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TOTAL CAPACITY MANAGEMENT USING SIMULATION

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ABSTRACT

Simulation has been used to support many different manufacturing activities including product design, process design, facility design, operational scheduling and schedule managment.

Fundamentally, models developed for simulation analysis relate to the setting of capacity requirements for the manufacturing facility and the determination of how to use the capacity to process orders through the facility. Simulation is further used to manage these activities over time in order to achieve continuous improvements in manufacturing capabilities.

This paper presents a discussion of how modeling and simulation can be used to support Total Capacity Management (TCM). First, TCM is defined, an example architecture for simulation based TCM is described and then two applications which relate to TCM concepts are given.

1 INTRODUCTION

Total Capacity Management (TCM) is a manufacturing management orientation or philosophy. It is a commitment to base manufacturing decisions on the real productive capabilities of the plant. The productive capabilities of a plant depend on production planning methods, material planning requirements, engineering designs, desired customer service, available production support and business management practices. Manufacturing decision-makers should have access to information about production capabilities in all these forms and to forecasts of operational performance when deciding on how to meet current and future demand.

2 TCM IS IMPLEMENTED THROUGH SIX FUNCTIONS

TCM is achieved through six capacity specific functions each of which supports a distinct set of decisions in a manufacturing enterprise. The six capacity-specific functions are shown in Figure 1 and are described in the paragraphs below.

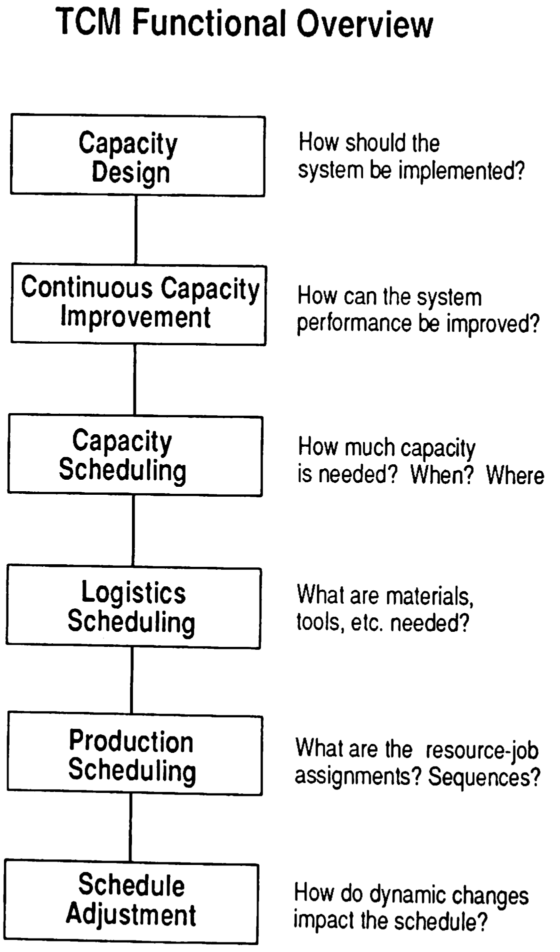

Figure 1 TCM Functional Overview

- **Capacity Design** is used to design new, expanded or modified manufacturing facilities to ensure that the production strategy, the capital equipment specifications, and the labor strategy meet long-range production objectives. A sample question addressed with Capacity Design is "Will this equipment configuration meet projected demand using a small-lot strategy?"

- **Continuous Capacity Improvement** is performed to enhance the processes and methods of an existing operation. Questions such as "Should equipment be upgraded?" and "Should job sequencing methods be changed?" are addressed with this capacity function.

- **Capacity Scheduling** is used to plan capacity availability and loading to meet current demand and near-term expected demand. "How much overtime, if any, should be worked, and when?" is one question addressed during Capacity Scheduling. "Can an order be accepted without making other orders late?" is another.

- **Logistics Scheduling** determines the dates at which materials, tools, fixtures and other production support are required. Questions such as "When are the tools needed for this order's broach operation?" and "When is the best time to do preventative maintenance on these workstations?" are answered during Logistics Scheduling.

