Forensic Schedule Analysis – Chapter 2: Delay Analysis on Non-CPM Scheduled Projects[1]

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Abstract – AACE's Recommended Practice 29R-03 – Forensic Schedule Analysis, provides detailed insight into how CPM based schedule delay analysis should be performed. This RP provides thorough and detailed protocols for each of the nine methodologies identified. However, industry surveys from around the globe indicate that a substantial portion of construction projects do not employ critical path method scheduling techniques. Other industry studies indicate that a large percentage of projects complete later than planned. Therefore, it can only be concluded that there are a large number of delays and delay claims on projects that do not use CPM schedules. RP 29R-03 offers no guidance concerning the performance of schedule delay analysis if there are no CPM schedules on the project. This paper presents recommendations on how schedule delay analysis can be performed on projects using nine different non-CPM scheduling techniques. The paper also discusses the five types of constraints present on most, if not all, construction projects and how these constraints must be used in non-CPM schedule delay analysis. The goal of this

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paper is to initiate Chapter 2 of RP 29R-03 – Forensic Schedule Analysis on Projects without CPM Schedules.

Introduction

AACE's Recommended Practice ("RP") 29R-03 was issued initially on June 25, 2007. It has been twice revised, the first time on June 23, 2009 and more recently on April 25, 2011. The purpose of this RP, however, has never changed. The stated purpose is set forth in Section 1.1 as follows:

> "The purpose of AACE® International's Recommended Practice 29R-03 *Forensic Schedule Analysis* is to provide a unifying reference of basic technical principles and guidelines for the application of critical path method ("CPM") scheduling in forensic schedule analysis."

The RP provides detailed insight into the performance of schedule delay analysis and thorough protocols for forensic scheduling using CPM schedules. However, the current RP 29R-03 does not contain any discussion concerning schedule delay analysis on those projects executed without CPM schedules nor could the authors locate any current literature on forensic schedule analysis on non-CPM schedules.

Industry surveys indicate that a substantial percentage of projects executed globally do not use CPM scheduling. The Chartered Institute of Building ("CIOB") in their survey of the U.K. construction industry found that only 14% of the respondents had experience with fully linked critical path networks on their projects. Another 8% of the respondents had experience with "…a partially linked network … to show some of the priorities and sequence of tasks, but without the benefit of a dynamic network." The remaining 78% of the survey respondents used Bar Charts (54%); Time Chainage Diagrams (1%); Line of Balance Diagrams (1%); Flow Charts (3%); meeting minutes (11%); and correspondence (8%) to manage time on their projects. The CIOB report also noted that a similar survey in Australia found that in over 1,000 construction schedules examined, less than 10% had fully developed schedule logic.[4] In a similar wide ranging survey of the construction industry and how it views CPM scheduling it was determined only 47.6% of the owners responding to the survey indicated that CPM scheduling was always required on their projects. Contractors participating in this survey reported that when CPM scheduling is not required in their contracts approximately 33% do not use the CPM scheduling methodology.[5]

In a construction industry survey released in December 2011 84% of the respondents reported that they had experienced delayed completion on their projects. The average delay was 17% over the planned or contracted time of completion. Further, 76% of the respondents had experienced disputes and claims on their projects.[6] Thus, it can be concluded that there are a large number of delays on projects that were completed without CPM schedules. It can be further concluded that there are a large number of requests for time extension and/or delay claims on projects executed without CPM schedules.

Forensic schedule analysis is a retrospective – backward looking – schedule analysis. That is, an event occurred that delayed the project. Under most contracts, the affected party (typically the contractor) is required to provide written notice of potential delay to the other party (typically the owner). Once a delay event has arisen the contractor is typically required under the contract to submit a time extension request (either excusable or compensable) and document liability, causation and damages related to the delay. The contractor's project manager or scheduler prepares the time extension as the time the impact is defined. This paper deals exclusively with the delay aspect of the construction claims equation; that is, how to prove the extent of the delay arising from an event.

