Real-Time Artificial Intelligence for Scheduling and Planning Make-to-Order Manufacturing

Introduction

This white paper explores how the use of Real-Time Artificial Intelligence (AI) can dramatically simplify the management of complex make-to-order and engineer-to-order projects.

American manufacturers long ago ceded long-run manufacturing to countries such as China with lower labor rates and weaker environmental laws. In its place, manufacturers in the USA became experts at short-run, quick-turn make-to-order manufacturing. This has brought with it a major increase in the complexity of operations management.

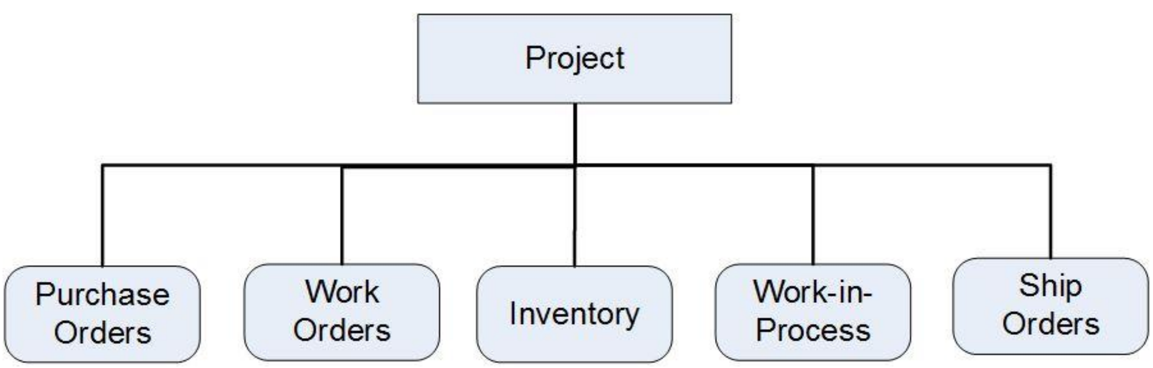
In this white paper we describe how BellHawk Systems applies real-time artificial intelligence methods to assist managers in the scheduling and planning of their make-to-order projects as well as to alert managers when operational problems are about to occur.

Examples of Make-to-Order and Engineer-to-Order Projects

Make-to-order projects that BellHawk Systems is currently involved in range from the relatively simple to the very complex. These include:

- Coating and slitting non-woven fabrics to order
- Repairing aircraft subsystems
- Making of custom electro-mechanical assemblies
- Making custom kitchen cabinets and countertops for kitchen retrofits
- Making curtain wall windows for skyscrapers

In each case projects (also called customer orders, contracts, or jobs) typically consist of many activities and components, as shown below:



Many of our clients have dozens of projects simultaneously working their way through a multitude of work centers with hundreds of work orders and purchase orders and thousands of purchased and manufactured parts needing detailed real-time planning and scheduling.

The biggest challenges for the management of such make-to-order organizations are:

- Scheduling the manufacture of parts through a variety of different work-centers such that the parts are made in time to be part of their scheduled ship order to the end customer.
- Planning the manufacture or procurement of needed materials on a just-in-time basis.
- Planning which machines, equipment, or people to use.
- Determining when things are going wrong and taking appropriate action.

If everything went according to schedule then the planning and scheduling task would be complex but tractable using Excel spreadsheets and planning boards or the type of materials requirements planning (MRP) performed by most ERP (Enterprise Resource Planning) systems. But then employees fail to show up for work, machines break down, operations take longer than planned, and parts may be found to be defective or needing rework. As a result, frequent re-planning and re-scheduling are required, which can consume large amounts of costly management and staff time.

We see many organizations first try to solve these planning and scheduling problems by adding staff members, such as expediters, to try to make sure that products get out on time. But all that happens is that overhead costs increase dramatically and production plateaus. As a result, orders are shipped late and profits plummet.

In this white paper we propose an alternative where we use real-time artificial intelligence methods to augment management decision making so as to enable a small team of managers to efficiently run complex make-to-order and engineer-to-order organizations.

