Finite-capacity scheduling

is not a new idea,

but it's a good one

Analyzing production schedules

By Gregory Quinn and Mike Novels

The acceptance and availability of the Windows operating system, cheap and powerful PCs, and highly visual and rapid software development tools such as C++ and Visual Basic have made technology once reserved for the Fortune 1,000 accessible to all manufacturing tiers. This phenomenon was first felt on the factory floor, driving the cost down on SCADA systems. The next systems impacted were the MRPII and ERP systems. As these information management systems matured, the middle layers of the factory had to be addressed to achieve complete integration of the enterprise information network. Sophisticated modeling and analysis functions are now being offered at commodity prices, with no sacrifice in their sophistication or usability. One area of tremendous breakthrough is finite-capacity scheduling.

What is FCS?

Finite-capacity scheduling emerged as a response to the limitations of infinite capacity scheduling, which is common to all MRPII systems. The basic problem in MRPII is that the production plans lack realism, since they are produced under the assumption that all resources have an infinite capacity to perform work. As any production manager knows, the real world does not work that way, and many of the problems of resource under-utilization, excessive inventories and work-in-progress, and job lateness relate to the inaccuracy of the production plan.

FCS itself is not a new idea. For many years, versions of FCS emerged to enhance the accuracy of the production plan to better manage inventory, resources, and customer satisfaction. The first systems were simple, involving the measure of the primary resource to do work, and either scheduling forward from the current date for new orders (single constraint finite forward scheduling). Multiple constraints were later added to provide more accurate modeling of the production resources. About the same time, backward and bi-directional scheduling began to appear in some packages.

Then the explosion of different production philosophies challenged American ideas about MRP and mass manufacturing, notably just-in-time and theory of constraints. Variations of FCS systems emerged, some committed to supporting one of the three competing philosophies. This forced the innovative FCS companies to face the reality that to remain flexible, the new FCS systems would need to: 1) model any production philosophy and 2) extend the model with rules that capture the nuances of the competitive model of the client as it related to scheduling. To achieve these goals, the new FCS systems had to support job-based, resource-based, and event-based modeling. By applying any one or a combination of these three views of the production floor, an FCS model can produce the accuracy that adds value to the business goals of the enterprise.

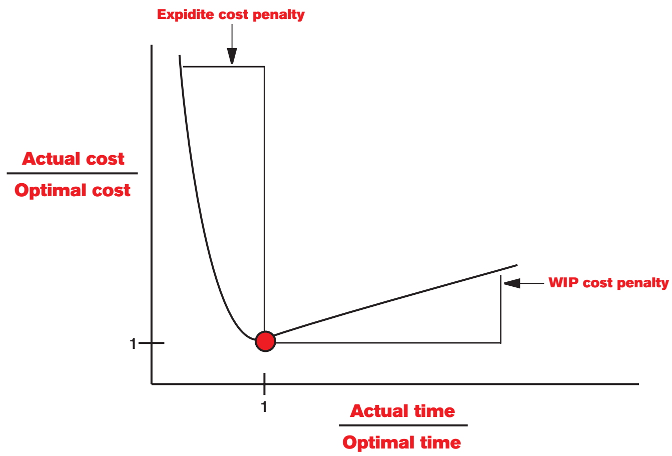

Figure 1. Time-cost plot for manufacturing

The value of FCS

The value of FCS comes from the accuracy not obtainable in traditional infinite-capacity planning. With this accuracy, raw material levels can be in sync with demand from the production floor, customer service levels improve because throughput is predictable and due dates are more reliable, work-in-progress is reduced, and better resource utilization means hidden capacity is uncovered. These are strategic goals, but there is also a very important operational improvement as well.

Figure 1 shows that for a given need to produce goods (or provide a service), there is an optimal point in time and cost at which goals are met. In manufacturing, there are two means to advance the delivery time: expedite the order or create WIP to have excess products to deliver against.

