Scheduling and Controls of Project Manufacturing

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Abstract

Production controls are usually based on either mass production or job-shop manufacturing. These techniques are tailored to manage production of quantities of the same product. Outside of that spectrum is the manufacturing of sets of unique products. Every product is the ultimate result of a project. Although these products are created in manufacturing environments similar to the job-shop conditions, they still need different management and controls techniques. In project management, product manufacturing is usually a phase in a larger project such as EPC (engineering, procurement, and construction.) Most EPC projects involve manufacturing that is either internal to the performing organization, or outsourced. Usually the schedule of manufacturing is lumped with the procurement phase as one long task. This shows a disconnection in the project schedule. The project manager has no control over that task because manufacturing by itself is managed by job-shop or make-to-order production management techniques. Projects require a unique product to be manufactured. Project planning and scheduling for unique products is not common in most manufacturing plants.

This paper presents and redefines the concept of project manufacturing and based on a unique and temporary product. The paper examines the scheduling, sequencing, and resource pooling operations required for a plant dedicated to project manufacturing. A methodology for automating the creation of a schedule based on the critical path method is outlined in the paper. An implementation is discussed to prove the usability of the proposed procedure. The goal of this procedure is twofold. The first is to integrate the manufacturing schedule with the rest of the project schedule which gives the project manager more control over the whole project including the manufacturing phase. The second is to introduce a new method for managing and resource loading in production plants dedicated to project manufacturing. That enables the production controls personnel to manage each project individually and in the same time combine all projects worked concurrently at the plant.

Overview

Project manufacturing or engineer-to-order (ETO) manufacturing is known and practiced in the industry but not in a formal way. Project manufacturing is to produce or assemble one unit of each unique product. Although it is a manufacturing environment, it follows the definition of the project of being temporary and unique. In mass production, there is a production or assembly line that produces thousands of units from a certain product. The methods used for production planning, scheduling, and controls of mass production cannot be employed to project manufacturing. Instead, a company that owns or operates manufacturing plants dedicated to manufacturing or assembly of projects use job-shop techniques to schedule and controls their production. Not only that, they try to implement state of the art production process improvements that are designed mainly for production of high volume such as mass production or job-shop manufacturing.

Blevins (1999) introduced the topic of project manufacturing in a very nice and simple way. He stated that the project manufacturing business has a set of islands and urged that they need to be integrated for a better planning and controls. Fox et al (2009) introduced a comprehensive list of challenges and sources of complexity that face project manufacturing. Interested readers are encouraged to review Fox's article. Some of these challenges are:

- Giving an authority to the customer. That is typical in project environments but not very helpful in scheduling project manufacturing.
- Change of priorities of individual customers makes the project manufacturing schedule to stop and resume several times during the lifecycle of the project.
- High number of components that are needed for the assembly of a single sub-product. For example a side wall of a boiler may need more than 100 tubes in different shapes and sizes.
- Components for the same sub-assembly may have a high variation in delivery times.

Abdelmaguid and Nassef (2010) stated that the job shop scheduling problem (JSP) is a traditional decision making problem that is encountered in low volume–high variety manufacturing systems which are known as job shops. Although job-shop scheduling is dedicated for low volume manufacturing, it is still a good technique for repetitive products but not as good for a project manufacturing. Every final product and all of its components are totally different from any other product. Therefore, it is unwise to apply an approach for repetitive products into non-repetitive parts.

Another simple reason to examine project manufacturing problems is that manufacturing the product is one part of the whole project. Integrating production schedule with the rest of the project schedule will be a nightmare if production is scheduled using job-shop approach. Caron and Fiore (1995) urged to find an innovative approach to integrate manufacturing and logistics with project management. Their approach was suitable back then before the popularity of the enterprise project management tools. On their study of construction project complexity, Bertelsenand Koskela (2005) urged that using two different systems for project management and project production adds to both the complexity of the project and the uncertainty of the objectives.

The following table shows some differences between the repetitive production and project manufacturing. These differences are given to emphasize the need of a different method for scheduling and controlling project manufacturing.

Category	Repetitive Manufacturing	ETO / Project Manufacturing
Products	Makes standard products	Products are unique
Pricing	Uses a price list	Estimates, quotes, and Bidding
Number of components per sub-assembly	Low	High
Inventory	Based on part number	No Inventory
Engineering	No or only a few engineering changes	A significant number of engineering changes
Value	Low value	Typically higher in value
Production routing	Standard	Customized for every product
Lead time	days or weeks	months or years
Shipping	Ships from finished goods	Ships from WIP(work-in-progress)
Progress measures	Measures cost variance from the standard cost.	Measures cost variance from the original budget.