The Starting Point

The starting point of all good automated planners and schedulers is knowing the current state of all materials, labor, and machines as well as the current status of purchase orders, work-orders, pick-orders, and ship orders. Without this accurate "ground truth" basis, the plans and schedules created for make-to-order manufacturers are worse than useless, because they don't make sense, and are typically ignored by managers.

This real-time operations tracking information has to be provided by a real-time operations tracking system such as BellHawk, which tracks the status of materials and orders in real-time using tracking technologies such as barcode and RFID. Real-time tracking data may also be provided by process control and test equipment from which data may be integrated into the real-time status knowledge base maintained by the operations tracking system.

It should be noted that the information in most ERP and accounting systems is neither precise enough nor timely enough to use as the basis for real-time planning and scheduling. A system like BellHawk tracks the detailed location and status of materials in nested containers as they are moved and processed in real time. This is beyond the capabilities of most ERP systems, which are designed to plan and schedule long-run manufacturing jobs, with time frames in days, weeks, and months and not to handle the minute-by-minute changes of make-to-order manufacturing.

For smaller organizations, with simpler make-to-order products, simply having a real-time view of the status of their projects can be enough to enable them to efficiently manage their operations. But for many others, the large number of orders and parts in motion at the same time becomes an overwhelming management burden.

What is Real-Time Artificial Intelligence

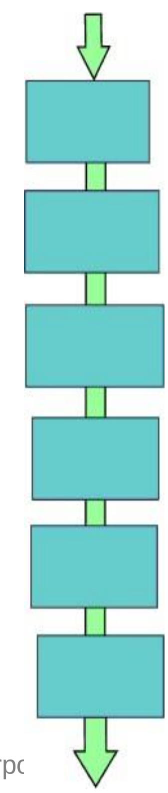
Real-Time Artificial Intelligence (AI) is the use of computers to:

- Detect when problems occur and notify system users when they need to intervene.
- Dynamically schedule the use of resources to best achieved the desired outcome.
- Plan, and especially re-plan, the use of resources to meet desired objectives

These real-time AI methods have their roots in classical rules-based AI expert systems, as well as classical optimized planning methods, such as are used for automated chess playing. They are different, however, in that the rules need to reason about time, importance, and the reliability of information. Also automated planners and schedulers cannot plan too far ahead as the world view of the system may change "on-a-dime", such as when a critical machine goes down.

As a result, these real-time automated planners and schedulers need to generate good decisions quickly rather than optimum decisions slowly. Also information received from people and other systems may be delayed or inaccurate. As a result the automated planners and schedulers need to be able to reason about uncertainty – just like a good operations manager.

BellHawk Systems was funded to develop such real-time AI methods by the US Air Force and NASA to aid pilots in managing complex missions. BellHawk Systems now applies these methods to provide real-time planning, scheduling and alerting support for managers of make-to-order and engineer-to-order manufacturers.



How Real-Time AI is used in Make-to-Order Manufacturing

Scheduling

The most frequent use of real-time AI is in scheduling work orders through a sequence of work centers. Here work is electronically queued up in front of each work center. As they complete each task, employees in the work center are then presented with a prioritized list of jobs they can work on. Employees will then normally pick the top task but can pick other tasks if their general knowledge indicates otherwise.

The prioritization of the task order is performed using a set of rules that take into account factors such as when the resultant product from a work order is due for completion or shipment, how long it is estimated to take to finish the remaining operations in the work order, and the importance of the customer job to the organization.

Note that this prioritization is dynamic, in that the priority order may change as some orders will leave the queue for a work center after being assigned to an employee and others may join the queue as an operation in a prior work center is completed. Also the priority order increases in subsequent work cells if operations in prior work centers take longer than expected.

This dynamic scheduling takes place without human intervention thus avoiding the need for an employee to ask “Hey boss, what do I work on next?” and then waiting while the lead person tries to figure out how to prioritize a multitude of work orders with different delivery dates and different customer importances.

This frees up a tremendous amount of supervisory time and also largely avoids the problem of a lead person making his work center run very efficiently at the expense of other work centers or customer deliveries. Having the computer pick which job to work on also avoids the problem of “cherry picking” which jobs they will work on. So an employee cannot just pick an easy job further down the list rather than a top-priority harder job without a good reason.

