

VALUE OF VISIBILITY AND PLANNING IN AN ENGINEER-TO-ORDER ENVIRONMENT

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ABSTRACT

Engineer-to-order industries are a special kind of a manufacturing industry wherein every order is custom and is managed as a project. Planning in these industries is typically done using traditional CPM techniques and likely in silos across various departments. Hence these industries are plagued with poor due-date performance problems and resource overload problems. Effective tools will help better manage these issues and improve operational performance. The paper below discusses these issues through the case of one such company that specializes in making equipment for the beverage industry and their attempt to address the problem.

The solution involves better management of the entire lifecycle of the orders. Due-date quoting is improved by taking resource capacity into consideration. Better project planning tools are provided that provide resource and material constrained project plans. The planning scenario involves a multi-project planning with shared resources and the objective is to maximize the enterprise throughput. Emphasis is placed not only on enterprise wide project planning, but also on problem visibility that empower planners to better collaborate and resolve problems (project delays and resource capacity variations) as they come up. The problem visibility and advanced optimization technology provided enable the company to realize valuable savings and improve customer satisfaction.

In its nature of being project based, the engineer-to-order industry is similar to construction industry. Analogies and extensions to the construction project management industry are discussed along with the potential value to be realized. But the supply chain differences between the two industries lead to problems and limit immediate adoption. Issues on how to rethink the construction supply chain to realize some of the hidden value is also discussed.

KEY WORDS

Engineer-to-order, Multi-project planning, Construction supply chain, Visibility

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INTRODUCTION

Engineer-to-order companies are a distinct category within manufacturing industries whose production planning needs are different from other manufacturing industries that traditionally make-to-stock. In make-to-stock industries, a company makes inventory based on historic sales forecasts, stores them in inventory, distributes them to distribution centers, and sells them to customers. Herein, the company has a standard set of finished goods (SKUs) that they manufacture. The same finished goods for different customers are manufactured exactly the same. The manufacturing steps are identical or the bill-of-materials (BOM) is static. But engineer-to-order companies typically build-to-order. Each order is manufactured only after a customer order is received. Finished goods are directly transported to the relevant customer after manufacturing. Each order is independently configured for the customer and a lot of the details on what is needed for the order is clarified as part of the design process that precedes the manufacturing process. In other words, the BOM is dynamic.

In simple build-to-order companies like Dell computers, the variation of the BOM is relatively minimal. For instance, Dell procures standard components and assembles the computer after the customer order is received. But in more complex build-to-order systems, there is a design and engineering phase prior to manufacturing. In such environments, production orders are handled as projects and production planning is done using traditional project management theories rather than traditional production planning theories.

Traditional project management is fraught with problems that make management of the business difficult. Popular tools for project management still support CPM based planning and scheduling (Kelley1961) that create project plans without resource capacity considerations. Business practices are such that planning is done in functional silos with no visibility of schedule interactions from one department to another. All of this leads to poor due date performance and overworked resources. One engineer-to-order company is looking to take control of the situation and address the problem. The company is in the business of manufacturing machines for the beverage industry. The company has been in business for over 50 years. They specialize in making machines needed in the beverage industry. Having started with labeling machines, they have over the years grown organically and expanded their expertise into inspection, rinsing, filling, packing, and conveyor machines. Their latest area of growth is in plastics molding and pasteurization. They have a worldwide client base and have shown a steady growth in revenue. In fact, a local business magazine called them a “shining star” that showed strong revenue and profit in today’s bleak economic conditions.

They are looking to implement a supply chain management solution that will help them better manage their process. Their objectives for putting in a new solution is:

- Improve due date performance
- Forecast resource demand, reduce resource overload, and increase resource usage efficiency

THE COMPANY

The company typically performs two categories of projects – *new facility* and *upgrade facility*. As the names imply, a new facility project involves the complete design and layout

of machines for a new factory. The scope of the project can vary by customer. For instance, if Coke wants to put a bottling facility in Brazil, for 40,000 bottles/hour they might require one or more lines for inspection, rinsing, filling, labeling, and finally packaging machines, all interlinked with conveyor system. The complexity of the new facility is a function of the customer requirements. Currently, the new facility project takes anywhere from 9 to 12 months, from design to order delivery and facility inauguration.