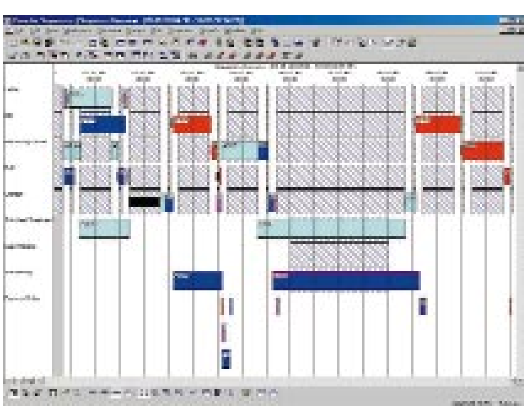

Figure 2. Example of a Gantt chart

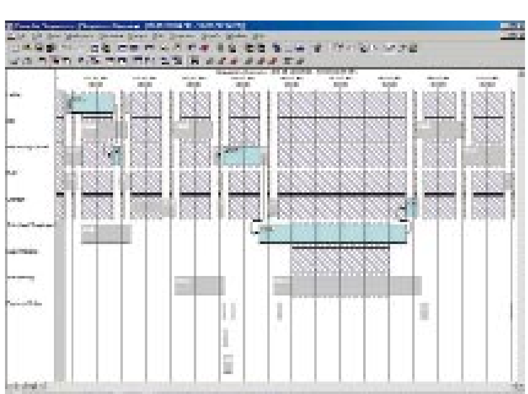

Figure 3. Job flow display in a Gantt chart

One obvious drawback with WIP is that the value added is not recovered quickly; therefore the manufacturer has lost the time-value of the money. What is not obvious is that expediting costs much more than WIP because of the ripple-through impact of moving other orders around (which means pushing orders later in delivery) and otherwise disrupting the optimal point for all the other orders, accumulating a much greater financial impact than creating excessive WIP.

It is difficult in the real world, where the product-quantity mix can change daily, to determine these optimal points, which is precisely where the FCS has the greatest value. A good FCS can compute scheduling solutions that set these points for all orders, within the context of the production philosophy and the business goals to be achieved.

However, the scheduling solution cannot exist in a vacuum, and the output of a scheduling system needs to provide useful data in order to fulfill its other role as a decision-support tool.

One of the primary advantages of an FCS system is that it offers the user a what-if tool to try methods of scheduling or dispatching rules, routings, or constraints that are in use. This is because a truly interactive FCS system doesn't just give the result of a scheduling run. It also provides a mechanism by which, with the aid of analytical tools, alternative schedules can be generated and compared. There are a number of ways by which scheduling systems offer tools to display and analyze the results of scheduling runs. These include:

- Gantt charts and schedule performance metrics
- Order trace charts
- Due-date compliance
- Bottleneck identification
- Job analysis
- Material allocation

Gantt charts and schedule performance metrics

The Gantt chart is the earliest and best-known type of planning and control chart. It is the most common way of displaying the proposed loading of jobs onto individual resources over time and comparing it with the actual performance of the facility in meeting scheduled start and finish times for each job.

On the vertical axis of Figure 2 are the names of the resources that have to be scheduled. The horizontal axis represents time. In this case we have chosen to display the order number on the bar, which is colored to highlight the product type. Tools are usually available in FCS systems to highlight the process route that a particular job has taken. Notice that the job highlighted in Figure 3 has been processed on the same machine more than once.

There are a number of ways schedules can be measured. For example, resource utilization may be an important performance parameter in one plant, due-date compliance key in another, and total changeover time essential in a third. The example in Figure 4 shows data collected from a scheduling run. There is data associated with jobs and with resources.

Key performance indicators are often in conflict with one another. For example, it may be possible to obtain reduced setup times by sequencing like jobs together on resources (e.g. material type, color, or flavor) but this may make some other orders late. Often it is necessary to try different scheduling methods and compare schedule performance data from each to make more informed decisions.

Added value percentage is a good indication of the amount of queuing in the schedule generated. Value is only added to a batch of components when being processed. Setup and waiting time do not add value. The added value percentage compares the process time with makespan time, excluding waiting time due to off-shift periods. The higher the added value, the less time was taken in queuing and setups.

Order trace charts

Some FCS systems will also have the capability to display a similar chart in 'Order Trace' mode whereby the vertical axis has the order or job number. Now all operations for a single job appear on one horizontal line (see Figure 5).

Some systems also offer the capability to directly compare the actual completion times with the anticipated times as the data is received from other systems such as SCADA packages or data collection devices such as bar-code readers.

