Visualizing Capacity and Load: A Production Planning Information System for Metal Ingot Casting

Peter Y. Wu
wu@rmu.edu
Department of Computer and Information Systems

Sushil Acharya
acharya@rmu.edu
Department of Engineering

Robert Morris University
Pittsburgh, PA 15108, USA

Abstract

Information system for production planning needs to deal with myriads of parameters and conditions to cope with the ever-changing marketplace today. The visualization of production schedule provides the basis for interactive decision support. We study the problem of metal ingot casting, and design the abstract machine models to visualize capacity and loading of the production schedule. We identify two categories of machines: setup sensitive machines and batch operation machines. The graphical user interface design partitions the time domain into capacity buckets in order to visualize the schedule according to the specific characteristics of the machines. Our design may also be extended to support many other important functions such as tracking availability of raw materials, projection of inventory due to production overage, as well as critical business analysis. We briefly discuss the extensions.

Keywords: production planning, schedule visualization, interactive decision support, setup sensitive machine, batch operation machine, metal ingot casting.

1. INTRODUCTION

Production planning is traditionally treated as an optimization problem seeking the best schedule under the constraints of delivery due dates and availability of resources. However, in a rapidly changing marketplace, production planning decisions need to be made quickly to be responsive. Quite often, we have to make judgments when objectives and constraints are not even readily quantifiable. We need the information system to be able to visually present production plan with its capacity and load, allowing human interaction to make changes while showing the ramifications by immediate feedback (Greene 1996; Mcilvaine 1996; Wu 1999). The human planner would like to be able to promise to deliver based on the available production capacity.

Production planning is known to be an extremely difficult task and the use of the right tool will make the job easier and may result in higher efficiency as well as profits (Takahashi 2008). From research to practice in the past couple of decades, the production planning system has gone through three stages of evolution. First, the scheduling information system supported or replaced the scheduler's daily task of Gantt chart sequencing. Second, scheduling began to involve enterprise integration. The MRP-ERP conversion took place: production planning evolved progressively from materials resources planning (MRP) to enterprise resources planning (ERP) (Jacobs & Westen 2007). Third, the present focus has now moved to the requirements of management reporting throughout the production process from promise to delivery (McKay & Black 2007). During the evolution, different approaches and practices developed. Much of the effort concentrated in the application of artificial intelligence in planning and scheduling. Psarras (2007) applied the genetic algorithm approach to production planning. Guo, Wong, Leung and Fan (2009) developed an intelligent production control decision support system. Our approach is to use visualization to support making manual changes to a production plan, thereby augmenting and extending the use of intelligent planning and scheduling systems (Wu 2001). Visualization is the ability to see and understand the present situation and therefore visualization tools are important in production planning (Takahashi 2008). We believe this approach will allow businesses to better cope with the dynamic changes of constraints in production planning, and will improve versatility and enhance usability of information systems for production planning. (Gunther & van Beek 2003; Juraz 2000; Zhang 1996)

Our study is prompted by the production planning problem of metal ingots casting. Applying the analysis at the bottle neck of the assembly line (Goldratt & Fox 1984), we identify these bottle-neck machines of the production process, namely the melting furnace and the heating oven. Our approach is based on visualizing the production capacity and load on the schedule of these machines. We design an interactive load graph to visualize the production capacity and load on the schedule of these machines. Using the interactive load graph, the planner can interact with the production plan and make changes manually, while relevant information about the impact of the changes may be shown immediately through visual feedback.

The paper first describes the metal ingot casting process. We then outline the design of an interactive load graph to visualize capacity and load in the schedule. We focus our attention on the potential bottle-neck machines since they characterize the efficiency of the production plan (Goldratt & Fox 1984). The user interface design being the central thesis of our paper, we then discuss the details of the visual models which capture the operational characteristics of the machines to support visualization and interaction. In the case of metal ingot casting, we identify two categories of potential bottle-neck machines, namely, the set-up sensitive machines and the batch operation machines. Each machine category demonstrates its uniqueness in our design.

2. METAL INGOT CASTING

A metal ingot is an alloy to supply all kinds of metal product manufacturing. In metal ingot casting, the bill of materials is relatively simple: for each alloy, the bill of materials specifies the proportion of ingredients to be mixed with the metal ore. The mixture is poured into the melting furnace. The molten mixture is then released into the dropping tool for casting into ingots of the alloy product. The ingots then need to go through the oven for heat treatment. Each type of ingot product will have its recipe detailing the temperature profile for heat treatment for the desired metallurgical properties. The manufacturing process is illustrated in Figure 1.