- **Production Scheduling** is performed to develop accurate, achievable work plans of the short term by assigning jobs to workstations in a specific sequence. "Which grinder should be used to run this job in order to minimize setup?" and "Should this order be given priority because its due date is approaching?" are the types of questions addressed by Production Scheduling.

- **Schedule Adjustment** is used to make modifications to the near-term production schedule to reflect updates based on the most recent information available. The answers to such questions as "How should today's jobs be reassigned since one mill went down?" are shown on the production schedule using Schedule Adjustment.

3 SIMULATION-BASED TCM

Capacity design within TCM involves the use of a model of manufacturing operations to estimate the performance of the manufacturing system for different levels of demand in conjunction with designed or actual process plans and resource allocations. Process plans can be included in a model and would specify the jobsteps including resource and material requirements to make the product. A separate model is sometimes developed to characterize the orders that make up future demand. Capacity improvement analysis can use the same or similar model to determine if manufacturing operations can process released shop orders in a timely manner. It is during this function that longer term solutions to bottleneck areas are resolved.

Finite capacity scheduling is performed to determine the level of resources required to meet current demand. When capacity levels are set, detailed production and logistics scheduling can be accomplished by simulating the model to allocate available resources at specified start times to the actual jobs included in the shop orders. Since the model contains the detailed process plans (jobsteps), the start and completion times of each operation can be established and hence, the order and material and tool requirements can be scheduled. These schedules can then be distributed for schedule management which entails the use of current operational status and knowledge of critical issues to adjust the schedule. Maintaining shop floor discipline with respect to a schedule is important and involves employee knowledge of the value system employed in making schedule adjustments.

The outputs of schedule management are dispatch lists detailing the schedule time to perform each job with required resources and material prescribed. In addition, methods for improving the scheduling process through the collection of data and the parameterizing of rules to improve the scheduling process is part of TCM. For example, the application of artificial intelligence tools in conjunction with simulation models can lead to better scheduling practices.

The dispatch lists are the basis for schedule execution/dispatching, that is, the actual resource allocations to jobs. Data on operational status is fed back to scheduling and schedule management in order to determine the frequency with which new schedules need to be prepared. The display of this status information provides a basis for ongoing decision making. The current status and an up-to-date analysis of immediate past performance can be used in the continuous capacity improvement function where additional simulations can be performed to assess future performance. Through the use of a common modeling language, continuous improvements in manufacturing operations can be made.

4 TCM ARCHITECTURE

Total Capacity Management will be performed in a heterogeneous computing and software applications environment. MRP II systems, purchasing systems, process plans, and shop floor control will most likely be performed on one or more computers using different database systems for their individual performance (Baudin, 1990). This will require an integrated architecture for software developments to achieve TCM.

A key to obtaining TCM will be the use of a common modeling language and common data throughout the functions depicted in Figure 1. An architecture based on this concept for TCM is shown in Figure 2 (Compton and Heim 1991). The architecture is layered to include user interfaces, underlying utilities for accessing data through a standardized data interface and a fundamental reliance on common models and common data storage (International Business Machines 1989). In this architecture, the user interface is provided through four windows for designers, planners, schedulers, and schedule managers. Each of the windows should have a similar look and feel and be organized to satisfy specific user needs. Although the design of these windows will depend on particular applications, there will be a large overlap in the displays. Figure 3 lists several of the capabilities required for each functional window type. Future windows will be required for direct delivery of information to decision makers and corporate executives. Before this can be accomplished, the roles of the decision maker or corporate executive relative to TCM should be clarified for the specific application set.