This paper presents an approach for scheduling and control of project manufacturing using the critical path method. The approach provides solutions to the two requirements of the project manufacturing business:
i.   Integrating the manufacturing schedule with the rest of the project schedule.
ii.   Managing the overall load of the manufacturing plant using enterprise project controls systems.

In fact, this approach has been implemented in a few plants dedicated to project manufacturing of heavy power generation products. The approach simplified the planning and controls that used to be performed using job-shop methodologies. It provided more flexibility in stopping the project and resuming it again.

The proposed system can be integrated with the manufacturing execution system of the plant. That will make it fully automated which can provide real time status of the project. If there are not enough capabilities to integrate the system with manufacturing execution systems, it can be implemented by itself and the initial schedule and its progress could be updated manually.

The rest of the paper is dedicated to the description of the system and how it is integrated with other systems. The description of how to use the system and to get the benefit from it is also outlined below.

Creation of a Manufacturing Project Schedule

For every project or product a unique routing sheet is always developed by the manufacturing engineering team. The routing sheet consists of a set of routing sheets for shippable products or subassemblies of the final product. Every shippable product is considered as a single node in the work breakdown structure (WBS) of the whole project. Each routing sheet at a WBS node consists of a set of work-orders. A work order describes the sequence of operations that are needed to produce a smaller subassembly. Products from work orders may be assembled using a set of operations described in another work order. A work order may have one or more operations.

Typically each operation in the routing sheet contains the following:
- operation duration
- labor class
- number of needed man-hours
- work center
- number of machine hours
- material being processed
- number of material units

In the critical path method (CPM) world, each operation can be considered an activity. Therefore, the routing sheet allows the creation of the activity list complete with its duration, labor resources, machine resources, and material resources. If the routing sheet is in electronic format, which is most probably the case, it can be easily converted into a list of activities in the project scheduling software. That activity list will be complete with all resources loaded. Moving activity data from the routing sheet into the scheduling system can be automated and can be performed in few moments even if the project is very large.

To have a complete schedule, one important feature is still missing. That is the activity sequence. Examining the workflow of project manufacturing, it found that for every project or product, there is a unique engineering bill of material (EBOM) not a standard BOM. Knowing that each work-order represents a component or part in the product, the EBOM specifies the parent assembly of each subassembly. That kind of parent-child relationships, allows for generating activity sequencing. Consider the following example:

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Part C is a subassembly of part D. Part C is assembled by welding parts
A and B. Part A is a 40 feet tube. It needs to 4 operations; cleaning,
milling, bending, and heat treatment. Part B is a flange and needs only
two operations; drilling and grinding. Then the sequence will be A1,
A2, A3, A4, C1, C2, C3, D1. In parallel, there will be another sequence
B1, B2, C1, C2, C3, D1 as shown in Figure 1.
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Following that procedure, activity sequencing can be easily generated and automated. The WBS of the project should be recognized and followed during generating the activity list either manually or automatically. Imposing activity sequence on top of that will produce a rotated shape of the EBOM.
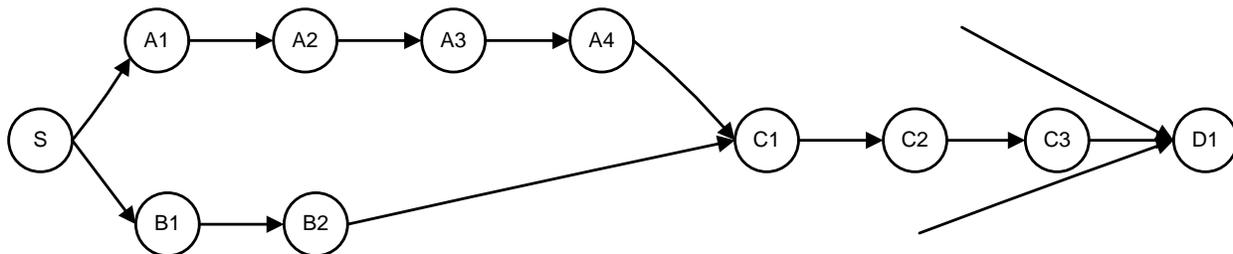
Figure 1: Activity Sequencing Example