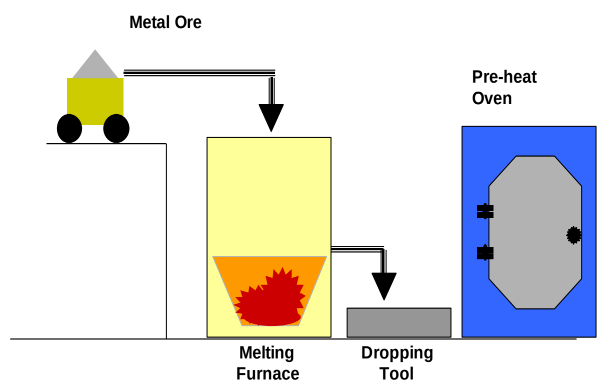

Figure 1. The metal ingot casting process

3. VISUALIZING CAPACITY AND LOAD

Traditional planning approach lays out the tasks of each machine of the process in a Gantt chart. To satisfy an order for production, we load the machines, each at the appropriate time slot needed for the production process. However, the Gantt chart does not make it easy to assess the production capacity still available. This becomes evident when the load is close to the total available capacity. While the overall plan is a global optimization problem, we observe that planners will still need to make incremental manual changes every now and then. The need to visualize the available capacity in the production plan becomes critical.

The loading situation at the bottle-neck gives us an accurate measure of the available production capacity (Goldratt & Fox 1984). With respect to each machine, an order to produce then loads the production plan in two key dimensions: the time (duration) and the timing (slot). We partition the time domain into contiguous and disjoint buckets to visualize these two dimensions: an order which needs to use the machine is represented as a block in the time bucket, occupying a time duration in its timing slot. The maximum capacity of the machine is then simply the total available time. Figure 2 illustrates such a production plan, a load graph with the time bucket size of one week. The maximum feasible load may then be 168 hours, if the machine is available to operate 24 hours a day, 7 days a week. Each block represents a job assigned for production within that week. The height of the block represents the load on production capacity, that is, the time duration it will have to occupy the machine. We can easily see any case of overloading, as well as the availability of capacity for production. Furthermore, each job assigned to any particular week may be late for delivery, too early for production, or optimal. We color code the blocks, so that late jobs are red, early jobs are blue, and the ones done just in time are green. Interesting interaction can then occur on the load graph when the planner can drag and drop each block, moving it from one week to another, re-arrange their order within each week, or split up a block and move one part away. When the ramifications of these changes are computed automatically with visual feedback, the planner can then decide whether or not the change is feasible, or desirable.

Each block may also serve as a window (screen real estate) to facilitate interaction with the planner to drill down and find more detailed information about the order such as product code, customer order number, customer name and select to display any of the information as label on the block.

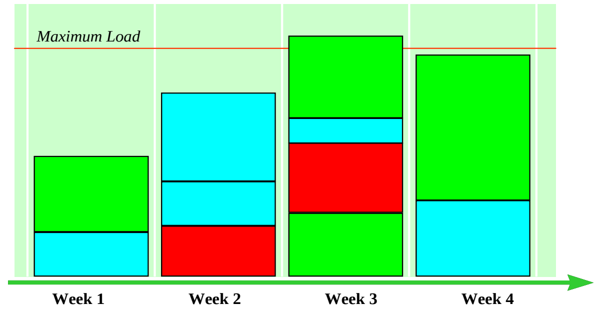

Figure 2. Schedule showing capacity and load

4. TWO CATEGORIES OF MACHINES

We now extend our basic model of the machine to cover two categories of machines, namely, the set-up sensitive machines and the batch operation machines. These two categories are common, but they do require special attention. We will describe in detail the characteristics of these machines, and then discuss the problems involved with planning them for production. Our main point however is in the visual presentation of the schedule and the interaction supported on the load graph.

Set-up Sensitive Machines

By set-up sensitive machines, we refer to machines that may require substantial time for preparation when switching from one job to another. The melting furnace in metal casting is a good example of the set-up sensitive machine. Changing from one alloy to another can be very costly because of the need to wash and flush the whole furnace with expensive molten metal, the precious machine time to melt the metal. Note that this is different from the overhead set-up of a machine to prepare for operation, but is due to the sequencing of operations on the machine for different jobs.

While the planner needs to be concerned about minimizing set-up cost, he should be more concerned about finding a acceptable production plan. Each job usually would have a certain feasible time window restricted by the availability of raw materials as well as the promised delivery date. In practice, the problem is in fact a time-constrained version of the travelling salesman problem, and some of the constraints may be negotiable (Gutin & Punnen 2002). We believe a planning system helpful to the planner would be partially automated for assistance with sub-optimal solutions or partial solutions, but should be an interactive system which supports manual changes and final adjustments.

Note therefore that on the set-up sensitive machine, whenever the planner assigns a job to a certain time bucket for production, the sequence of operations may also generate additional set-up jobs, before and after the new job. The new sequence thus formed may or may not be optimal, and the planner can apply a sub-optimal solution to the jobs within the time bucket to minimize set-up.

