Second International Conference on Construction in the 21st Century (CITC-II)
"Sustainability and Innovation in Management and Technology"
10-12December, 2003, Hong Kong

The Role of CPM Scheduling in Project Risk Analysis and Decision Making

Mark W. Cohen
Vice President and Corporate Manager of the Dispute Resolution Division
The Nielsen-Wurster Group, Inc., Princeton, New Jersey, USA

Abstract
As engineered and constructed projects worldwide become more technically and contractually complex, the challenges associated with risk analysis and critical project management decision making are enhanced. These challenges are further exacerbated by the current international trend of streamlined project delivery mechanisms, increased multi-firm project execution, and alternative contracting arrangements. Critical Path Method (CPM) scheduling is one tool that when utilized properly can significantly increase the effectiveness of the project management decision making and risk analysis process. The use of CPM schedules in the construction industry has increased dramatically over the past 20 years. However, while this scheduling tool has become widely utilized as a mechanism for establishing a plan for executing a project, its ability to serve as an effective decision making and risk analysis tool has routinely been ignored by a majority of project managers. This paper offers insight and discussion relative to the potential ways CPM scheduling can be utilized as an effective project management tool throughout the life cycle of a typical engineered and constructed project. Specific examples are detailed to offer insight to contractors, construction managers and owners involved with international engineered and constructed projects in order to allow for an understanding of how CPM scheduling can assist in the project risk analysis and decision making process.

Keywords
Risk, CPM Scheduling, Management, Delay, Planning

1. Introduction

It is universally accepted that the potential for complications exist with respect to the completion of a task and the achievement of a goal. This "Risk" is inherent in all undertakings, maybe nowhere as broadly as prevalent in engineered and constructed projects intended to meet commercial, industrial or public purposes. Despite the great many differences in such projects there does exist certain common characteristics among them all:

- Technology and standard practice are continually evolving and changing.
- Goals are universally defined in terms of time, cost and performance.
- Services are occurring over an extended period of execution, specifically with the increased utilization of design-build or lump-sum turnkey (LSTK) project delivery mechanisms.
- The demarcation of responsibility and interfaces between constituents shift as performance patterns and trends evolve.

Given these historic characteristics, when projects have issues impacting execution the risk associated with cost and schedule is exacerbated. Project risk analysis has developed to address this risk challenge through managed planning. Critical Path Method (CPM) scheduling is one tool that can significantly increase the effectiveness of the project management decision making and risk analysis process.

2. The Benefits of CPM Scheduling

CPM scheduling, developed during the 1950s, did not really become prevalent in the construction industry until the early 1980s with the advent of the personal or "desk-top" computer. Obviously, major construction projects were successfully undertaken prior to that time period without the utilization of a CPM schedule as a management tool. This fact leads to the obvious question – "*Why do you need a CPM Schedule?"* The short answer is as projects have become increasingly larger and more technically and contractually complex, there is just too much at stake (in terms of resources) to undertake a construction project without a well thought-out plan. This is clearly supported by the fact that inadequate and poor scheduling can lead to material, equipment and labor disruption and delay, thus resulting in significant increased costs. CPM scheduling offers the most efficient and effective mechanism for generating and monitoring the planning process throughout the entire life-cycle of a project. As such, it is one of the most useful tools manager's have at their disposal for analyzing and mitigating risk. Below is a discussion of some of the more prevalent benefits of planning and scheduling.

2.1 Demonstrates that there is a Plan and Communicates it to the Project Constituents

The preparation of a CPM schedule is a detailed and complex undertaking. It requires a substantial effort from the management team because of the level of detail necessary (activity durations, logical relationships etc.). Thus, preparing a proper CPM requires that the overall project has been thoroughly analyzed, and defines the goals of the project with respect to time. The provision of the CPM to the various project constituents allows for the assessment of the execution approach, including relationships between work disciplines, flow of work between areas and phases, and the interface between design, procurement and construction.