It is important, however, to allow employees to make use of their general knowledge, such as that a specific machine is starting to fail or that their company President plays golf with the CEO of a specific customer and so this customer’s order may have increased importance. It is for this reason that we use computerized “specific knowledge” rules to prioritize the scheduling choices but allow the use of employee’s “general knowledge” to override the computer’s recommendation.

Note that this form of scheduling is very different from the scheduling performed by an MRP (materials requirements planning) system, where a schedule is produced for a day, week, or even a month in advance. It is also different from the scheduling performed in daily production meetings, where the runs for the day are planned.

With real-time AI based scheduling, new rush orders can be introduced into the production mix at any time. They will get appropriately prioritized as they compete for human and equipment resources in each work centers. Also this form of scheduling allows for dynamic variation in the availability of these resources and still produces a quasi-optimal schedule.

Note that there is no claim that the resultant schedule is optimal, only that the scheduling decisions make sense given the current “world view” of the tracking system and the general knowledge of the employees who work in each work center. In a real-time make-to-order world there is no “optimum” schedule because the future is unknown: new rush orders may arrive, machines may break, a truck delivering materials may run into a ditch, employees may get sick, or the plant may have a power failure. All the scheduling system can do is to make the best decision it can based on the facts available at that moment – just like a good operations manager.

The biggest benefit of real-time AI based scheduling is that it can relieve managers and supervisors of a huge work load in trying to dynamically manage these schedules themselves.

Resource Planning

While scheduling is concerned with what order jobs should be processed through work centers to efficiently use the resources in those work centers, resource planning is concerned with which resources to use to do a specific operation.

These alternatives may arise when it is possible to:

1. Use different machines with different setup times and run rates. Here we are often trading off the ease of setup of a manual machine versus the setup time for a CNC machine.

2. Use people with different skill levels.

3. Assign work to different work centers in different physical plants.

In simpler operations, with for example three similar CNC machines in a work cell, these problems may be solved using the scheduling algorithms described in the prior chapter. But where there are alternatives with disparate capabilities that may be at different geographic locations then we need to add a resource planning layer.

This resource planning layer matches up the capabilities needed for an operation on a work order with the available resources and then recommends or makes the best possible choices. In making these choices the resource planner will take into account factors such as:

1. Projected setup plus run time for each matching resource.

2. The length of the queue of higher priority work orders in front of the resource.

3. Projected time to complete the operation given the projected setup and run times for all the jobs in the queue and the work order operation being scheduled.

4. Wanted date for completion of the work order and the estimated time to complete the remaining operations on the work order.

5. Relative importance of the work order.

6. Skill level of employee or employees available to run a machine or to perform operations.

Note that here, in a make-to-order operation, we are not attempting to come up with an optimum solution by examining all possible outcomes before choosing one, in the manner of a chess playing program. Instead we are only evaluate a few steps ahead in the planning process before making a decision using estimates for values like time to complete for different alternatives.

The reason for this is that in a make-to-order manufacturing operation things can change very rapidly and so long-range plans are not worth very much. As a result, it is much better to make good decisions quickly rather than perfect decisions too late.

Examples of the use of such an AI based resource planner include:

- Adding to the recommended schedule to recommend which machine to use or changing the set of recommended tasks based on an employee and the machine they run.

- Recommending assignment of employees to work centers, especially for labor intensive operations.

- Recommending whether to use an in-house resource for an operation or whether to subcontract this operation.

- Recommending which work centers in which plants will perform operations. Here the algorithms need to take into account material transportation time and costs in addition to resource availability.

AI based resource planning typically takes place at a slower pace than resource scheduling but is still very dynamic and so re-planning has to be done every few minutes to take account of changes tracked in the "world state" of all materials and orders. Also such planners are best used in an advisory role to a production manager rather than used to make automated decisions without human intervention.

In this advisory role the system can take away much of the drudgery of planning what runs where and who does the work but at the same time enables the manager to make use of their general knowledge to ensure that the system does not make poor decisions due to its lack of general knowledge.

Examples of such general knowledge overrides include the system recommending the use of a specific subcontractor when the operations manager knows that they just filed for bankruptcy.

Materials Planning

Historically, materials planning has been done by MRP (Materials Requirements Planning) systems, which are often integrated with accounting systems to become ERP systems. These take a long-range projection of customer orders or planned production and then determine what materials to order and make and when. This works well for long-run manufacturers but not for quick-turn, short-run make-to-order manufacturers.