These two steps generate the initial resource loaded manufacturing schedule of the project. It is generated using the CPM and can be easily integrated with the rest of the project schedule. The benefit of the integration is known to

most people in the field of project scheduling. Any changes in the engineering schedule will affect the manufacturing schedule as soon as they are recorded. Although such a situation is not favorable in a manufacturing environment, it is the fact of life. Changes on engineering schedules and their reflections on manufacturing schedules are much easier to handle using the integrated schedule than having two different scheduling systems. However, these changes complicate the resource management of the manufacturing plant as shown below.
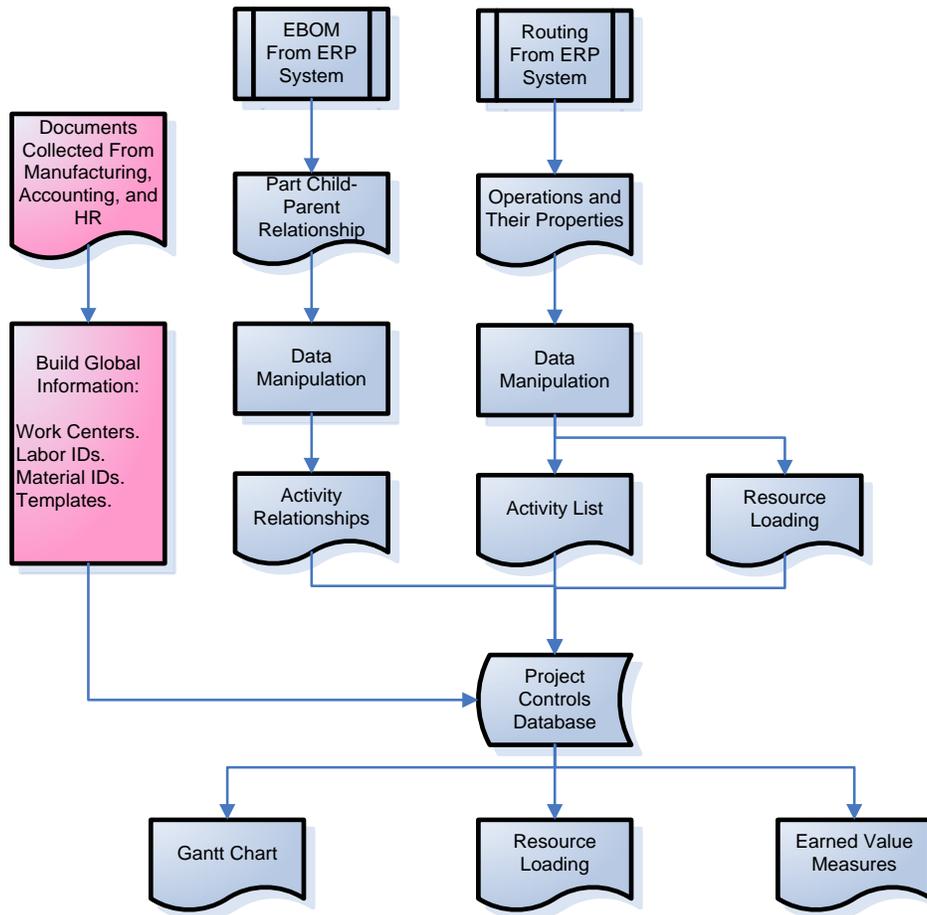
Figure 2: Process Data Flow

Figure 2 shows the flow of information to perform the procedure mentioned above. It is assumed that both the routing sheets and the EBOM are generated and posted into the ERP system of the performing organization. The two blocks in different color are assumed to be performed once in the lifetime of the system and then updated when changes happen. These are meant to build the global structures such organization chart and resource hierarchy of the manufacturing plant in the scheduling system.

Updating the Manufacturing Schedule

In most manufacturing plants, there is a manufacturing execution system which collects actual information from the shop floor. The system collects real-time information about each operation in the routing sheet. It collects the following information:
  o   Operation start time and date
  o   Time elapsed on an operation

- o Labor hours charged to an operation
- o Machine hours charged to an operation
- o Material consumed so far
- o Number of units completed
- o Operation finish time

A baseline based on the initial schedule should be generated for future comparison with the project progress. On a daily, weekly, or biweekly basis, the project schedule can be updated automatically by extracting the actual start date, actual duration, actual labor hours, actual machine hours, and actual material processed from the manufacturing execution system. If the process is automated, the update cycle might be daily. If it is performed manually the update cycle might me weekly or biweekly. The number of unites completed determines the physical or realistic percent complete of each activity. The earned value measures (EVM) can be employed with a great confidence since the percentage complete of the activity is based on a total objective measure. Therefore, the system will be able to report the project progress and more.