The upgrade facility projects are relatively smaller in scope. It ranges from the upgrade of one single machine to upgrade and/or addition of one or more machines. Upgrade projects last anywhere from 4 to 6 weeks.

The company performs an average of about 1,500 new projects and about 6,000 upgrade projects in one year. All projects have a project structure that is similar as shown in figure 1 below. Each project has three distinct stages – Clarification phase, Production phase, and Installation phase. The details of the jobs in the project structure below is not important for the discussion in this paper, but the structure itself is useful for discussion. In the figure below, the first few jobs right up until the first vertical line is the design and engineering phase. In this phase, the company works closely with the client to precisely understand the requirements of the client. The jobs between the two vertical lines represent the parallel procurement and manufacturing of the various sub-components and machines for the current customer order. For instance, the first horizontal layer might represent procurement and manufacturing of labeling machine and the second horizontal layer that of rinsing machine. The jobs beyond the second vertical line represent the assembly of the machines at the customer site. Herein, all the machines are transported to customer site, assembled as per the design layout, and tested.

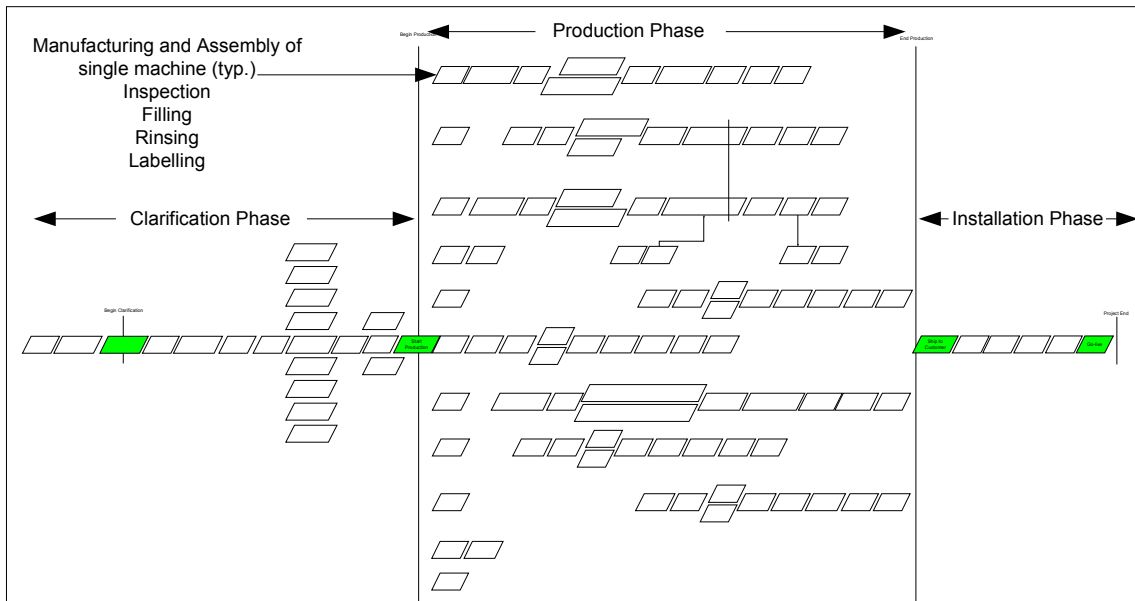


Figure 1: ETO Project Structure

Organizationally, the company is divided into functional units representative of the work structure above. At a very high level, they are split into three divisions – *R&D*, *Manufacturing*, and *Services*.

- The R&D group consists of designers and engineers. Designers perform all the design and layout for the project. Engineers work with the customer after the contract is signed to get clarifications regarding the requirements of the project. They produce final engineering drawings and specifications that then drive procurement and manufacturing. During the sales phase, sales folks work with designers and engineers to come up with cost estimates and due dates for the projects that are used to quote to the customer.
- In manufacturing, the company has workers that are split both along trade lines and along skill lines. Along trade lines, there are two kinds of workers in manufacturing (and final assembly) – mechanical labor and electrical labor. As the name implies they are responsible for the mechanical and electrical assembly of the various machines. Along skill lines, these workers specialize in certain machine types. Most workers are cross-trained in related machine types as well. For instance, people specializing in inspection machines learn about filling and labeling machines, but not about packaging or plastics molding machines. The cross training helps the company move workers around to level out peak work load in certain machines.
- The service group consists of workers who transfer the pre-built machines or sub-components via cargo freight on-site (about 80% of the company's orders are shipped abroad), assemble the machine per the design layout, test run the setup and hand over the production line to the customer. The project is considered completed when the customer signs off saying his/her order meets the desired specifications.