Instead, in a system like BellHawk, we start with an estimate of projected available inventory over time. We start current physical inventory and then add in materials for future delivery on purchase orders and materials scheduled to be made by work orders. We then subtract materials to be consumed on work order operations and on ship orders. This gives us a time varying graph of expected inventory levels.

For organizations with a simpler project mix, just having this information available in real-time enables them to manage the ordering of materials and the planning of when work orders will be started. But for those make-to-order manufacturers handling complex projects this is not enough.

So to this, we add an intelligent agent that periodically examines the available inventory graphs and generates Email alerts to operations managers that they may need to take action if there is not enough available inventory. Such shortages are typically due to new orders arriving but may also be due to late deliveries, delays in manufacturing intermediate materials, and the need to scrap defective materials.

The operations manager can then use BellHawk's Pull-Based Inventory Management system to make recommendations as to what materials to order and what production work orders to run, and when, to compensate for the projected inventory shortfall. Note that again the system makes incremental real-time recommendations based on the current state of available inventory. Unlike MRP systems BellHawk does not start planning "from scratch" and as a result the plan may be less optimal in terms of combining purchase orders and work orders to minimize costs.

However, in most make-to-order environments the plan that makes sense and is made quickly is much more likely to be of value to managers trying to juggle a myriad of activities in a rapidly changing production environment. The big benefit is that the real-time AI component takes care of the myriad of calculations needed for projected materials availability in a busy make-to-order or engineer-to-order operation.

As with scheduling, such materials planning is advisory so that operations managers can revise the plan in real-time to take account of their general knowledge.

Problem Detection

In additions to problems of potential inventory shortage there are many other production problems that operations managers need to contend with. These include:

- Materials not staged at the appropriate work centers when needed
- Manufacturing operation taking longer than planned
- Machine down for too long
- Too high a level of failure when product inspected
- Order predicted to be shipped late to customer

These problems can all be detected by using intelligent agents to periodically inspect the "world view" and use estimates based on this world view to alert a manager or supervisor that they need to take action, typically by sending an Email or text message to their mobile phone.

This enables much more efficient use of a manager's time. It is an alternative to:

1. Walking around the floor looking for problems
2. Waiting until an employee tells you there is a problem
3. Waiting until your customer calls to say they didn't get their order on time
4. Looking at computer screens and reports to determine whether a problem has occurred

In this new paradigm, the real-time AI rules and algorithms detect the problem and alert the operations management staff when there are problems that need their attention. This is much more efficient in terms of manager's time than current manual methods of detecting problems.

In complex make-to-order manufacturing operations, these algorithms can spot problems before they occur and enable managers to be proactive rather than reactive. They can also find problems that are not immediately obvious from a casual inspection of the data but which will lead to problems, such as late delivery, in future.

Technology

At the base of all real-time AI based planning, scheduling and alerting systems is a real-time operations tracking system such as BellHawk that captures and tracks the real-time status of materials, employees and machines as well as the current status of purchase, pick, work, and ship orders. This is essential to track the "world view" of the production operation on which all the planning and scheduling takes place.

This system also tracks production history which can be used to compute aggregate throughput data, which can then be used to estimate how long production operations will take.

For operational convenience, real-time scheduling and available inventory tracking is built directly within the BellHawk tracking system as are the pull-based inventory algorithms used by managers to incrementally issue purchase and work orders. As standard these modules use relatively simple rules and algorithms that are common across most make-to-order operations. These rules are then be augmented on a case-by-case basis to meet the specific needs of each manufacturing or engineering organization.

Problem and event detection in a BellHawk system is performed using intelligent agents that run under the control of the same Bell-Connector framework that BellHawk uses to automatically exchange data with ERP, accounting, process control and other systems. These intelligent agents are scheduled to run on a periodic basis and use rules and algorithms to detect issues that need human or AI intervention.

The reasoning used by these intelligent agents is typically time-based as often they are looking for events that have not occurred within a certain time as well as specific events that have occurred. Once they have detected the presence or absence of a needed event these intelligent agents then normally send a message by Email or text message to one or more managers or supervisors.