Suppose that the baseline states that the activity duration is 100 hours and it requires 200 labor-hours to bend 1000 tubes. Two workers will be working on this activity for 100 hours. After 5 working shifts, 40 hours of the duration are gone, 80 labor hours are charged, and 300 tubes are completed. Using the EVM, this activity is over budget and behind schedule. However, there is another conclusion that can be captured. It was assumed that each tube will be bent using 0.2 labor hours. The progress shows that each tube consumed 0.27 of labor hours. That concludes that there is a problem with the process efficiency. This is different from accelerating a construction or engineering activity to finish on time. The situation here is about the efficiency of the manufacturing process which should be corrected. The measures do not only give progress of the activity but also they report problems with the production process. Manufacturing management should pay attention to these problems.

Resource Loading for Project Manufacturing Plant

One of the biggest advantages of the enterprise control systems is the combination of resource requirements for different projects. Combining the demand on resources helps the manufacturing managers plan their resources and prioritize the workload. Figure 3 shows a requirement for milling mechanist role for all projects currently active in the enterprise database (that are the active projects in the plant). This helps the manager of the milling group prepare for the peak resource allocation on milling mechanist by training other workers. Those with a secondary role as milling mechanist will serve as primary worker when they are needed.

Another planning scenario for the manager of the milling department is when he is negotiating with the project managers to move some of the activities back and forth in order to get rid of the demand peak. Of course the project manager needs to consult with the manufacturing scheduler on the possible effects moving an activity will cause on the overall schedule due to the dependency of other activities.

Is it possible to find one crew so heavily over-allocated? Yes, it is. Project managers usually know their employees. They know who gets the job right from the first time, or can give the initial results fast, or works with minimal supervision, or has many years of experience. During the initial planning of the project, they ask to put that crew on their project team. The result an over-allocation of a certain crew while under-allocation of other crews. It is the responsibility of the functional manager to reallocate the extra load to other crews who can also perform the job. The functional manager can coach the less experienced resource to achieve the job efficiently. These resources work for the functional manager who is assumed to know most of the details of their work. By keeping a close eye on the load of each resource in the group, the resource manager can avoid the situation of over-allocation from happening.

Changes on the start date of the project or the start and finish of certain activities are imposed by the client or the engineering group. These changes will force the project and its resource load to move back and forth. That will make the requirements on resources dynamic and uncertain as noted by Wullink et al (2004). Although it complicates the resource management process, it reflects the real life. The proposed system of managing resources using the CPM may seem to oversimplify the situation but implementing it in a few plants proved more efficient than computational systems. The CPM gives the true picture to the resource managers and leaves the decisions to them. Computational methods make the decisions without human involvements. They are also data hungry.
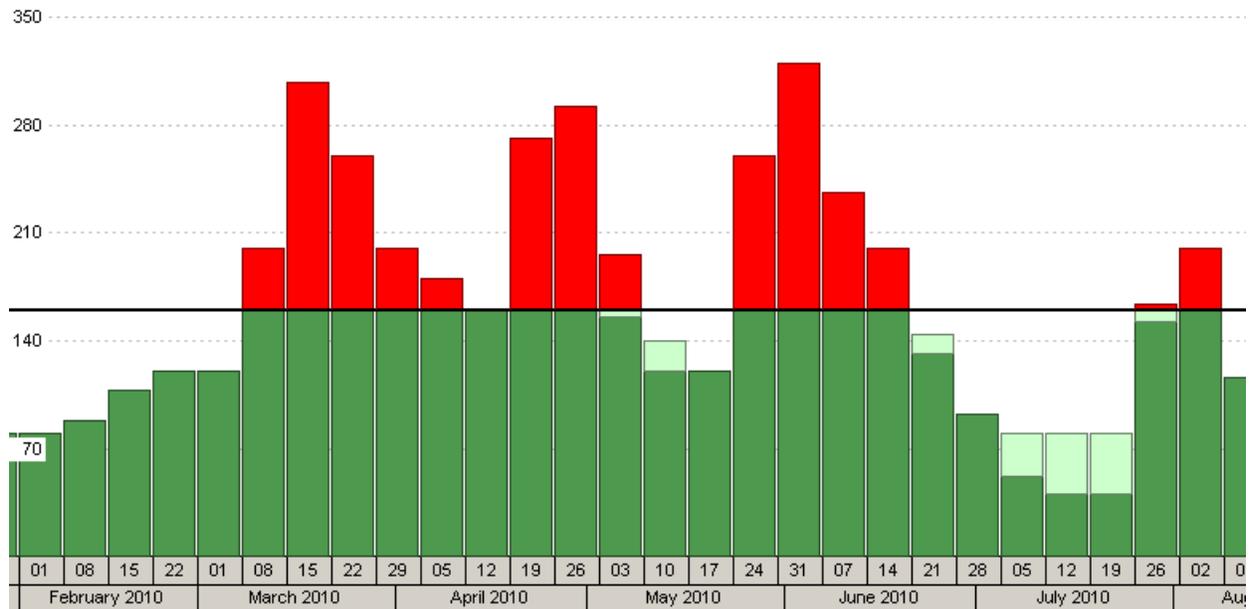
Figure 3: Role-Requirements Histogram