CURRENT BUSINESS PROCESS

The typical business process or life cycle of an order is as follows:

- Quote management: Sales requests a quote for a prospect based on high level requirements. Designers work with sales to come up with cost estimates and initial due date. The project duration for the due date calculation is computed based on average time to manufacture a machine and standard lead times to procure parts. All average times are computed based on prior experience. Due dates are calculated using CPM techniques. In other words, they are based on duration alone assuming infinite capacity resources.
- Clarification phase: Once the quote to a prospect is tentatively accepted, sales and engineering work with the customer to get more information on the customer requirements. They clarify the requirements of the order, develop preliminary specifications, and review the original quote in detail. Order scope is modified to reflect the new added information, job durations are modified, jobs are added or

deleted and the due date is modified. The due date is still calculated using CPM techniques.

- Production phase: Once a quote becomes a confirmed order, the order is entered into a legacy ERP system and the life cycle of the order begins. Based on the configuration requirements from the customer, detailed specifications are developed and a project is created. The ERP system creates another CPM based infinite capacity schedule for the project while trying to respect the due date of the order. Various divisions then get their workload on the project and begin processing the order, namely
 - ◆ Engineering develops detailed BOMs for various machines and machine components
 - ◆ Procurement starts procuring parts
 - ◆ And as parts arrive, workers start assembling components and machines

Further changes to the project during production (due to change in scope or rework) are manually entered into the system. Since there is a lack of integration between the production planning, human resources, and material management modules of the legacy system, all interactions are manually coordinated. People working on downstream jobs typically talk to upstream people to see if the job is ready for them to work on. Over time, using prior experience, the process management group of the company has developed job durations and labor efforts for the various jobs in the production of a machine to help muffle the impact of shared resources between orders, delays in projects, and poor schedule creation. Essentially, the durations for jobs are longer than they need to be. For instance, they might have a job that will need about 5 hours of work. The system would set the duration of the job to be five days and the work content to be five hours. Hence, the CPM schedule will assume that the job takes five days to complete, whereas the person assigned to the job knows that he/she has five hours of work to be done over the course of five days so as to not impact the due date on this project. This “padding” also ensures that the worker who is working on the job is not unduly overloaded.

In spite of their best efforts, all delays in the project tend to lead to overtime, or workers scramble to work extra shifts to make project due dates. Eventually, all machine sub-components are assembled in the final assembly stations, tested, and shipped to the customer site.

- Installation phase: Once the machines are assembled at the factory, they are shipped from the factory to the customer site. Since a lot of the customers are overseas, shipping is done via cargo ships. Service workers then do final assembly of the machines on-site to complete the project.

As of today, the only department wherein there are planners who try to manage the plan and ensure that it is capacity constrained is the final assembly department since it is here that there is the biggest need for coordination. It is here that machine components from various

units arrive, including components that are procured from third party vendors. All these sub-components are tested and pre-assembled into the final machines. Each machine is then independently tested at the factory for quality control purposes. The planners maintain excel based spreadsheet programs that give them information on average workload demand and approximate resource capacity. The planners meet frequently to ensure coordination amongst them. Table 1 shows a snapshot of the resource load in the final assembly department project out for eight months for the various machines. The colors indicate the amount of utilization as explained in the legend. For instance, the filling machines are overloaded in the months of December, January, February, and April but have normal utilization in the months of March and May. The later months have a lot of capacity available since no orders have been booked that far into the future yet. The planners discuss the “red” zones and ensure that projects that are high priority and/or late get preference vs. projects that have slack built into the CPM schedule. The whole process is manual as well as communication intensive. The existing legacy system provides little help for decision support for the planners.