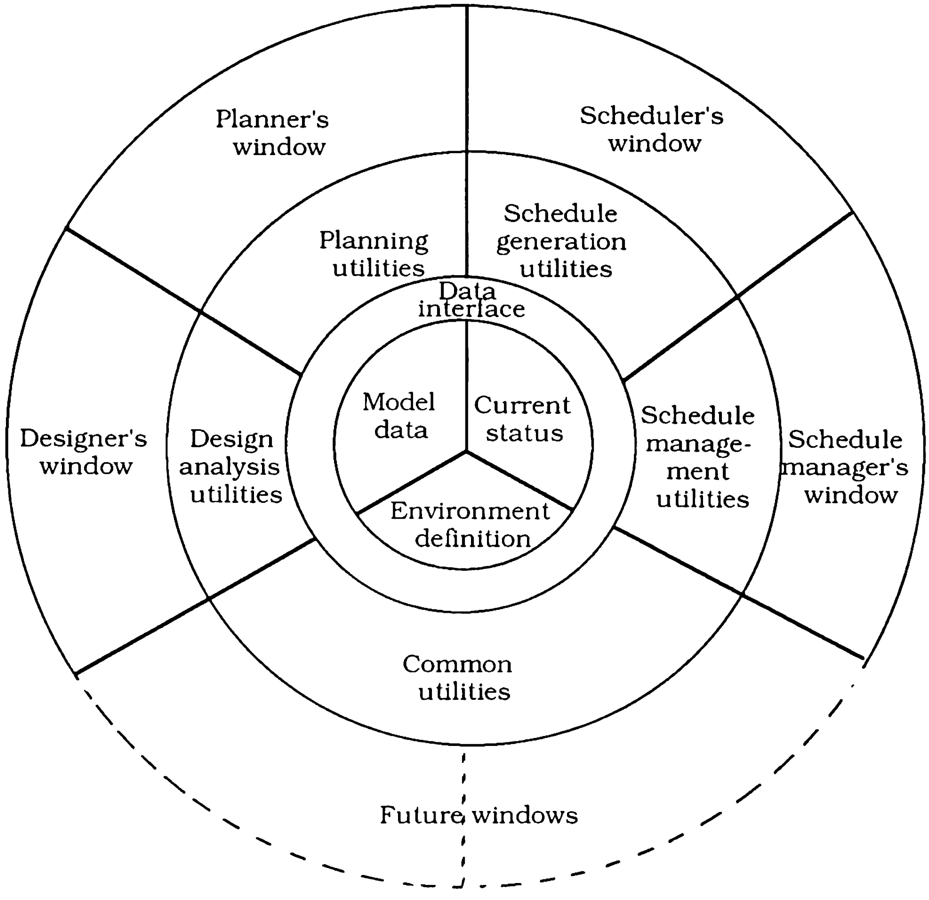

Figure 2 Total Capacity Management Architecture

Designer's Window	1.Graphical builders 2. Statistical analysis tools 3. Cost analysis/ spreadsheet tools 4. Animation builder
Planner's Window	1. Capacity planning displays 2. Resource availability builder 3. Shift scheduling builder 4. Order manipulation tools
Scheduler's Window	1. Multiple schedule reports 2. Rules for scheduling control 3. Alternative builders for: a. Resource schedules b. Work order releases c. Load manipulation
Schedule Manager's Window	1. Interactive Gantt charting 2. Expedite function evaluator 3. Schedule distribution capabilities

Figure 3 The User Interface Layer

The utilities layer in Figure 3 will need to include capabilities for performing simulations, graphic utilities, artificial intelligence, expert system rule building, and interfaces to databases for accessing information on process plans, orders, equipment characteristics, operational data, other modeling tools, and current status. Other utilities required relate to model building, display generation, animation generation, schedule distribution, and communications in general.

5 APPLICATION: EVOLUTION OF TCM AT PRATT & WHITNEY

In a project at Pratt & Whitney, a compressor blade manufacturing area which makes more than 50 parts was scheduled using FACTOR (Pritsker Corporation 1991). The area consists of a cropper, 6 extruder lines, 9 forge lines, 7 broachers, and other stations that perform intermediate operations, such as machining, heat treat, and surface finishing. Material handling and storage is accomplished through integrated AS/RS and AGV systems. Altogether, the process includes 15 operations, with a manufacturing lead time of 8 to 12 weeks.

The broach is the bottleneck operation; its setup takes from 1 day to 2 weeks and is a key consideration in production planning. Lots for the broach are typically sized at 10,000; whereas lots for the extrude and forge operations typically run around 2,000 to 2,500. These smaller lot sizes are designed to reduce inventory levels, while insuring the bottleneck operation has materials when needed.