These systems can also track when the problem has been fixed. This is so that they can send messages to people higher up the management hierarchy if the problem is not fixed within a specified time.

Implementation Cost and ROI

Systems like BellHawk to capture the real-time status of a real-time manufacturing operation typically range in cost from around $10,000 to $100,000 for software, barcode equipment, and implementation services depending on the complexity of the manufacturing operation and the projects being tracked.

Simple real-time scheduling, available inventory tracking and pull-based inventory management then only add a few thousand dollars to the system cost.

The biggest cost is in the development of custom scheduling, planning and alerting rules and algorithms for each specific manufacturing operation. These can typically cost from a few tens of thousands of dollars to over $100,000.

In our experience, our clients spend from around $30,000 to over $200,000 for a real-time operations tracking solution with integrated real-time AI based scheduling, planning and alerting depending on the complexity of their operations and the complexity of the custom rules that need to be implemented.

According to Industry Week, the average salary in 2015 for manufacturing managers, supervisors, materials managers, expediters and other staff people needed to manage a manufacturing enterprise was over $100,000 per year. Add in the cost of medical insurance, holidays, vacations, and other fringe benefits and the cost quickly climbs to over $150,000 a year.

As a result, payback periods typically range from 6 months to 2 years, although in one case the payback period was under 4 weeks (admittedly an exception).

Manufacturers in the USA have made great strides in automating production operations so as to dramatically reduce the need for production workers. Now the cost of managing the operation becomes a major overhead burden, which can be reduced by the use of real-time artificial intelligence methods, as described in this white paper.

While implementing these systems is a time consuming and expensive process, especially for the development of custom rules and knowledge-based algorithms, our clients quickly report that they could not run their make-to-order manufacturing operations without their BellHawk system to provide the management tools that they need. Not only do these systems enable management of manufacturing operations with far fewer overhead staff but they make life less stressful for managers by providing them with the automation tools they need.

Commentary

Implementing a real-time AI based operations management system is not an all or nothing proposition. Many of our clients start with a simple operations tracking system and then incrementally add scheduling, planning, and problem alerting capabilities, as they find ways to apply these AI based methods to improve the management of their make-to-order operations.

Many users of BellHawk are unaware that they are using real-time AI based methods for their scheduling and planning. For them, this is just the computer assisting them to efficiently schedule and plan their operations.

For those technologists interested in implementing real-time AI based planning and scheduling methods, the one big lesson that we have learned is that the algorithms need to make adequate decisions quickly rather than optimum decisions slowly. This means limiting the look-ahead branching of the planning algorithms and using many approximations in estimating the times for future actions.

A good analogy is to think of being in the middle of a road with an 18 wheeler truck bearing down on you. It is much more important to leap out of the way than to take the time to figure which choice, leaping left or right, would be optimum for minimizing the time for your overall journey. You might look ahead one step to see whether there is a car coming round the truck but otherwise it is much more important to get out of the way of the truck and then to figure out how to complete your journey. This is opposed to standing there trying to make a decision while the truck runs you down.

Author

Dr Peter Green received his BSEE and Ph.D. degree in Computer Science from Leeds University in England. He was a senior member of the reseach staff at MIT, where he performed reseach into real-time intelligent systems under a DARPA funded contract.

He was subsequently a full Professor of Computer Engineering at WPI, where he performed reasearch into software methods for implementing real-time intelligent-agent based systems for the US Air Force and NASA. He then founded BellHawk Systems to continue this research and development using SBIR grants to enable comercialization of this technology.

While this technology had tremendous potential over a decade ago, it failed to gain commercial traction for industrial use because the real-time data on which these systems are based was simply not available from most systems in industrial use at that time. As a result Dr. Green turned his teams attention to the real-time operational data collection problem and over the past decade they have implemented close to 100 systems that are able to collect the needed data in real-time.

As these systems have grown in capability, the BellHawk team has incrementally integrated real-time AI based scheduling, planning and alerting methods. These methods are now coming into their own to solve the increasingly complex project management problems faced by make-to-order manufacturers and engineer-to-order organizations.

Information

For more information, please contact Peter.Green@BellHawk.com. Also, please see www.BellHawk.com for more details on BellHawk System's software technology.