Managing all resources needed for all active projects in the manufacturing plant helps in *identifying bottlenecks*. Manufacturing projects use high value machines like an overhead crane, a mobile 100 ton crane, a large sized milling machine, etc. If such a machine is overloaded, it represents a bottleneck and everything else will be scheduled around it. To upgrade from one unit of that equipment, another unit should be added. Because adding one unit is so expensive and requires a big investment, it is important to make sure that both the added unit and the existing units are almost fully utilized. In a project manufacturing plant, most resources are always under loaded with the exception of one work center, which is always over loaded. A typical project uses only some of the work centers. However, one work center is being used by all projects that come to the plant. This is the over allocated machine. When a new project is assigned to the plant, it is scheduled based on the availability of the over allocated work center.

The author was helping the plant by implementing the concepts and tools of enterprise project manufacturing systems. The project/production controls team was used to allocating only human resources, but was advised to allocate all resources needed for all activities. They did so for a few months until they found that the over allocated work center was the bottleneck driving the schedule of everything else. Actually, this bottleneck causes more problems to the plant than the scheduling problems do. In a follow up visit to the plant, it was found that they only allocated and planned for the bottleneck work center, while not paying any attention to the rest of the resources. Although it sounds reasonable, it is not recommended to forget about the wasted hours of the under allocated resources.

To maximize the utilization of the under allocated resources, the plant is advised to acquire a second unit of work center similar to the one that is over allocated. However, with that investment, will the second machine be reasonably utilized? There is a need to optimize between the two factors to make the decision that is best for the organization. If there are many projects assigned to the plant, in order for the two units to be reasonably loaded, then the plant would go with the option of acquiring another unit. If this assumption is not true, they may study another solution to minimize the waste in the under allocated areas.

The proposed system provides a methodology to answering all of these questions and to generating different what-if scenarios. It provides a the big picture of the resource loading for the plant in a dynamic environment that can be apply the optimization methods to level resources or leave the task to the resource managers as described above. It also provides a tool to respond to customers about estimates and quotes for new projects. Knowing the current and

projected resource load, plant management can determine when a new job will fit in the plant schedule. Although the estimate is not a clear answer as noted by Wullink et al (2004), every customer requires a time and cost quotation for their project.

Conclusions

The technique described in this paper is the automatic generation of the initial schedule and the automatic update and progress recording. To generate a detailed schedule for a large project, it takes at least two weeks from the scheduler to build it manually without loading resources. If resources are to be loaded into the schedule, it will consume another two weeks and will not be accurate due to usual human errors. The new system generates the initial schedule loaded with resources in less than five minutes and gets the progress information in no more than two minutes per project. Further modification may enhance the system to reduce the processing time and allow a group of projects to run by batches. The proposed system makes use of the enterprise project scheduling systems to manage the resource loading of the whole plant.

The proposed system facilitates integrating the manufacturing schedule with the rest of the project schedule while enabling the resource management in the manufacturing plant. The system was implemented in two project manufacturing plants and proved effective in spite of its simplicity. The system does not use sophisticated computational methods but relies heavily on the use of CPM and the common sense. The simplicity of the system makes the manufacturing managers comfortable in using it which adds to its success in the implementations.

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