Table 1: Current Resource Utilization at Company

	Dec	JAN	Feb	Mar	Apr	May	Jun	Jul	Aug
Labeling	95%	102%	92%	90%	76%	30%	13%	1%	0%
Inspection	74%	97%	82%	53%	23%	27%	46%	0%	0%
Conveyors	144%	120%	144%	92%	82%	54%	20%	0%	0%
Filling	117%	156%	132%	100%	147%	99%	42%	8%	0%
Blow molding	107%	176%	155%	162%	130%	82%	25%	22%	0%
Rinsing	150%	138%	117%	105%	65%	32%	12%	16%	0%
Packing	114%	125%	100%	90%	70%	23%	8%	5%	0%

Legend:

Capacity unused	< 60%
Under utilized	60 - 90%
Normal utilized	90 - 110%
Over utilized	> 100%

CURRENT PROBLEMS

The above business process has led to several problems discussed briefly below as highlighted in figure 2:

- Due date performance: Since due dates are computed using CPM techniques without regard to current work load and/or resource capacity and availability as well as material availability, due dates computed are largely infeasible. While the padding of durations (see discussion in Current Business Process section above) helps some, that in turn makes the project turnaround time longer than required. The poor due date performance has also led to lower customer satisfaction levels and some lost business opportunities.

- Resource utilization: Since due dates are created without regard to resource capacity, during peak loads, the company resorts to bringing in temporary labor or has employees work extra shifts during the weekends to “catch up”. Both of these has led to higher costs which in turn has lowered the margins in their business. The overwork of the workers has also led to some burn out that in turn has lowered the productivity.
- Lack of visibility: Since there is no integration between project load, resource capacity, and material availability, there is no visibility into delays in one system on the other system or on the enterprise throughput. Coordination between systems is manual that is error prone and sometimes difficult to keep track of. Especially since resources are shared across projects in the same functional department, it amplifies the need for an enterprise wide visibility.
- Material Procurement: Material needed for the various jobs are procured based on the original CPM project schedule created. Delays (or advances) in schedule are not reflected in procurement plans unless somebody bothers with keeping the material management system upto date. Early procurement creates a situation of WIP and locked in capital. Delayed procurement leads to delay in schedule, disruption in the resource utilization, and workload etc.

SOLUTION

The solution to the above problems is being addressed with an implementation of an SCM planning solution combined with a small change in business process. The solution involves designing an integrated system that combines the project, resource, and material data. In terms of data management and process change, all the employees of the company from sales to project managers, from resource managers to workers, and procurement, will view and manipulate data within the new unified system.

The system not only models the interrelationships within jobs in projects and its needed resources and materials, but also has a new project planning solution that is being implemented at the company. The planning solution is capable of creating constrained project plans that respects precedence, resource capacity, and material availability constraints. The planning engine uses a genetic algorithm based optimization solution to create a project plan for all the projects in the enterprise. The constraints are modeled as soft constraints with penalty for violation. For instance, each project has a soft due date and a penalty for violating the due date. Each resource has a normal capacity and a penalty for overtime capacity. Similarly, using temporary labor incurs a penalty. The optimization algorithm generates a schedule trying to minimize due date violation and resource overtime usage while maximizing overall enterprise throughput.

