The Differences Between CPM and Resource-Loaded Scheduling and How They Applied to The Martinez Tesoro Refinery Flare Header Replacement Project

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A case study was conducted to analyze the scheduling challenges faced on a refinery construction project in Martinez, California. The main issues on the project were complications experienced by the general contractor in fulfilling a requirement to produce a resource-loaded schedule. Unable to create one, a CPM schedule was produced instead. Research on the differences between a CPM and resource-loaded schedule was conducted in order to uncover how they applied to the refinery project. The most significant differences between the two scheduling methodologies is that a CPM assumes infinite capacity, while resource loading recognizes that resources have finite limits in terms of availability, capability, and proficiency. Consequently, resource-loaded schedules are substantially more advantageous to projects in terms of feasibility, tracking productivity, controlling cost overruns, and eliminating schedule impacts. Three separate interviews were conducted with the GC, CM, and a scheduling expert to gain further insight on the matter. Information from the interviews led to the discovery of the main scheduling differences between MS Project and Oracle P6, the disadvantages of resource-loading, and where the future of the construction industry is going in terms of efficient scheduling methodology.

Key Words: CPM, Resource-Loaded Scheduling, Microsoft Project, Oracle P6, Productivity

Introduction & Background

The general contractor on The Martinez Tesoro Refinery Flare Header Replacement project faced tough scheduling challenges due to complications with resource-loaded scheduling. This was a complex project to install a new flare stack in the Tesoro Refinery located in Martinez, California. A portion of the job was awarded to Carone & Company Inc. (the general contractor), who is an experienced civil engineering firm that specializes in paving, grading, excavation, underground utilities, and shoring. Carone's scope of work entailed providing the labor and materials necessary to install fifty-eight piles to a depth of sixty feet, and eleven pile caps that vary in size over the course of a 14-week duration. Overseeing the project and representing the Tesoro Refinery as the construction manager agency was Eichleay Engineering. Eichleay is a midsized multidisciplinary firm that provides integrated engineering, architectural, and construction management services.

Submitted within the bid documents to Eichleay, Carone used Microsoft Project to create a critical path methodology schedule (CPM). The schedule reflected a break down of the construction activities it would take to complete the job and also included percent complete for each activity, milestones, duration, early start, early finish and the baseline cost for each activity. Eichleay accepted the schedule but wanted to take things a step further, which is where things began to get challenging for Carone & Company. Eichleay then required that the schedule must be resource-loaded in order to easier track productivity. Resource-loaded scheduling was a type of schedule that Carone has never been asked to produce, and had no experience with creating one. Along with a resource-loaded schedule, Eichleay also wanted an S-curve graph that displayed various project data pulled directly from the resource-loaded schedule. Eichleay required that these deliverables were to be presented at weekly construction coordination meetings.

Methodology

This case study will shed light on the differences between CPM and resource-loaded scheduling and how they applied to The Martinez Tesoro Refinery Flare Header Replacement Project. Quantitative data was gathered from multiple interviews with Carone & Company Inc., Eichleay Engineering, and a scheduling and project controls expert with the objective to answer the following questions:

- Why should a PM incorporate a resource-loaded schedule into their project?
- Why should a PM stay away from this method?
- By utilizing this type of schedule, how is it useful to a CM-Agency, or owner?
- Which scheduling software is more efficient for this method, Microsoft Project or P6?
- If a resource-loaded schedule is not required by specification, should a PM choose to make one?

Additionally, the advantages and disadvantages of resource-loaded scheduling methodology will be examined, as well as the different software capabilities between the two most widely used scheduling programs in the industry: Microsoft Project and Oracle P6. As a result of this case study and conducting research, the discovery of efficient scheduling techniques can be determined. Insight will also be discovered on where the industry should be turning to in construction scheduling in terms of tracking productivity, eliminating project delays, and eliminating cost overruns.

Scheduling at a Glance

In the industry today, most construction projects stem from a master construction schedule that includes activity names, durations, milestones, and the projected project completion date. A construction schedule is produced and used as a tool to ultimately control a company's competitive advantage and profitability. Good project scheduling methodology is critical for managing the various processes within a construction project and reaching a final quality product that is on time and under budget. The frustrating issue with scheduling is that sometimes the project doesn't always pan out exactly how it was scheduled to. The reality is that there are always unforeseen factors that will inhibit a project to go as it was scheduled. However, good project scheduling methodology can control these factors and stop them from throwing the project off schedule. CPM and resource-loaded scheduling are two scheduling type methodologies that both have advantageous properties to control unforeseen factors.