The generation of the CPM also facilitates communication between the various parties on a project. Communication between the constituents in all phases of projects is important as it is a vital prerequisite to adequate coordination. Without coordination execution will not proceed smoothly and the project will inevitably fall behind schedule. The CPM provides for this necessary communication.

2.2 Monitoring and Measurement of Progress and Performance

In order to monitor and measure progress, there must be a baseline schedule against which progress can be measured. The generation of the initial CPM provides this baseline yardstick against which the current status of the project can be compared with to determine if execution is ahead or behind schedule. As time elapses, the CPM schedule can be updated with discrete activity progress, changes in scope, alterations in logic, and modifications to resource allocation. This updated CPM schedule provides the current status of the project, and thus allows for the evaluation of each update against the baseline schedule to determine: if the overall project is on or behind schedule, if the critical path of the project has changed or evolved and the degree of float and schedule contingency consumption.

2.3 Managing Change

There is an old saying, *"that there are two certainties in life – death and taxes."* Anyone who has been involved in engineered and constructed projects knows all too well that a third "certainty" could be added to this infamous list – *"Projects never proceed exactly as planned."* There are always unexpected events,

changes in scope and issues that occur during the execution of a project that negatively impact its execution. These unexpected occurrences require that the baseline schedule be revised to accommodate these issues. CPM scheduling is unique in that it allows for the integration of change into the baseline schedule, as well as serves as a mechanism by which the impact resulting from the subject event can be identified and quantified. Subsequently, the CPM schedule can serve as a tool to develop and test methods to mitigate impact and recover delay resulting from a scope change or issue. As such, a CPM schedule mirrors the dynamic nature of actual project execution. The following is a discussion of ways in which CPM schedules can be utilized for risk management both prior to and during the execution of a project.

3. Utilizing CPM Schedules for Risk Management

3.1 Identifying Party Responsibility

The current international construction market's utilization of multi-party contracting has increased in an effort to share the enormous risk in executing large-scaled infrastructure, power and process projects. Examples of these multi-party contracting arrangements include:

- Consortiums, Joint Ventures and Partnering
- Multi-Layers of Subcontracting
- Design-Build / LSTK utilizing Owner Equipment Manufacturers or Third-Party Technology
- Traditional Design-Bid-Build with outside Construction Management (Owner's Representative)

Within these contracting arrangements there is significant risk associated with the demarcation of responsibility amongst the various constituents. As an example, let us envision a cogeneration power plant being constructed utilizing a LSTK contracting and project delivery mechanism. However, the major equipment (gas turbine, HSRG, and steam turbine) is being procured from manufacturers directly by the Owner. In this situation certain risks are quite apparent, for example:

- What are the battery limits for design and construction with respect to each major piece of equipment? For example, the size and location of discharge pipe on a HRSG will have an impact on the overall stress analysis and piping support design for the balance of plant engineering.

While often issues like the above will be referenced in theory via the Contract, they are not addressed on the execution level. A CPM schedule can fulfill this need through the utilization of activity codes. Activity codes are assigned to each individual activity to enable the extraction and sorting of work tasks, as well as the generation of tabular reports and graphics that are consistent with the integrated project control system. Activity codes are one of the primary CPM mechanisms that allow the overall schedule to be summarized and presented in understandable format, thus allowing for decisive definition of party responsibility. Typical activity codes in CPM scheduling include:

- Work Break Down Structure, Area and Phase
- Overall Discipline (Engineering, Procurement or Construction)
- Discrete Discipline (Civil, Mechanical, Electrical, Instrumentation, Controls, etc.)
- Overall Responsibility (Contractor, Subcontractor, Owner, OEM, Vendor, Construction Manager, Engineer etc.)
- Discrete Responsibility (Individual within each party overseeing the discrete activity)
- Contract Deliverables

The creation of above-referenced activity codes within the CPM code dictionary and their corresponding assignment to the various work tasks enables the generation of mini-schedules applicable to certain individual parties. In addition, each of the constituents having reviewed the CPM schedule can readily identify the activities that they are responsible for, as well as the subsequent activities that are dependent on their timely completion. For example, the detailed execution schedule for a large power plant could have as many as 10,000 discrete activities. The utilization of activity codes would allow the civil subcontractor to easily identify and review the activities that are its responsibility, or within a certain area or location etc. This not only greatly reduces the risk of poorly defined responsibility among the various constituents, but also increases the frequency in which the schedule is **actually utilized** by the individual parties executing the work.