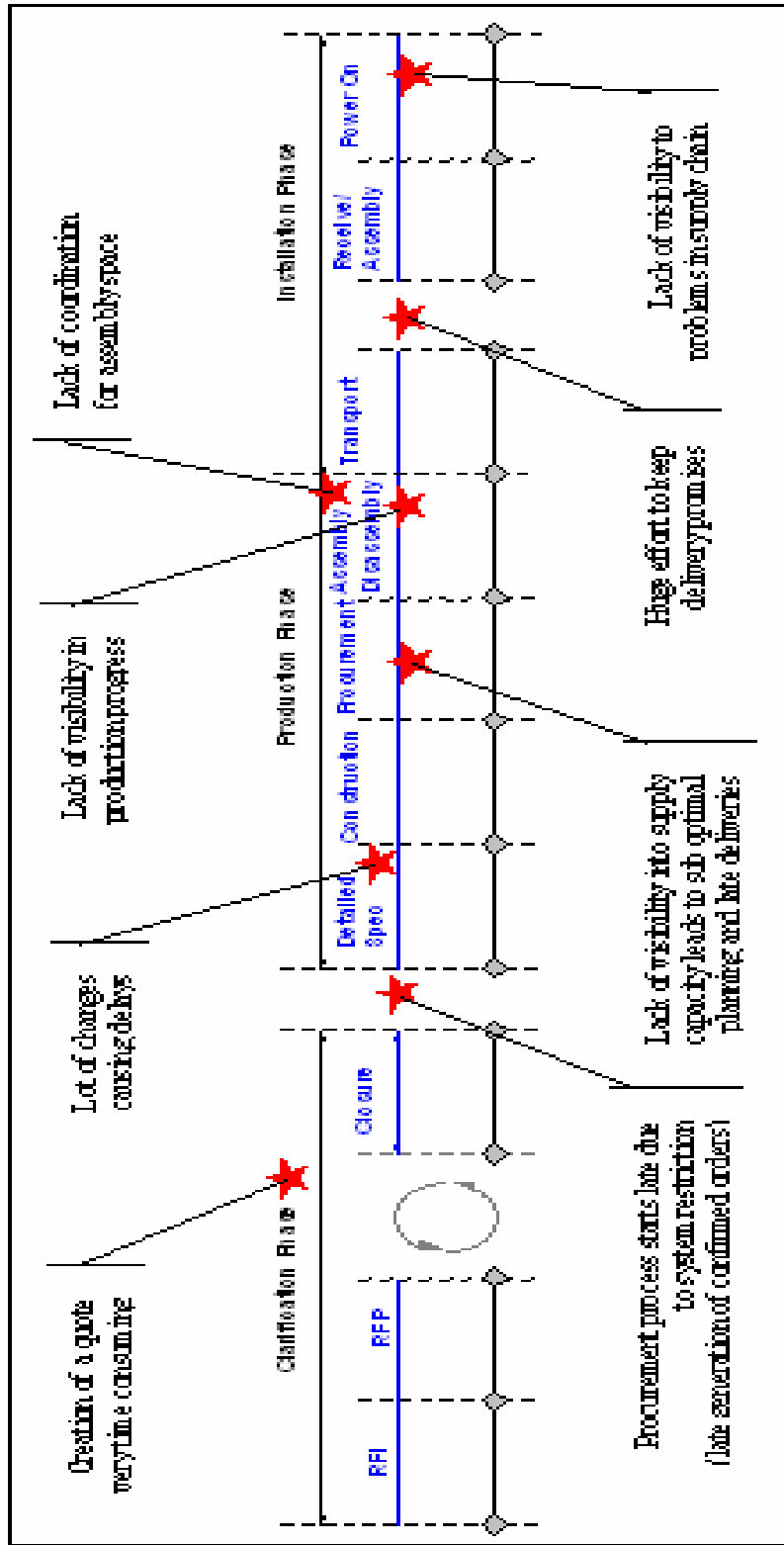


Figure 2: Current Business Problem

The planning solution will be effective only if the lifecycle of the order is entered into the legacy system right from the original due date quote phase. In other words, the process change needed is a more comprehensive order lifecycle management. With the system, the orders will be managed from quote to delivery rather than from confirmed order to delivery. Hence, in future, sales will create quotes in the new planning system. Due date computation will be done by creating a project plan while respecting existing workload and hence is feasible. Unsuccessful quotes are immediately removed from the system to ensure that capacity is not being overbooked and under utilized. Frequent re-planning is done to take into account delays, change in scope, material lateness, capacity changes etc. The solution provides system wide visibility and calculates and propagates the impact of changes in a project on other projects in the enterprise. Studies by Elfving et al (2002) in the switchgear industry has shown that early and more comprehensive lifecycle management in the ETO industry lead to better order fulfillment process and reduced overall lead time.

Master planners will be introduced at the company for each functional department in R&D, manufacturing, and service to keep track of resource utilization. The planners will ensure that the system generated plan is feasible and manually only solve any problems associated with their department that cannot be solved automatically. Resource managers for each department will ensure that resource capacity data is accurate and reflects current changes. Project managers get updated information on their projects from the system as well. And finally, workers will get their assignments from the system. Workers will feed their actuals back into the system that in turn will trigger any re-planning, as needed.

DISCUSSION

The solution, once in production, will provide several important values to the company. Managing the entire lifecycle of the project, in one centralized integrated system provides all the stakeholders with the needed visibility into resource workload and project status. Due dates calculated for quotes from the system will be capacity constrained and hence assured to be realistic and achievable. In future, confirmed orders will hence have a capacity constrained plan that has a lower likelihood of due date slippage.

