to restart the production process.

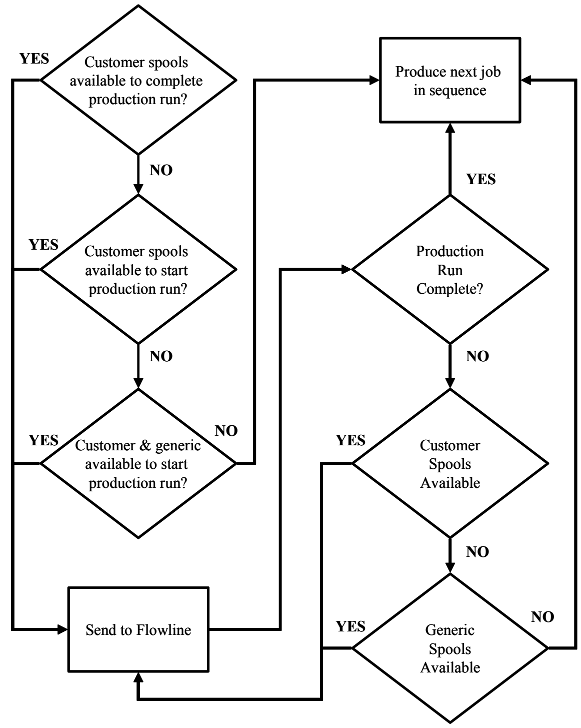

Figure 5: Production Run Start Logic

4.4 Additional Modeling Issues

4.4.1 Inventory Management

When the daily kanban quantities are set, they are based of projected demand. There will be some cycles in which there might be no demand for the scheduled product. The simulation logic examines future order shipments and determines if there is enough inventory coverage to skip the current cycle's production and not create backorder situation. If there is sufficient inventory to satisfy demand through the next cycle, the logic will instruct the simulation to skip processing that product during the current cycle.

4.4.2 Backorders

The simulation logic also monitors any products that have backorders. In this situation the spool requirement for staring a production run is ignored and the production run will commence and produce with whatever customer or generic spools are available.

4.4.3 Overtime

During the production of unscheduled products, the situation exists where not enough shift time is available to complete the production for that order. In order to take into account that production control would not abort the production run if less than two hours of overtime were required to complete the order, the simulation also applies this logic. When an order is analyzed and the production run time is calculated, if less than two hours of overtime is required to complete the order, the production run is completed and the user is notified of the amount of overtime required during that cycle.

5 SIMULATION EXPERIMENT

5.1 Output Analysis

The simulation model was built using Promodel software package (Price and Harrell 1999) and took advantage of the ability to export the simulation output in Microsoft® Excel spreadsheets. The simulation output is formatted for the user as shown in Tables 1 and 2.

The simulation output is used to determine if the capacity planning process, and the sequence of scheduled products, is feasible. Table 1 shows, by product, whether backorders would be generated, whether production cycles are skipped due to inventory levels, and whether spool shortages impacted the sequence of products run on the flowline. Some of these issues can be directly related to the amount of spools in the system. The user has the ability to perform "what-if" analyses and introduce more spools into the system to determine if the problem is corrected. Additionally, if backorders were created the user can trace these backorders to spool shortages or the lack of sufficient open capacity slots for the production of the unscheduled products.

Table 1: Summarized Simulation Output

Product	# of Times Spool Shortage Caused Skipped or Delayed Run	# of Times Unable to Fill Customer Order (Backorder)	# of Times Production Cycle Skipped due to Amount of FGI	# of Times Overtime Used to Produce Spools	# of Hours of Overtime Used to Produce Spools
100	0	0	0	0	0
200	0	1	3	0	0
300	0	1	0	0	0
400	0	0	0	0	0
500	0	0	4	0	0
600	0	0	0	0	0
700	0	0	0	0	0
800	0	0	1	0	0
900	0	2	0	0	0
1000	2	15	0	0	0

The user has the ability to modify certain parameters, such a daily kanban, production processing speeds, and the sequence of scheduled products. Table 2 allows the user to verify what parameters have been changed in order update the capacity plan with the new parameters or to identify areas for continuous improvement.

As part of the planning process, the simulation output is also used to help design the space allocation in the facility for storage of FGI and empty spools. The ability to analyze the fluctuation in spool inventories (see Figure 6) is used to determine the amount of space that needs to be allocated in the facility for spool storage.

Table 2: Adjusted Capacity Plan Parameters

Product	Scheduled Flowlane	Planned Cycle Days	Adj. Cycle Days	Planned Kanban (lin. Ft.)	Adj. Kanban (lin. ft.)	Planned Run Rate (ft/hr)	Adj. Run Rate (ft/hr)
100				10000		100	
200	4	15	10	35000	40000	303	
300				10000		200	
400				10000		213	
500	2	15		20000	30000	213	
600				10000		250	325
700				10000		213	
800	4	15	10	7500		136	
900				10000		250	
1000	1	15		105000		252	300

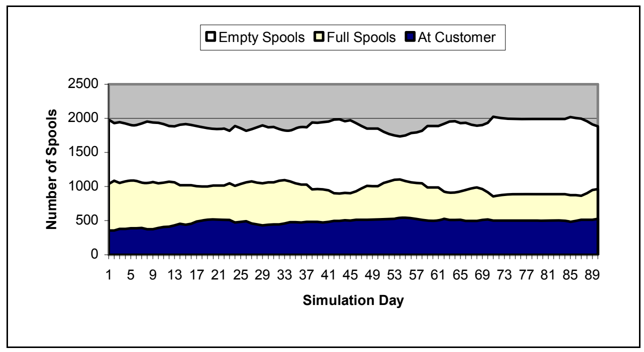

Figure 6: Spool Distribution

The simulation output also generates the "as-simulated" product sequence so that an analysis of the usage of the open slot capacities can be performed as well as identifying potential usage of unused slot capacities for preventive maintenance.

5.2 Validation and Verification

Validation and verification evidence was gathered from the simulation results for the run simulating 90 days of activities using the techniques described in Sargent (1999). There were a total of 3376 entities in the system. Since this was a closed queuing network there were no new entities entering or leaving the system. The simulation output verified that total entities in the system were constant.

Spreadsheet modeling of one flowline, using deterministic processing time parameters, verified that the logic for the amount of shift time consumed for the scheduled products as well as the selection and processing of unscheduled products.

6 CONCLUSION

This simulation application provided a complete planning solution for this tier two automobile supplier. In conjunction with the capacity planning process, the simulation model was able to validate the sequencing and scheduling of the top 30% of the product line that generated 80% of the business, as well as scheduling the remaining 70% of the product line, based on MRP ship dates, by determining where and when open gaps of capacity would be available on individual flowlines. The simulation also took into consideration the logistical issues with customer supplied materials that were used in the production process, as well as flagging when shortages of these materials would cause either delays in production or inventory backorders. The production planners are also able to use the model to perform "what-if" scenarios to determine where to focus their continuous improvement efforts. The development of the simulation model is meant to provide a planning tool that provides not only the ability to determine if the capacity planning process was valid but also provides the ability to: schedule the balance of the product line; identify problems that may cause customer service issues and provide the ability to evaluate the impact of continuous improvement efforts.

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