Critical Path Method

A CPM schedule is a type of schedule that prioritizes construction activities and their predecessors in the order in which they need to be completed to reach the project's targeted completion date. This type of schedule proves to be beneficial in many ways. If executed properly, the project is broken down into discrete activities with estimated durations, and forces the project team to logically sequence each construction activity. The CPM process then forces the team to address critical questions that might not have otherwise been considered. The final project schedule will show the critical path and float time between each activity, which is an excellent tool for controlling the project during execution (Griffith, 2006). When it comes to CPM, however, there are certain limitations.

CPM Limitations

In a paper by Herbets, J.S., published by the Project Management Institute, the limitations of CPM is explained in a clear model. A basic CPM schedule with activities may be illustrated in the example below.

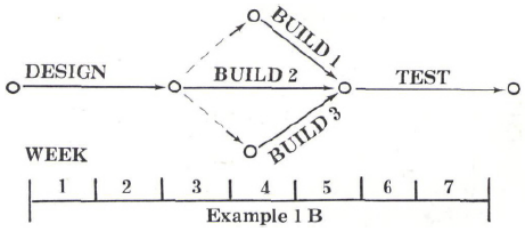

Figure 1: A CPM Model

In this basic schedule, there is a Design activity, three Build activities that are dependent upon the design activities, and a Test activity that is dependent upon the three build activities. It is easy to see that the critical path can be followed to be Design, Build 2, and Test in that order, with float time between the start of Build 2 and the start of activities Build 1 and Build 3.

Herbets uses this example because it is so easy to understand. However, Herbets then asks if it's still easy to understand after he proposes the following questions:

- Who is going to work on these activities?
- Can we assume this project is standing alone, or is it one of twenty, or more projects, of differing priorities?
- Can we assume unlimited resources available for each project and is each resource able to spend full time on all activities assigned?
- Can we assume that Build 1, Build 2 and Build 3 will be assigned different, and available resources?

Does the model still make sense? After observing the CPM and asking the above questions it becomes clear that CPM is limited to only providing activities and the sequence in which they flow in. In order for the job to succeed, the project team should know answers to the points mentioned above as they are important to the planning and control of any project (Herbets, 1976).

The Problem with Infinite Capacity

When a CPM is developed, it is assumed that there is the availability of an unlimited amount of resources. Even though this assumption simplifies the scheduling process, it actually contradicts reality (Matthews, 1994). Imagine that the resources thought to complete the Build activities are not available when they are scheduled to be executed. This would extend the critical path, increase time, and the above model will not look as it does now. This is the primary limitation of CPM, that it assumes that projects have infinite capacity.

A feasible construction schedule should explicitly and systematically incorporate an organization's capacity to complete a project. This can be done by realizing specific resource requirements versus resource availabilities and capabilities for each construction activity on the schedule. CPM by itself does not address capacity and can make it problematic as a scheduling and analytical methodology (Matthews, 1994).

The problems associated with infinite capacity is that nearly all projects have defined limits on the pool of resources available for utilization due to costs, disciplines and skills required, demographics, and other factors. Additionally, the capabilities required for various construction activities are often not transferable between resources (Matthews, 1994). This problem can be fixed by loading each construction activity with available resources, which ultimately adds another dimension of information to the schedule.

Resource-loaded Scheduling

Resource-loaded scheduling is substantially different from CPM because it loads physical resources into the project schedule such as labor, capital equipment, facilities, and materials. By doing so, making decisions about capacity is then incorporated into the scheduling process. It is a methodology that encompasses resource loading, resource leveling, and time analysis (critical path) all in one dynamic schedule. Moreover, it involves the prioritization of task activities based on resource utilization strategies, determination of resource availabilities, and the utilization of alternate resources (Matthews, 1994). After evaluating a resource-loaded schedule, it will help determine if the planned approach, schedule, and project cost are all feasible (Griffith, 2006).

Types of Resource-loaded Schedules

Resource-loaded scheduling methods typically begin by establishing an initial set of dates based on time analysis, or critical path analysis. The activities and dates that are created are then used as inputs for the resource scheduling process. Next, resource requirements and/or targets for each activity are loaded. Lastly, dates and quantities

available are established for each resource (Matthews, 1994).

There are two types of resource scheduling: time-constrained scheduling, and resource-constrained scheduling (Matthews,1994).