The objectives of the scheduling project were:

- automation of routine scheduling decisions;
- "what if" capabilities to evaluate scheduling decision alternatives;
- extend the scheduling horizon for manufacturing support organizations, tooling in particular;
- provide a capability to evaluate reactions to unplanned events; and
- provide a single coordinated schedule for all departments.

Tooling was one of the manufacturing areas largest problems. Even though a large tool inventory was carried, tool related production interrupts (wrong tools on hand) were experienced. Part of the long-range strategy is to provide sufficient forward visibility in the production schedule to support tool planning and scheduling. Purchased and fabricated tooling have lead times ranging from one week (expedited) to 6 months. In addition, forward visibility could benefit material purchasing since titanium stock lead time is about 16 weeks.

The blade area scheduling strategy used a combination of manual and computer-based steps. Each quarter, a schedule is manually developed for the broach, based on orders from the corporate MRP system. The plan horizon is 18 months, and accounts for part sequences and setups. From this, an 18 month cropper release schedule is manually prepared, using an appropriate setback. The FACTOR scheduling system is used to develop a 30 day schedule for the remaining operations. Scheduling the two forge and two extrude operations required the consideration of a large number of capacity and operating constraints, and involved logic relations to intelligently sequence operations and plan changeovers.

The 30 day schedule is regenerated daily, using current status information from a CIM database. Production Control reviews the schedule to ensure tool availability and makes changes as appropriate. The schedule is then reviewed at the daily production meeting where further revisions may be made. Once accepted, the schedule is released to the production floor. Further adjustments are made manually. For example, manufacturing and production control will decide what to run if a particular order can not be started or is aborted because of a die problem. The FACTOR scheduling system incorporates these decisions in the next run. The 30 day schedule provides information to expedite needed tools within the 30 day window.

The next step is to expand the model-based 30 day schedule into the Disk Manufacturing and Experimental Blade areas. Another model is planned to generate the 18 month broach schedule. This schedule will determine which parts will be setup and processed on the broach. The system will include decision support capabilities for making lot size, change over, and sequencing decisions. The outputs will provide additional visibility into tooling and material requirements. With a longer term horizon, tooling requirements can be planned more effectively.

The pace at which FACTOR models are installed is determined by need, budget, and the degree of success of earlier efforts. The scheduling system is currently being operated by Production Control personnel. The evolution of the system to include more TCM functions is now in progress as a long-range CIM strategy is envisioned for this plant. The scheduling system described above is part of this strategy. A CIM database is designed to be the plant's repository for inventory, process routings and standards, order status, tooling status, etc. The strategy is a Total Capacity Management one that drives production activities, tool scheduling, and purchasing from model-based production schedules produced by FACTOR. The TCM organization in this situation is shown in Figure 4.

6 APPLICATION: TCM AT BETHFORGE

BethForge's primary business is the fabrication of large, machined steel products. Typical products include hardened steel rolls (used by steel and aluminum plants for mill rolling operations), steel propeller shafts for ships, electric power equipment forgings, and defense products. Production times for these products range from 8 weeks to 2 years. Each product follows a process flow similar to the one shown in Figure 5.