The expected value of the solution comes from the following:

- Value and ROI
 - ◆ Enterprise wide visibility between projects, resources, and materials
 - ◆ Proactive planning to account for project delays and scope change
 - ◆ Reduced resource overload, overtime, and weekend shifts
 - ◆ Improved due date performance
 - ◆ Planned procurement that leads to reduced inventory from sub-contractors and WIP in manufacturing
- Business value (intangibles)
 - ◆ Increased customer satisfaction, referencability, and repeat business

- ◆ More satisfied workforce, not burnt out and overloaded
- ◆ Forecasted demand for contract labor
- ◆ Increased throughput

In addition to improving due date performance by over 95%, the table 2 summarizes the quantifiable benefits expected from the solution. In addition, it is expected that the company will realize an increase in revenue of over 10%.

Table 2: Expected Value from SCM Planning Solution

Item	Realistic % improved
Reduction of expedited freight (inbound & outbound)	30%
Reduction of labor inefficiencies	6%
Reduction of outside contracting	7%
Reduction in service cost	12%
Reduction of inventory including obsolescence	8%
Reduction of non value-added planning labor	40%
Improvement in customer service	1%
Ability to better fulfill and capture "Garniture" orders	5%
One time reduction of inventory obsolescence	8%

But the implementation is not without risk. As with every enterprise system, the success of the implementation at the company is a function of adoption. The system only works if the data needed is fed and the system is kept up to date. Change in business process calls for company wide adoption and the importance of that cannot be undermined. Without successful adoption, the expected savings and value cannot be realized.

ANALOGY TO THE CONSTRUCTION INDUSTRY

The construction industry, similar to the engineer-to-order industry is project based. CPM based project plans are created in the beginning of a project. These project plans have the same problems in that they are resource unconstrained and hence the due dates are near infeasible. Hence, the industry is plagued with poor due date performance. Resource overload, additional shifts, and expedited shipping are common make up strategies to avoid due date delays. In short, the problems are similar to that of the ETO company. Hence, it is conceivable that the construction industry can also realize value from an SCM solution like the ETO company. Constrained project planning, system-wide visibility between project demands, resource capacity, and material availability, and complete life cycle management should help alleviate problems in the construction industry as well (Vaidyanathan 2001). But just as in the ETO company, there needs to be a process change before such effective SCM solutions can be deployed. I concede that the business processes in the two industries are different, but I believe that with adequate structural process change, the construction industry can realize the same value that the ETO company has derived. The rest of the section will discuss the supply chain differences and process changes needed.

The supply chain of the ETO company is simple (Figure 3). It has one single enterprise that delivers goods to the end user and procures parts from suppliers. All decisions are made in the context of a single enterprise. Even when contract labor is procured it is procured for

known period in known capacity. Hence, all information needed for constrained project planning is available. This makes it feasible to design a better planning solution and a modified business process. Adoption is within the company with minimal unknown/unmanageable outside interaction. And finally, any savings realized as a result of better planning will go to increase the bottomline of the company. This provides adequate ROI to justify the SCM solution.

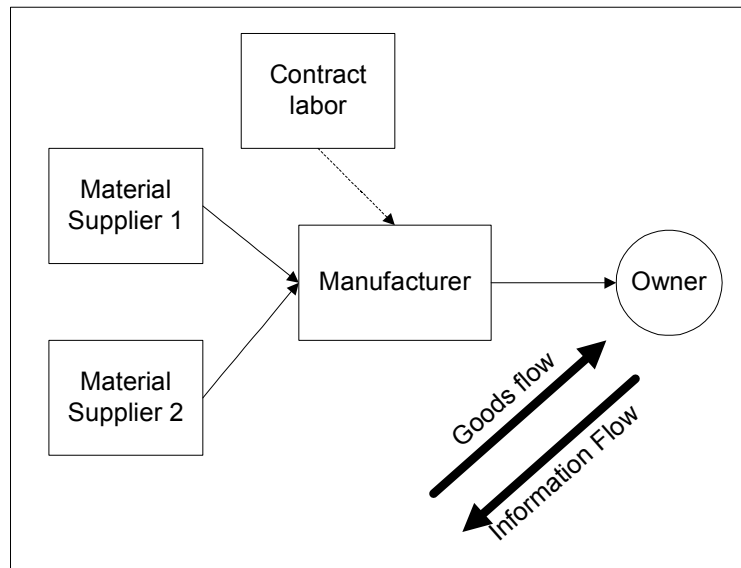


Figure 3: ETO supply chain

On the other hand, the construction supply chain (Figure 4) is complex and multi-tiered. It is also multi-enterprise oriented. From a project (owner's) perspective many companies interact with many others, both for labor and service, to get a project completed. Each of the companies involved, in turn, are concurrently dealing with several customers (or in effect are part of several project supply chains) not all of them being the same. The relationships between the various players are short-term (project by project basis) and not long term. And finally, contractual detailed provide little to no value to early information sharing.