3.2 Interfaces between Constituents

Similar to the issues with the demarcation of responsibility, interface and coordination among the various parties are significant areas of potential risk prior to and during the execution of a project. These areas of potential risk include the interfaces between:

- Joint Venture and Consortium Partners
- Owner, Contractor and Construction Managers
- Contractor, Subcontractors, Equipment Suppliers and Vendors
- Engineering, Procurement and Construction

CPM scheduling allows for the mitigation of potential risk resulting from these various interfaces through the utilization of logical relationships. The assignment of logical relationships (dependency) between various activities within the CPM model integrates the potential risk into the overall schedule. Using the same example of the cogeneration power plant, it is clear that major equipment procurement needs to be logically linked to the appropriate preceding engineering activities such as data sheet and equipment specification generation. In addition, the procurement of major equipment should also be logically connected to the generation of piping and instrumentation diagrams as these procurement activities require this information at the preliminary review status as a minimum. While the interface between procurement and preceding engineering work is obvious, it is important to note that the completion of engineering is often dependent of receipt of vendor information and data. CPM scheduling allows for the insertion of logical relationships that tie-back the completion of detailed engineering to the receipt of vendor information, therefore mitigating against the potential risk of prematurely completing detailed engineering before the receipt of critical vendor information. The lack of this type of logical connection is a common error in scheduling, and typically results in engineering cost overruns and delay.

3.3 Critical Path Analysis

The development of a workable schedule for a project is key to its successful execution. As such, there is significant potential risk if a schedule is unreasonable, overly aggressive, and/or deficient in some manner. Therefore, the management team's ability to analyze the overall reasonableness / workability of a schedule is paramount to ensuring that this risk is minimized. CPM scheduling allows for this to be performed effectively and efficiently through the utilization of critical path analysis. The critical path analysis allows the project management team to focus its attention on the most crucial work tasks, items and areas of the project, thus enabling them to more readily provide any additional attention and detail necessary. Critical path analysis typically addresses the following issues:

- Is the schedule complete, and do the activities reflect the contractual scope of work and deliverables?
- Are the activity durations reasonable?
- Are there sufficient logical relationships between the various work tasks to ensure an adequate level of interface between the constituents, disciplines, and work areas?

- Is the CPM generated critical path reasonable, and does the work flow in a logical, realistic manner?
- Are there concurrent critical paths and/or an excessive amount of work at any given time?
- Are there any potential conflicts between work tasks with respect to craft labor availability or site access?
- Are there sufficient resources (including craft labor, supervision, management, equipment and materials) to support the planned activity durations?
- Can subcontractors, suppliers and vendors meet their schedule obligations?
- Has there been "buy-in" from the various project parties?

The performance of a critical path analysis that addresses the above-mentioned issues prior to the start of execution will significantly mitigate the potential risk exposures that face most engineered and constructed projects. However, despite all the upfront efforts of project management to mitigate risk prior to the start of the project, it is impossible to completely eliminate it. Below is a discussion on several ways in which CPM scheduling can be utilized to assist the project management team in addressing these risk issues, and mitigating the impact resulting therefrom.

3.4 Analysis of Float

The calculation of float or "slack" for each work task is one of the major focuses of CPM scheduling. The total float of an activity represents the level of scheduling flexibility that exists within that activity with respect to the overall completion date of the project. Project management teams can analyze float in order to identify and mitigate risk associated with executing the project. As previously discussed, CPM schedules, like projects themselves, are dynamic in nature. Therefore, they are routinely updated with information including progress and scope change. Following the integration of this information into the schedule, it is recalculated. The comparison of the float (between the baseline and updated schedules) associated with each discrete activity provides the project management team with valuable insight relative to the change in criticality of activities as well as the consumption of float. Upon the identification of a shift in the critical path, analysis can be performed and corrective action taken by the management team as necessary. Equally as important as a shift in critical path is the significant change in a discrete activity's total float because near critical activities can quickly become critical and impact a project's completion date if not monitored closely. CPM scheduling provides the framework and mechanism by which this monitoring can occur efficiently and routinely.