Visually presented on the load graph, the additional set-up jobs generated by the sequence of operations are in yellow blocks (or strips, because they are usually thin); the set-up jobs are not associated with any customer order and have no promised delivery dates. These yellow blocks may appear or disappear as required by the sequence, when the planner moves the blocks around to adjust the production plan. They do not support other interactive functions except in showing the details of the specific set-up job. But they give the planner an easy visual perception of the performance of the production plan in saving set-up time. Figure 3 is an actual screen capture of the interactive load graph.

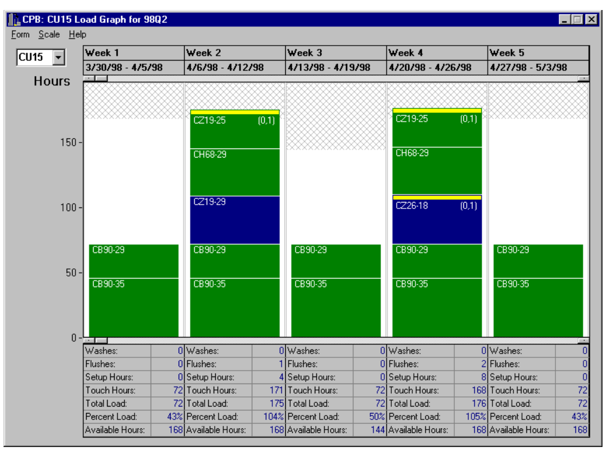

Figure 3. Setup-sensitive machine: the furnace

Batch Operation Machines

By batch operation machines, we refer to the category of machines which can handle multiple jobs in one single operation, taking a fixed duration of time for the operation. The heating oven in metal casting is an example. Metal products need to go through heat treatment - a temperature profile over time called the recipe. While a recipe may take a substantially long time, the oven can conveniently apply the same recipe to different jobs at the same time provided that there is sufficient space. Hence, the oven can take multiple jobs in one batch. Whether or not the batch is filled, the operation takes a fixed duration dependent only on the recipe.

Therefore when planning for the batch operation machine, we want to be able to fill each batch as much as possible. Our model for the batch operation machine is an extension to the basic model. In the case of the oven, the recipe for a batch defines the time duration required, that is, the height of the block in the load graph for the whole batch. Since each batch can take multiple number of jobs, in our model, the batch operation also keeps the information of a list of jobs currently assigned to the batch. When planning for a job at a batch operation machine, we will first check to fill existing batches for the same recipe (or an acceptable recipe), within the feasible time window. If deemed appropriate, the planner may also generate a new batch for use. Thus, in our approach, we present the batch operations on the interactive load graph to the planner, visually showing the empty/filled status of each batch. The design then supports interaction with the production plan, including the moving of jobs in and out of each batch.

Figure 4 depicts the interactive load graph for the batch operation machine, showing batch operations as frames (instead of blocks), and jobs as blocks within each frame.

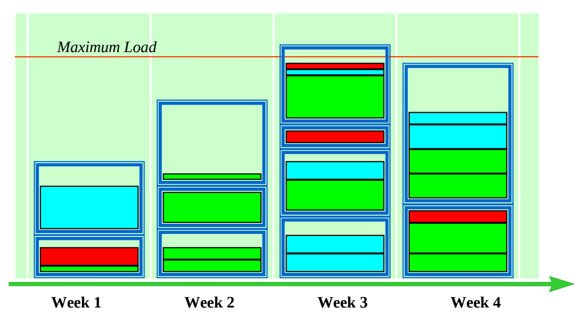

Figure 4. Batch operation machine: the oven

The height of each frame is a measure of the time duration of the batch operation which is dependent on the recipe. Each frame should also support direct manipulation with drag-and-drop, so that the planner can interactively move them around. The frame itself is not associated with a customer order, and has no status for late, early, or on-time delivery. Since each frame is a batch which may or may not be filled. We show the jobs assigned to the batch as blocks within the frame, visually presenting the filled/empty status of the batch operation. Each block inside the frame is a job assigned to fill the batch. Hence they are color coded for late, early, or on-time delivery. They also support direct manipulation with drag-and-drop: the planner can move a job to another batch by moving the block from one frame to another. The system also updates the color coding immediately in interaction. If the planner moves the whole frame, all the blocks within the frame will move along together, and the system must update the color status of all the jobs assigned to the batch.

5. DISCUSSION AND FURTHER WORK

Modern production planning also needs quick response to changing market situations. While the work reported in the paper is on-going, we believe our design of the interactive load graph will provide the context to extend the planning and scheduling systems to include these functions. In the following, we briefly discuss each of these functions. They indicate further work to be done.