To address each of these issues, process changes are needed. According to Macomber (2002), there can be system wide financial incentives that can justify information sharing across organizational boundaries. If contracts can be rewritten to permit such cross-organizational boundary incentives, then players in the project supply chain will share information to better manage the information flow in the project supply chain.

CPM based scheduling inherently creates delivery problems. The basic assumption of unconstrained capacity plans paves the way to infeasible due dates. Additionally, the fact that resource interaction between projects are ignored is another factor that contributes to project due dates being promised that cannot be met. And to keep such a due date, contractors use overtime, additional shifts, temporary labor, and expedited shipping; all of which leads to cost overruns and smaller (if any) margins. A better solution is to use a constrained project-planning tool that atleast gives feasible plan. Optimization may not be of great need in the construction supply chain since the volume of projects being done in

construction is not the same as the ETO company, but feasible constrained planning is still essential to create feasible due dates. Also, it is crucial to keep track of project progress and proactively communicate delays to avoid cascading downstream implications. The above contractual changes with such a project planning and visibility tool will go a long way in improving due date performance and containing costs in construction projects.

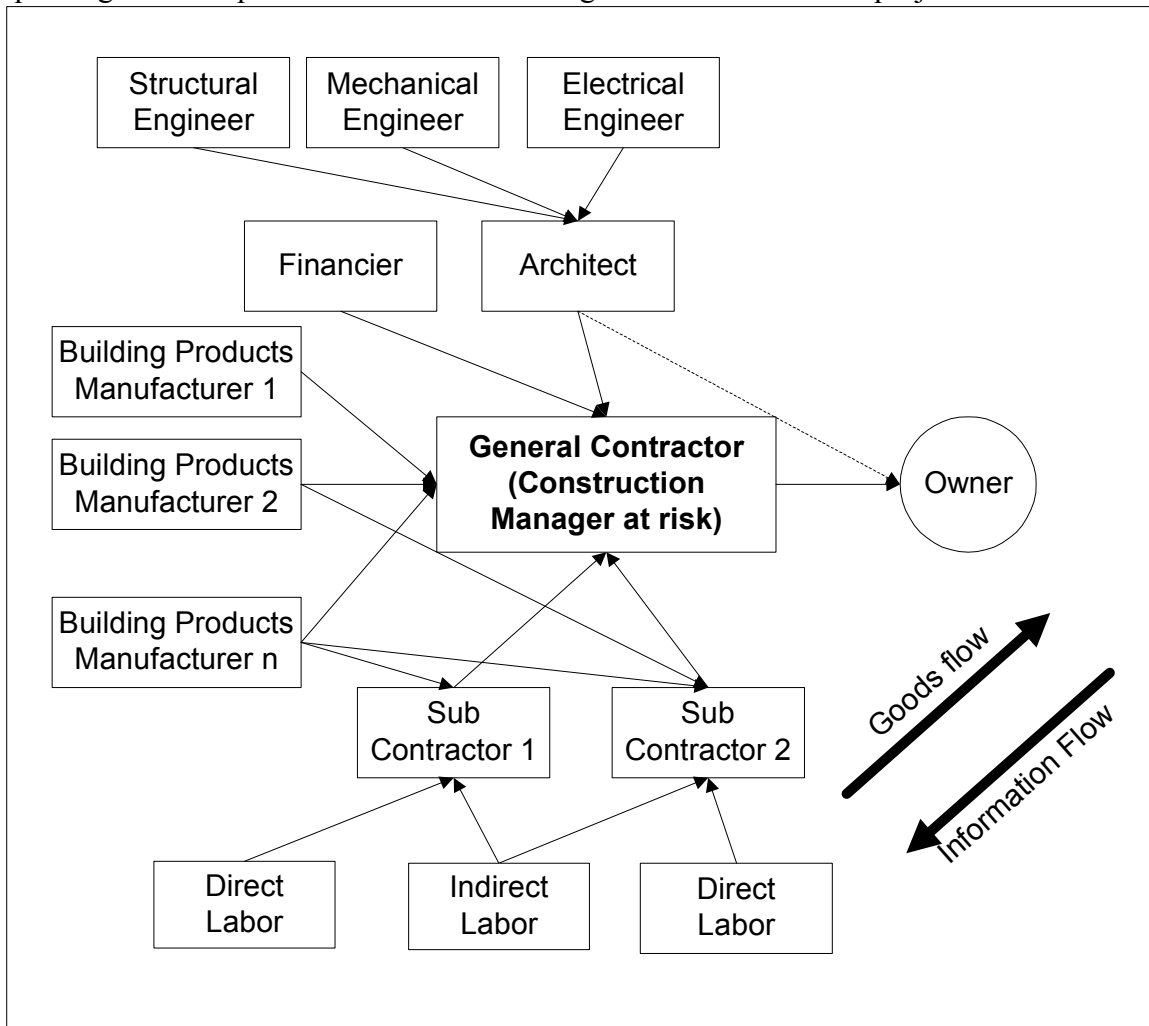


Figure 4: Construction supply chain

Finally, to provide data for planning, there is a need to openly share information that is proprietary including resource capacity and material availability. Several researchers and industry players are working on various initiatives to achieve this. A retailer in the home reconstruction business is attempting to get sub-contractor capacity information as part of the contractual agreement to do business with them (Vaidyanathan 2002). The retailer's objective is to create feasible constrained project plans and manage the home reconstruction projects better. O'Brien et al (2002) are developing techniques and technology to enable firms to share minimal information to enable constrained capacity planning. Lean

construction techniques are gaining popularity and they also attempt to address the inter-firm interaction to create feasible project plans (Ballard 1994).

Once the industry experiments and more successful case studies evolve of the value derived from such SCM solutions, I believe that adoption of SCM practices will happen in the construction industry. And the industry will see the value and ROI of efficient SCM solutions.