3.5 Impact Analysis

CPM schedules can also be employed to perform analyses in order to quantify the time impact associated with scope change, disruption and other issues affecting project execution. This is typically accomplished through the integration or "insertion" of the impacting issue into the baseline schedule. This modeling of the impact issue is performed using one or a combination of the following techniques:

- Insertion of a new activity into the CPM schedule
- Insertion or deletion of logical relationship between activities
- Modification of existing logical relationships between activities (for example, changing from a finish-to-start relationship to a start-to-start relationship between activities)
- Modification to an existing activity's original or remaining duration

Following the modeling of the impact issue, the CPM schedule can be recalculated in order to provide insight as to the potential impact. For instance, let us assume that a contract allowed the Owner two weeks to review and comment to the submittal of Process and Instrumentation Diagrams (P&IDs). However, during the execution of the project, it was determined that the Owner, due to a lack of design resources was going to need four weeks. The risk associated with this issue can be readily modeled in a CPM schedule by modifying the original duration associated with the activity representing the "Owner Review

of P&IDs." The schedule could then be recalculated, thus providing the project management team with an estimate of the time impact (relative to each discrete activity as well as to the overall completion of the project) resulting from this issue.

3.6 "What-if" Scenarios

As demonstrated above, CPM schedules can be useful tools for identifying and quantifying the risk impact resulting from various issues commonly experienced on engineered and constructed projects. In addition, CPM scheduling techniques are also uniquely suited for analyzing means in which impact can be mitigated. The most common used CPM technique is the performance of a "what-if" scenario, or the modeling of ways in which delay, disruption and impact can be mitigated. There are several methods that can be utilized by the project management team to mitigate schedule impact. These Schedule Compression techniques usually involve; the reduction of discrete activity durations, the performance of activities concurrently or in parallel, and/or the re-sequencing of activities.

These various time impact mitigating techniques can be effectively and efficiently modeled using CPM to allow the project management team to "test" which modification will result in the maximum mitigation of impact. My practical experience in analyzing schedules has been that usually the best alternative for mitigation is some combination of the three above-mentioned techniques. As such, this modeling approach is an iterative process which plays into one of the major strengths of computer-based CPM scheduling – speed of calculation. Following each iteration, the project management team must analyze the modified schedule to determine if the planned completion date has changed, shifts in the critical path, and the degree in which activity float has modified.

As a result of the performance of "what-if" scenarios, the project management team will determine that additional resources will be necessary in order to undertake the necessary steps for adequate mitigation of impact. This utilization of additional resources in conjunction with schedule compression is commonly referred to as "acceleration." CPM schedules can be readily resourced and cost loaded. Therefore, they provide a sole-source mechanism that allows the project management team to quantify the resources necessary to mitigate an impact, as well as the corresponding cost.

In conclusion, risk is prevalent in all engineered and constructed projects, and it needs to be addressed by the project management team throughout the entire project life cycle. CPM scheduling is one of the most effective tools at the disposal of the project team for performing the vital functions of risk analysis and management (identification, assessment, analysis and mitigation).

4. References

Nielsen, K.R., (1993). "Project Risk Management – Achieving Goals and Minimizing Disputes", The Nielsen-Wurster Group, Inc., Princeton, New Jersey, USA.

Primavera Systems, Inc. (1996). "P3 Primavera Project Planner Reference Manual", pp. 119-128

Project Management Institute (2000). "A Guide to the Project Management Body of Knowledge". *Project Management Institute Standards Committee*, pp. 59-72

Wickwire, J.M. et al, (1991). *"Construction Scheduling: Preparation, Liability, and Claims"*, Aspen Law & Business, USA, pp. 23-34