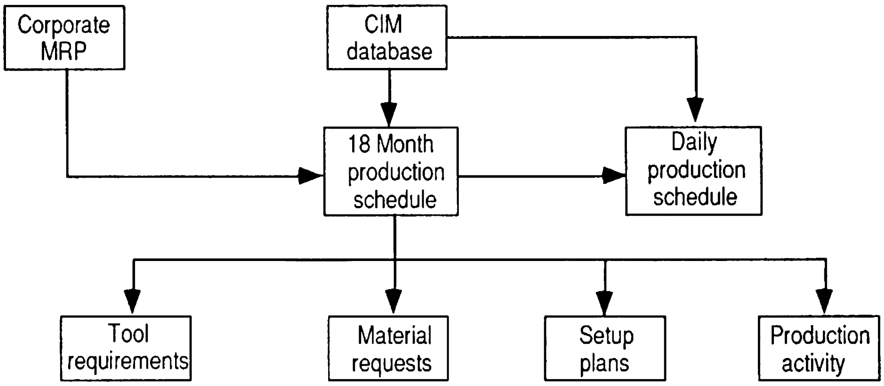

Figure 4 TCM Strategy Identified at Pratt and Whitney

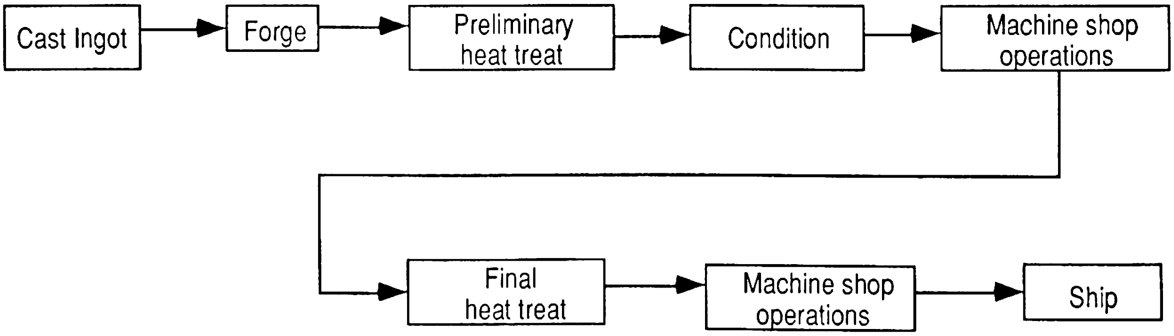

Figure 5 Process Flow for Fabricated Steel Products

The process begins with ingots forged into the rough geometrical shape required for the order. The pieces are then routed through preliminary heat treat and are conditioned. Orders are then shipped to the appropriate machine shop where they are processed through lathes, mills, drills, and other operations according to its specific routing. The orders are then sent to a final heat treat area where the pieces are treated in one or more of six furnaces. Each furnace has special characteristics such as size, temperature, range, consistency, and certification. Operations within the heat treat area include: preheat, high heat, quench, equalize, furnace cool, air cool, test, and temper. The pieces may require additional final machining operations before being shipped.

An initial project was undertaken with the goal of implementing a model-based scheduling system to provide a functional schedule throughout a production reorganization period. Two machine shops and three treatment facilities were being consolidated. The principal focus of this model was machine shop operations and the final heat treat area. These areas maintained on-line information about machine and order status.

The objectives of the scheduling system were to provide the following functionality:

1. Schedule operations during the consolidation effort.
2. Determine the on-time performance sensitivity to routing changes and equipment removals during the consolidation effort.
3. Determine if on-time performance may be accomplished during the various phases of the consolidation.
4. Improve the effectiveness of scheduling procedures for the machinery and furnaces.

Within the TCM philosophy, this project comes under the Continuous Capacity Improvement function.

Given the focus of this phase, the processing steps preceding the initial machining steps were modeled using fixed lead times. Resources were specified but did not constrain the operations. These infinite capacity resources were included only to obtain department load levels.

A production schedule for machining operations associated with each resource was determined using the FACTOR system. The following criteria were employed in producing the schedule, listed in order of importance:

1. Criticality (when dynamic slack is less than some acceptable level)
2. Order priority
3. Dynamic slack (available time - remaining processing time)
4. Setup minimization
5. Dynamic slack per operation
6. Number of remaining operations
7. First in, First out

The scheduling logic gave primary consideration to on-time performance. When no order was in jeopardy of being late, the logic chose to run orders in a sequence that minimized setup or permitted batching in a furnace.

For this application, FACTOR was installed to take advantage of the data available in BethForge's MICOM database. Their MICOM system was previously implemented to support order management and tracking. Information was available on process plans, orders and order status, and materials. Selected information was accessed by FACTOR for each run. (Although a net-change information strategy was designed, it was concluded that a regeneration approach (common data) would be more expedious in the long run. Performance was not significantly affected by this approach.)

FACTOR generated order summary and resource statistics reports to assess the overall schedule performance. FACTOR also generated a file describing expected operation start and complete dates, that is, operation and resource schedules, which were loaded back into MICOM. MICOM distributed the schedules and tracked transactions against operating performance.

In addition to using the FACTOR information for scheduling, the completion date information is used by other financial systems. For example, because some production lead times are so long, Beth Forge is eligible for progress payments. Thus, expected timing for key milestone operations provides information which was used to project billing dates and to forecast cash flow requirements.