Due-date compliance

Finite scheduling systems invariably have a number of methods of comparing alternative schedules, perhaps generated using different job priorities or scheduling rules. One of the most common is to compare due-date compliance. Figure 6 is typical of a normalized order trace chart. The operations for each job are positioned in relation to its due date; in this example the two schedules are compared (two sets of operations for each job). The red vertical line represents the due date — any operations to the right of the line are late. In this case, order A006 is completed just before the due date in one schedule run, while in the other it is completed almost three days late.

Some scheduling systems take this comparison a stage further by offering the due-date compliance statistics in a bar chart or histogram format as shown in Figure 7. Jobs that are early have bars above the due date line while those that are late have bars below it. The height of each bar represents the degree of earliness or lateness. This gives a better overview of the schedule as a whole.

Bottleneck analysis

There are a number of ways scheduling systems provide methods by which bottlenecks in the production process can be identified. These include those associated with resource and those that are associated with each order. Typical ways of displaying bottlenecks at resources are waiting time and resource usage plots. Figure 8 shows a typical waiting time plot.

Figure 4. Overall schedule performance statistics

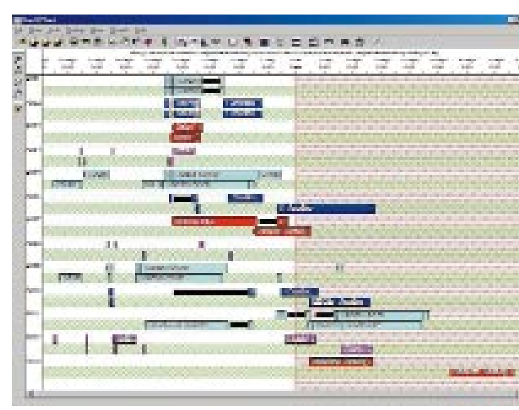

Figure 6. Normalized due date order trace chart for two scheduling runs

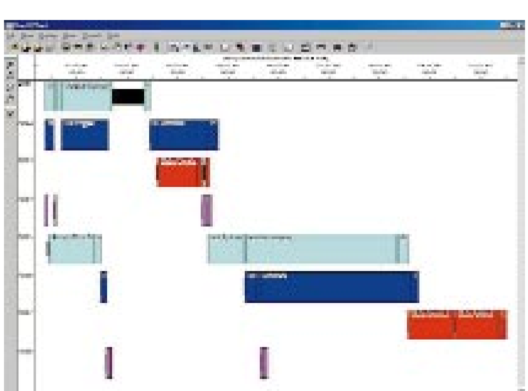

Figure 5. Order trace Gantt chart

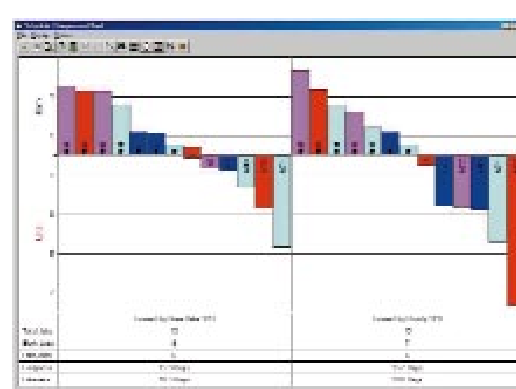

Figure 7. Comparison of due-date compliance using histogram/bar chart display

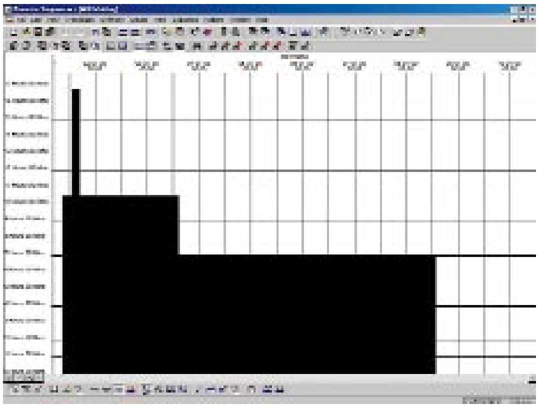

Figure 8. Waiting time plot

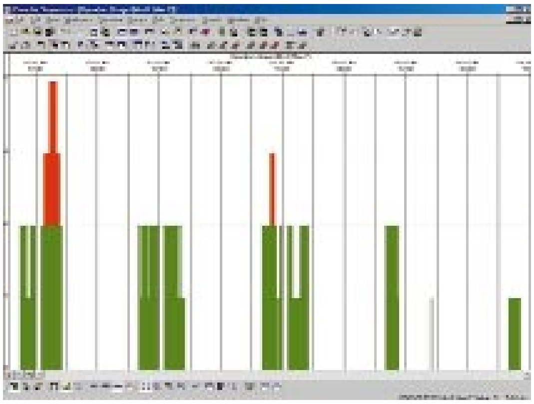

Figure 10. Operator usage plot (unconstrained)

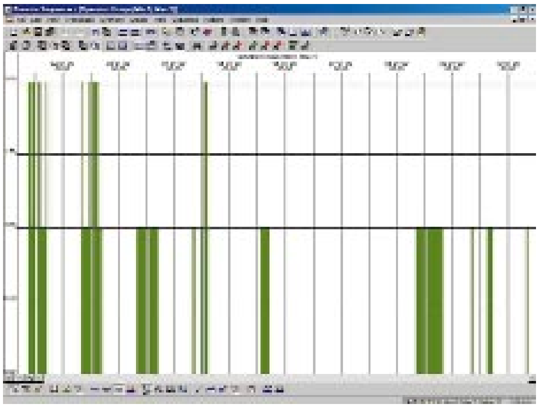

Figure 9. Operator usage plot (constrained)

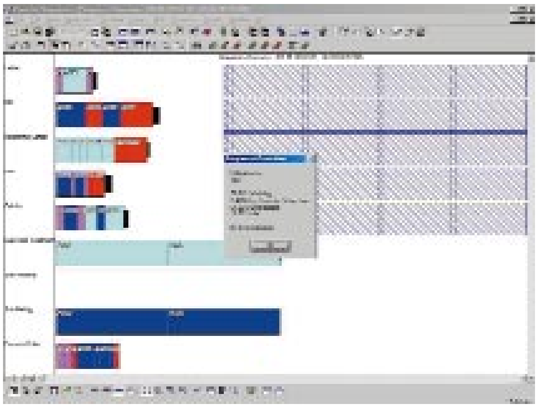

Figure 11. Resource utilization chart

The vertical axis shows the total amount of work waiting for (in this case) a mill resource during the period of the schedule generated.