CONCLUSIONS

Design and implementation of an SCM solution has helped the engineer-to-order company improve due date performance and resource usage efficiency. Key aspects of the solution include constrained project planning, proactive system wide visibility between project demand, resource capacity, and material availability. Business process has been modified to enable an early and more comprehensive lifecycle management of the order fulfillment process from quote-to-delivery. The system and the process have the potential to significantly bring in cost savings and increase in the bottom line, apart from increasing customer satisfaction.

Construction industry has the same kind of inefficiencies and hence can derive the same kind of value from constrained project planning and system wide visibility. The problems of delivery are inherent in the process itself. CPM based schedules do not account for resource capacity, material availability, and interaction of shared resources of other projects. Cost overruns, resource overload, and delays can be greatly reduced with efficient planning solutions. Process change to enable information sharing across the various players in the construction supply chain is needed to realize the value from better supply chain management.

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REFERENCES

Ballard, Glenn and Howell, Gregory. (1994). "Implementing Lean Construction: Reducing Inflow Variation," presented at the second annual conference on lean construction at Catolica Universidad de Chile, Santiago.

- Elfving, J., Tommelein, I.D., and Ballard, G. (2002). "Reducing Lead Time For Electrical Switchgear," *Tenth Annual Conference of the International Group for Lean Construction (IGLC-10)*, Gramado, Brazil, August 6-8, 2002.
- Kelley, J. (1961) "Critical Path Planning and Scheduling: Mathematical Basis," *Operations Research*, Vol. 9, No. 3, May-June 1961, pp. 296-321.
- O'Brien, W., R. Issa, J. Hammer, M. Schmalz, J. Geunes, and S. Bai. (2002). "SEEK: Accomplishing Enterprise Information Integration Across Heterogeneous Sources," *ITCON-Electronic Journal of Information Technology in Construction, Special Edition on Knowledge Management*, 7, 101-124.
- Vaidyanathan K. (2002). "Case study in application of project scheduling system for construction supply chain management," *Tenth Annual Conference of the International Group for Lean Construction (IGLC-10)*, Gramado, Brazil, August 6-8, 2002, pp 161-169.
- Vaidyanathan K., and Zachary Michael J. (2001). "Schedule Based Procurement with Fulfillment – A Vision for the A/E/C Industry," interview and article with the AECVision magazine.