The type of schedule to be used for a project is dependent on whether the project emphasis is placed on the variables "time" and "resource." Time-constrained scheduling assumes that time constraints are fixed, so activities must be undertaken within time constraints. Resource-constrained scheduling assumes that the resources and resource quantities are finite, making it so that activities must be conducted within the resource constraints (Matthews, 1994).

Both scheduling methods try to resolve resource overloads by delaying construction activities to future start dates when the capacity to undertake that activity exists. In time-constrained resource scheduling, the projected completion date is accepted as fixed after the time analysis, or critical path has been determined. If an activity cannot be delayed without affecting the generated project completion date, then the schedule will flag those time periods when the project is faced with potential capacity overloads (Matthews, 1994).

A Resource-loaded Schedule Example

If we Take Herbets' simple model mentioned above, and load labor resources to it, we can see how the critical path and time analysis change. Let's assign Designer #1 to design the project, Engineer #1 to Build 1 and Build 3, Engineer #2 to Build 2, and Tester #1 to test the project. The results are illustrated in a new model below.

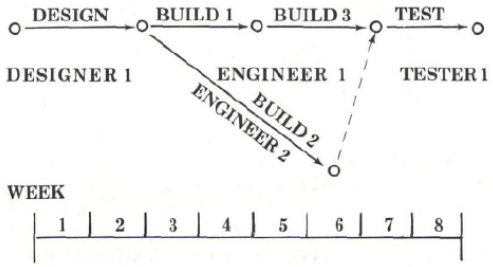

Figure 2: A Resource-Loaded Model

Can you see how the schedule has changed? Resource availability has been added to the model changing the sequence of activities. Before, in the CPM model, Build 3 did not depend on Build 1, but now that Engineer 1 is assigned to those two activities the required resource now becomes critical. When adding the availability of a resource to work on an activity, the activity and subsequent dependent activities may alter the critical path (Herbets, 1976).

The Main Differences

To summarize the above points, the main differences have been collected in the table below.

The Differences Between CPM and Resource-Loaded Scheduling

Attribute	Critical Path Method	Resource-loaded Scheduling
1. Activity/resource relations	Activity relationships are stable	Resource relationships are temporal and dynamic
2. Network Logic	Assumes that all logic is based on actual precedence relationships	Incorporates natural precedence and environmental preferential precedence relationships
3. Critical Variables	Time	Time and or/resources

4. Treatment of resource constraints	Assumes infinite capacity	Recognizes finite capacity (resource constraints)
5. Resource activation and utilization assumptions	Resource activations and utilization times are the same	Resource activation and utilization times can be different
6. Float time and critical paths	Based on duration and logic	Based on duration, logic, resource requirements, resource availabilities, and resource utilization patterns and processes
7. Impact of delaying critical path activities	Will lengthen the total duration of the project	Will vary depending on how resources are allocated and utilized

Source: Matthews, 1994

Challenges Faced On The Martinez Tesoro Refinery Flare Header Replacement Project

Now that light has been shed on what resource-loaded scheduling is and how it differs from CPM, it can be better understood what scheduling challenges were encountered on the Martinez Tesoro Refinery project. The general contractor, Carone, attempted to create a resource-loaded schedule by assigning resources to each activity on the CPM schedule generated on Microsoft Project. Problems were soon encountered when Microsoft Project was flagging activities as over allocated, and the project completion date was continuously being pushed passed the contractual completion date. Having no prior training or experience with producing a resource-loaded schedule, the process of trying to meet Eichleay's scheduling requirements turned into a very frustrating and arduous task for Carone.

One of the main problems was Carone's lack of knowledge on producing resource-loaded schedules. By first establishing a CPM schedule through time analysis and later attempting to load resources to each task, Carone was unknowingly attempting to create a time-constrained type resource-loaded schedule. Microsoft Project was not accepting the resources assigned to each activity in conjunction with the predetermined completion date, therefore activities were being flagged with capacity overloads. Since this was a schedule-driven project, this new schedule was not appropriate to present to Eichleay, and Carone was unable to produce an accurate resource-loaded schedule within Microsoft Project.

The Interviews

To determine the purpose of why a resource-loaded schedule was applicable to this project, three interviews were conducted. The first was with, Grant Carone, the project manager on the project representing Carone & Company Inc. The second interview was with Rob Lozano, the project manager from Eichleay Engineering. Finally, a third interview was conducted with Christi Banks, a project controls and scheduling expert, to gather further insight on the subject and to compare it with the information obtained from the CM and GC.