Another method is to display plots of the usage of resources such as labor, tooling, power, or other constraints to the system. Figure 9 shows a plot of the usage of up to two operators. Figure 10 is the same schedule generated on the assumption that operators have unlimited capacity. The red areas show where additional operators are required to make throughput unrestricted by operator capacity.

These plots are for individual resources or resource types. Sometimes the user may wish to look at all resource utilization data over a period of time. Figure 11 shows one method. It is a variation on the Gantt charts shown earlier. Each resource has all the tasks allocated to it shown left justified (the black rectangle represents the total setup time), while the off-shift periods are right justified. The white area between them represents available capacity.

While this shows the utilization over the total scheduling period, a Manhattan diagram, which is available for example in an Excel spreadsheet, can show utilization by day or week (see Figure 12).

Job analysis

Another tool that can be useful in analyzing schedules is to track the progress of individual jobs in particular to compare the scheduled start and finish times for each operation step with the actual times achieved. This has implications not only for the estimates of process times that have been used in schedule generation, but also to indicate the need for action should a job start to lag the required due date for delivery. Typical data collected is shown in Figure 13.

As each operation is completed the scheduled start and scheduled finish times are compared with the actual values. A critical ratio value is also calculated. The CR is a ration found by dividing the remaining process time by the time left to due date at the actual finish time of the operation. The closer the value gets to 1, the more urgent the job becomes. By looking at the values, the user can judge whether a change in job priority should be made at the next re-schedule. Additional information such as job cost can also be computed and comparison made with the expected cost.

Gantt charts may also be used as a visual record of the progress of jobs as shown in Figure 14. Two sets of bars are visible for each job, one set representing the expected starts and finish times for each operation and the other, in the shaded area, the actual start and finish times.