With the success of the production scheduling system, a second project was undertaken to implement a business planning system, driven by a model-based view of production. This system was designed to provide BethForge's Controller with a six quarter financial forecast on a quarterly basis.

This FACTOR application was designed to operate in parallel with the production system. The information flow for this application is shown in Figure 6. Basically, the model was extended by adding sales forecasts to the open orders. Each quarter, sales forecasts for various products were developed. From the forecast, planned orders were generated for each category of order. The order forecast, combined with the on-hand orders, were scheduled through production over an 18 month time horizon.

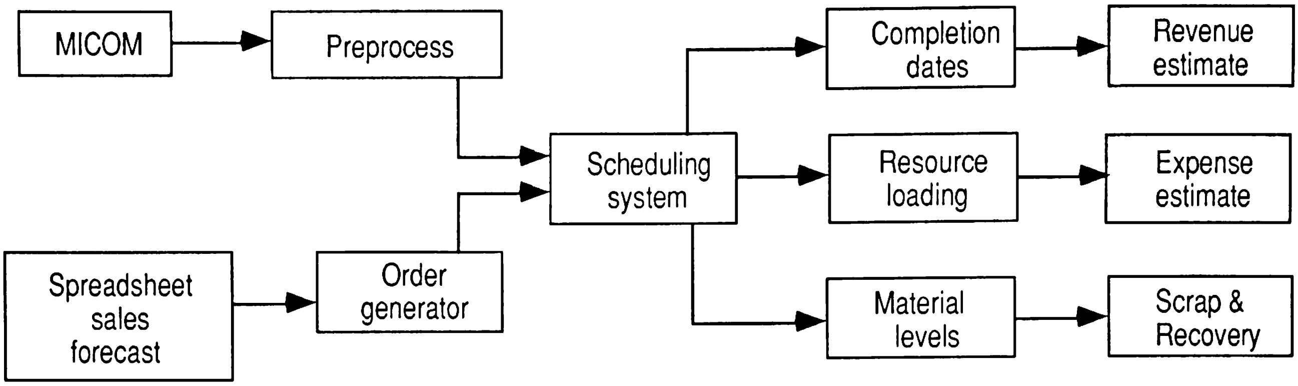

Figure 6 Information Flow for Financial Analysis

The production model provides forecasts for order completion dates, material requirements, resource loading, and quantities of product shipped by period. This information is post-processed and combined with standard cost and price information to generate the following reports.

Resource Activity is reported by machine and by quarter and by available and scheduled hours.

Material Forecast is made by operation (ingot cast, forge, rough machining, finish machining), by grade, and by period and the material tons produced are reported. This information is processed to estimate scrap and recovery, which is in turn used to determine how much outside scrap must be purchased to meet production requirements.

Commercial Forecast is established by product type and by period, and the number of tons shipped is reported. Operating performance values provide information on the number of orders shipped early and late. Estimates of expense and revenue are also made and used to input to extrapolate the cash flow for the business.

At the time of this writing, BethForge is continuing the project to expand this system. Their next step is to expand the scope of their MICOM system to incorporate additional information on BethForge operations. As the information becomes available, the operations scheduling application and the financial forecasting application will be expanded. The intent is to continuously improve through incremental steps.

7 SUMMARY

The concept of Total Capacity Management is not a revolutionary approach. It builds on existing systems and existing databases. In manufacturing, an evolutionary process has been shown to have the greatest chance of having a significant impact. Thus, TCM does not replace production control systems, process planning systems, CAD/CAM systems, or quality improvement systems. TCM promotes the integration of functions relating to capacity management and the sharing of information and decisions with those systems that are also involved in manufacturing system improvement. TCM is focused on the productive capability of the manufacturing system. It performs functions related to capacity setting and resource and job scheduling originally promised by MRP II but not currently provided in an accurate or usable form at the shop floor level. It provides a path to breakdown the barriers between the functional units of design, planning, operations, and control.

TCM as a concept will undergo continuous refinement. The integration of capacity management functions through the development of a simulation system to achieve TCM is currently feasible using available hardware, software and human capabilities.

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