Eichleay Engineering

Eichleay says that they require a resource-loaded schedule on all of their projects as a way to analyze schedule appropriateness and to track productivity. When asked what advantages a resource-loaded schedule serve to Eichleay, Lozano responded with the following benefits: allows the CM to evaluate options when required to support critical path, gains insight as to how the contractor would support changes in the project that required resources, validates earned versus actual to determine percent complete accuracy, and evaluate slippage and float to determine if the contractor was making the right decisions by moving resources to the right work fronts in order to maintain schedule. Eichleay said that most contractors like to provide a standard schedule illustrating a work

breakdown structure that ignores resources and is updated with the input of a percent complete based off a "gut check," or a personal estimate of percent complete. In this case, this practice is unacceptable to Eichleay and demonstrates poor scheduling methodology, which is exactly why a resource-loaded schedule is preferred by Eichleay on all projects.

The way Eichleay utilizes a resource-loaded schedule to track productivity is by measuring earned versus actual hours. Since Carone was unable to provide a resource-loaded schedule, Eichleay was able to cope with the issue by taking over the schedule and building a new one with the baseline hours Carone budgeted at the time of the RFP. According to Eichleay, Carone's high level estimate was on target, however problems occurred as there was no way for Carone to substantiate their assessment without a resource-loaded schedule, which could have actually worked against Carone and put Eichleay in a bad position with the possibility of having to report schedule delays to the owner.

Carone & Company Inc.

Even with the absence of a resource-loaded schedule, Carone used more traditional means to track productivity through daily reports. Grant claims that his methodology on the project was through wisdom and experience by knowing how much labor is required to complete a task, as well how many hours it takes for each activity. To Grant, a resource-loaded seclude for the project was unnecessary because he found that it was too much of a time consuming process to properly prepare a schedule than it would have been to aid the project efficiently in available labor and project projections. To cope with this problem, Grant's solution was by, "Seeking excellence in the field and by striving my best to ensure all of our work was completed properly and at minimum to code, and more importantly that every inspection agency left the jobsite with acceptance to Carone's work." By achieving such goals, Grant ensured the conflict of not producing a resource-loaded schedule did not affect Carone's overall performance.

Microsoft Project vs. Oracle P6

In this case study, it is crucial to realize that the level of depth of a construction schedule is not only dependent on the capabilities and knowledge of the scheduler, but also the capabilities and functionality of the scheduling software. In each interview, each party was asked which scheduling software they prefer to use between the two most widely used software in the industry (Microsoft Project and Oracle P6), and why. Eichleay prefers to use P6 for the following reasons: it allows for multiple user access, there are unlimited baselines that can be established, a master schedule incorporates multiple schedules from various parts of the world and the program can be maintained, and it is more user friendly. Additionally, according to Eichleay, Microsoft Project can be high maintenance when dealing with multiple schedules. Eichleay agrees that Microsoft Project seems to be easier for contractors to work with, but thinks that contractors should spend more time educating themselves on Microsoft Project.

Carone and Company Inc. prefers to use Microsoft Project because it is more ideal for smaller types of projects. An average project for Carone is in the ballpark of $2-3 million, and Grant believes Microsoft Project is suited well for their types of projects. Grant says that P6 is more for large scale projects and works well when you collaborate several trade tasks and durations into one master schedule.

While the scheduling expert, Christi Banks, finds that she uses a perfect 50/50 split utilizing both programs in her consulting work, she finds that Oracle P6 is by far a superior product and in fact prefers to use it over Microsoft Project. Banks sees the most significant differences between the two software as being the following:

1. Scheduling calculations (forward and backward pass) are not handled correctly in MS Project, whereas P6 gives an accurate critical path as a result of accurately calculating a forward and backward pass.
2. MS Project is a bit easier to utilize when someone new to scheduling is learning as result of it containing "wizards", but for the advanced user, Oracle P6 is by far superior in managing multiple projects simultaneously, setting up coding and filters, as well as cost and resource loading capabilities.
3. Reporting in Oracle P6 is superior to MS Project in terms of schedule report output, because MS Project has significant printing issues, as print drivers have to be updated or there is the issue of "what you see on the computer screen is not what you get."

Additionally, Banks says that for more advanced reporting functions such as creating and producing S-curves, Oracle P6 is a far better tool. According to Banks, since Microsoft Project does not calculate forward and backward pass correctly, it has inherent difficulties with resource-loading, and should be avoided for more advanced reporting functions. This is where Carone was disadvantaged when trying to produce an S-curve deliverable demanded by Eichleay. Eichleay said that they use an S-curve because it provides a high level perspective of how the project is performing by giving data points to asses positive and negative impacts, it is easy for management to read without getting into the weeds, and by measuring the project to its baseline to predict where the project is going (on schedule or late).