Materials allocation

More advanced planning and scheduling systems will use not only resources such as machines, labor, and tooling to constrain the loading of demand but will also use the availability of materials. Some systems are able to take the bill of material structure of a product and allocate materials for each level of the BOM. These additional links between jobs can be used to constrain the schedule based on the availability of

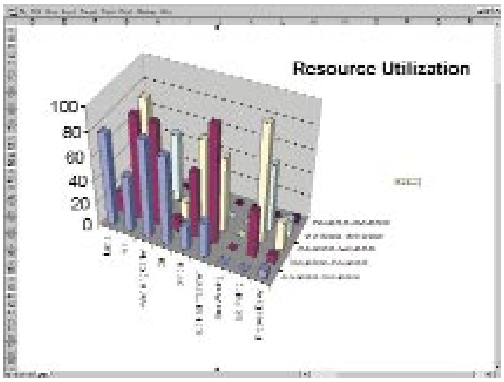

Figure 12. Resource utilization displayed in a Manhattan diagram

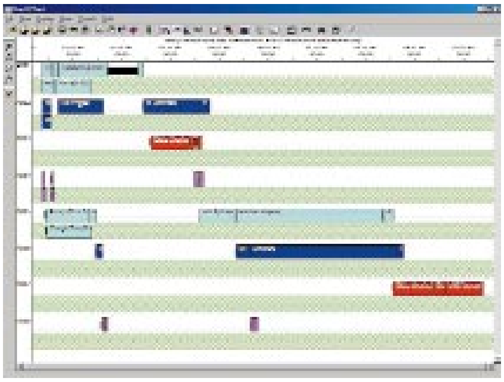

Figure 14. Job progress Gantt chart

Job Progress Report							
Order no.							
Due date							
Operation	Op name	Resource	Schedule start	Late/early	Schedule finish	Late/early	CR
10							
20							
30							
40							
60							
70							
80							

Figure 13. Job progress report

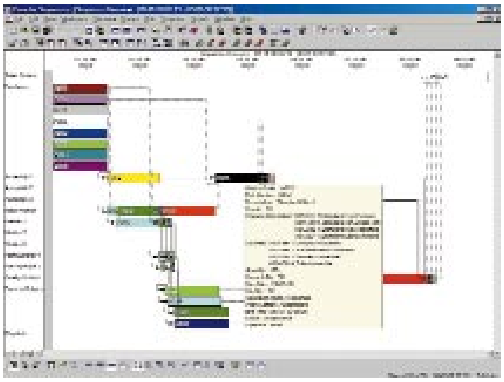

Figure 15. Pegging information in schedule with materials as a constraint

these materials. The process of material allocation is often referred to as material pegging and is most used when the scheduling system is used along with an MRP/ERP system in a make-to-stock production environment.

Figure 15 shows a Gantt chart with operations loaded with both resources and materials as constraints. The dotted lines show the materials that have been allocated between each level of the BOM for each assembly. The four dotted flow lines that go to the sales order bar (S01) show that there are four items or products that have been linked to it. The tool tip shown in this figure shows in text some details of the pegged materials that supply shop order A005 and that other shop orders have been allocated materials produced by it.

Final thoughts

The schedule analysis described thus far only scratches the surface of what a quality FCS can provide for decision support. The amount of data and the results of the subsequent analysis can be numbing. This is why it is critical in selecting and using an FCS system that the end users know what they need in order to do their jobs and how the FCS will support them. A recent survey among manufacturers revealed that FCS was deemed critical for on-time delivery, high-quality products, good customer relations, schedule reality, and providing answers in real time. The same survey showed that 45 percent who need finite scheduling cannot accomplish their goals because of the limitations of the package they selected.

The challenge with FCS, as with any information management system, is to create a model that gives the end user the ability to make timely decisions to support the company's business objective using the minimal data set. This is accomplished through careful analysis at the beginning of the implementation project. The data itself should not be a mystery; the scheduler has been using the same information prior to the scheduling project. A clear understanding of the objectives and processes is as important to an FCS project as any information systems project. Once the system is in place, the benefits will be forthcoming quickly as the end user obtains better visibility and understanding of the production environment. ◆

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