Inventory Projection
Each job order quite often produces a small overage. The accumulated overage becomes existing inventory. The inventory information can be incorporated into the interactive load graph for use by the planner. The important point here is the immediate re-calculation of the projected inventory level when the planner is making changes in the schedule interactively. The planner therefore can have the freedom to control the desired inventory level in anticipation of demand changes. Furthermore, since the inventory level computed is projected from the production plan, we need to integrate that with actual inventory level from stock piles. We should allow a loosely coupled scheme so that the application of our projected inventory strategy can be practicable in different environments, depending on the frequency with which we update the current level of inventory, the more often we take inventory, the more accurate our projection can be.

Beyond the flexibility in production planning with inventory control, the significance of bringing real-time inventory projection together with planning is that it facilitates for availability to promise. If projected inventory level is reasonably accurate, the planner can reliably make promises ahead of time with confidence.

Availability of Raw Materials
We also need to examine availability of raw materials as well as projected levels of inventory for production planning. In the interactive load graph, it should be desirable to also visually provide the updated information about raw materials available. Since metal ingot casting has a simple bill of materials, this addition will provide a rich source of useful information from the interactive load graph.

Extension to the machine models
We have identified two categories of machines and extended our model to provide special handling for them. There may be other categories of machines which we need to pay special attention. We envision organizing the software models into an object-oriented class hierarchy and develop a class library for software design and development.

Business Analysis Tools
Given the production plan, we also want to be able to analyze it based on the business objectives. For example, we may want to review the statistics on on-time delivery, or obtain an inventory of work-in-progress. The interactive load graph provides the place to perform these analyses. It should be most valuable to facilitate the interactive load graph with these analysis tools, and the system would not only be used by the planner, but becomes a precious source of information for the executives.

6. SUMMARY

We described the graphical user interface design for a production planning information system for metal ingot casting. Our approach is to visualize the capacity and load in the production plan so that we can interact with the system to obtain relevant information, including possible changes to the plan and ramifications of the changes. Our study was prompted by the problem in the metal ingot casting process. We described the production process and identified two potential bottle necks in the process: the melting furnace which is setup sensitive, and the heating oven which operates in job batches. We also presented our design which captured the special characteristics of the two categories of machines. The models provide for the visual presentation of the production plan to support interactive decision making. In closing, we discuss potential extensions to the system about relevant further work.

7. REFERENCES

Goldratt, Eliyahu. & Fox, Jeff. (1984). *The Goal: A Process of On-Going Improvement*, North River Press, Inc.

Greene, A. (1996). Decision-Support Tools Provide Competitive Edge. *Managing Automation*, *March 1996*, p.8.

Gunther, Hans-Otto. & van Beek, Paul. (eds) (2003) *Advanced Planning and Scheduling Solutions in Process Industry*, Springer-Verlag, Netherlands.

Guo, Z.X., Wong, W.K., Leung, S.Y.S, & Fan, J.T. (2009). Intelligent Production Control Decision Support System for Flexible Assembly Lines. *Expert Systems with Applications: An International Journal*, (36) 3, 4268-4277.

Gutin, G. & Punnen, A.P. (2002). The Traveling Salesman Problem and its Variations. Kluwer Academic Publishers, the Netherlands.

Jacobs, R.F., & Weston Jr., F.C.T. (2007). Enterprise Resources Planning (ERP) – A Brief History. *Journal of Operations Research*, 25(2), 357-363.

Juraez, O. (2000). Evaluating Visualization Based on the Performed Task. *Proceedings of the Information Visualization Internatinal Conference (IV'2000)*, July 2000, London, England, pp.135-142.

Mcilvaine, B. (1996). Planning and Scheduling Gets the Job Done. *Managing Automation*, *August 1996*, pp.24-26.

McKay, K.N. and Black, G.W. (2007) The evolution of a production planning system: A 10-year case study. *Computers in Industry*, 58(8-9), 756-771.

Psarras, J. (2007). GA-based decision support systems in production scheduling. *International Journal of Intelligent Systems Technologies and Applications*, 2(1), 58-76.

Takahashi, K. (2008) Increase Profits with a Production Planning Scheduler. Retrieved September 2001 from http://www.lean-manufacturing-japan.com/advanced-planning-scheduling.

Wu, P.Y. (1999) Visual Capacity Modeling for Interactive Production Planning, *Proceedings of the Computer Technology Solutions Conference* (CTSC'99), Detroit, Michigan, published by the American Society of Manufacturing Engineers.

Wu, P.Y. (2001) Visualizing Capacity and Load in Production Planning, *Proceedings of the Fifth International Conference on Information Visualization*, London, England, published by IEEE Computer Society, pp.357-360.

Zhang, P. (1996). Visualizing Production Planning Data, Visualizing Blackboard. *IEEE Computer Graphics & Applications*, *16*(5), pp.7-10.