The Disadvantages

In the case of Carone & Company Inc., is it quite obvious to see that a major disadvantage to resource loading is that it is an in-depth, time consuming, and convoluted scheduling methodology process. When Eichleay was asked what disadvantages are associated with resource-loaded scheduling, Lozano responded by saying that the only disadvantage is that if the schedule is not carefully monitored, then one may miss over-allocation on tasks that add no value to the overall schedule. Lozano says that this would have a negative impact to the contractor on a lump sum project by showing inefficiencies and cost overruns, or a negative impact to the customer on a time and material project.

When Banks was asked the same question, she provided a response that exemplifies the scheduling challenges faced by Carone. Banks says that a disadvantage is that, “It takes time and a knowledgeable person to implement. As a result of complicated schedules, companies get bogged down in scheduling techniques and end up incurring extra work hours and delays if an experienced scheduler is not on staff.” This can cause a company to hire a project controls consultant, someone such as Banks, to manage a schedule on a monthly basis that was not budgeted in their original work scope.

When asked if Grant would ever implement a resource-loaded schedule into any future projects as a PM even if a client did not require one, a surprising answer was given. Grant concluded that initially a resource-loaded schedules would never benefit Carone on $2-3 million dollar projects, however in the efforts of taking the time in learning how to produce one, he strives to learn and understand the benefits they can provide even on the smaller size scale projects that Carone operates on.

Banks was again asked the same question and as an experienced project controls consultant who works across all construction sectors, she has found that it is not the norm to have a resource-loaded schedule requirement, especially in private work. In this instance, Banks finds that a PM would not voluntarily produce a resource-loaded schedule if an owner or CM doesn’t require it, because of the overhead and/or consulting fees involved in making one. However, Banks had a similar outlook as Grant on the matter. She continued to say that resource loading would be tremendously helpful if a GC decides to produce one regardless of any requirement. Banks says that, “Project controls costs often are more expensive at the front-end of job but overtime a job is run more efficiently, and thus the costs over the life of a project (especially a larger project) are less if done correctly.”

Conclusion

Is it clear that construction schedules have been emphasized as a key tool in project management for various reasons such as time analysis, productivity tracking, resource allocation, etc. After conducting research on the differences between CPM and resource-loaded scheduling and applying it to the challenges faced on the Martinez Tesoro Refinery Flare Header Replacement Project, one factor has become increasingly evident. The vast majority of scheduling methodology has focused on the relationship between the Critical Path Method and schedule development, whereas the connection between resource management and project scheduling has suffered a substantial amount of neglect in the industry.

This neglect stems from a lack of knowledge on resource loading, the amount of front-end planning and costs

associated with producing a resource–loaded schedule, and the differing capabilities between different scheduling software. While it is inherently easy for an owner or CM, such as Eichleay, to require a resource-loaded schedule, it can be increasingly difficult for a contractor, such as Carone, to actually produce and implement an accurate resource-loaded schedule into their project, especially without the help of a scheduling consultant.

Banks emphasized that resource-loaded schedules are mostly utilized on large public projects due to specification requirements, while it is not the norm to require resource loaded-schedules in the private sector. When they are required in private work, it is typically because a company has more advanced project controls skill levels to benefit from the extra cost and expense of resource loading their projects. Even though it may not have been the most efficient procedure to require a resource-loaded schedule on the Martinez Tesoro Refinery project due to a very straightforward scope that was only a couple million dollars in work, how can a competent contractor such as Carone ever benefit from the advantages of resource loading on small projects? The answer lies in the direction the construction industry is heading in terms of scheduling methodologies.

According to Banks, a blend of Lean Scheduling and construction principles with Oracle P6 will be the wave of the future within the industry. In the interview, Banks said that studies have shown that the construction industry has not improved its productivity rates over the past 50 years because there is a lack of focus in doing so. While large projects that require resource-loaded schedules that prove to be successful in terms of tracking productivity, eliminating cost overruns, and eliminating schedule delays continue to persist, more and more construction companies will want to buy into new scheduling techniques that work to their advantage. In fact, Banks says that Oracle P6 has recently come up with a software that applies to managers with both hard skills in utilizing technology, and soft skills that invite teams to work collaboratively together to reach project phasing goals. Hopefully with new innovations in scheduling software and a direct change of focus for efficient scheduling methodologies, more construction projects can easily benefit from the advantages of resource-loading schedules, and use them to increase productivity on the jobsite.

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