[4] "Managing the Risk of Delayed Completion in the 21st Century", Chartered Institute of Building, Englemere, Kings Ride, Ascot, Berkshire, U.K., 2008.

[5] Galloway, Patricia D., "CPM Scheduling and How the Industry Views Its Use", AACEI International Transactions, CDR.07, 2005.

[6] "Mitigation of Risk in Construction: Strategies for Reducing Risk and Maximizing Profitability", McGraw Hill Construction Research & Analytics, Bedford, MA, 2011.

Since forensic scheduling is retrospective, forensic schedulers typically are not retained until the delaying event or even the entire project is complete. Once on board, if the forensic scheduler finds that the project was executed without any CPM scheduling, then RP 29R-03 offers no guidance concerning non-CPM delay analysis. This paper outlines some procedures for performing schedule delay analysis in the absence of CPM schedules. It presents an outline of how to perform schedule delay analysis in the following situations where no schedules or non-CPM-based schedule only information is available.

- No project schedules
- Bar Chart/Gantt Chart Schedules
- Milestone Schedules
- S Curves
- Linear Schedules
- Critical Chain Schedules
- Line of Balance Schedules
- Pull Planning or Location Based Schedules
- Rolling Wave Scheduling

Forensic schedulers are typically required to deal with schedules that were prepared during project execution. If a forensic scheduler is retained to perform a forensic schedule analysis on a project that had no CPM schedules the scheduler must deal with this fact and derive a method for analyzing delays on the project. The problem facing the forensic scheduler in this situation is that non-CPM schedules generally do not show the logical relationships between activities. Thus, on a Bar Chart, for example, if Activity A is delayed in its start or completion this does not necessarily mean that Activity B is subsequently delayed or even impacted. The forensic scheduler must find a way to define logic relationships between activities in order to demonstrate (1) that these relationships actually existed on the project even though they were not explicitly shown on a schedule and (2) that a delay to a specific activity or set of activities actually resulted in an impact to the end date of the project.

Forensic schedulers recognize that the fundamental weakness of a Bar Chart or a non-CPM schedule is that a critical path cannot be readily identified. Likewise, the critical path cannot be ascertained by normal scheduling methods. Therefore, to identify a critical path and analyze delays along this critical path forensically, the forensic scheduler has to employ special methods. This paper outlines the special methods to be used when defining the logic relationships between activities on a non-CPM schedule in order to ascertain a critical path and analyze delays to the project's end date.

A Theory of Constraints Applied to Non-CPM Schedule Delay Analysis

Every project is faced with constraints. These are factors, either internal or external, which affect when various activities on the project can be scheduled. AACE International defines the term "constraint" as follows –

> "**CONSTRAINT** – In planning and scheduling, any external factor that affects when an activity can be scheduled. A restriction imposed on the start, finish or duration of an activity. The external factor may be resources, such as labor, cost or equipment, or, it can be a physical event that must be completed prior to the activity being restrained. Constraints are used to reflect project requirements more accurately. Examples of date constraints are: start-no-earlier-than, finish-no-later-than, mandatory start, and as-late-as-possible."[7]

There are five types of constraints that may affect a project schedule. They are presented below in the order that they should be applied to forensic scheduling – that is from "hard" or mandatory logic to "soft" logic. The application of these constraints in the order presented is critical as they move from a "must comply" status to a "may be able to change" status as the forensic scheduler applies them to a schedule. The five types of constraints a forensic scheduler must consider, and the order in which they

[7] AACE Recommended Practice 10S-90 – Cost Engineering Terminology, AACE International, Morgantown, W.V., December 13, 2011, page 21.

must be applied, when analyzing schedule delay in a non-CPM scheduling environment are the following –

1. **Physical constraints (also known as "hard" logic)** – These logic constraints have absolute priority over all other constraints simply because, as Chief Engineering Officer Montgomery Scott frequently stated to Captain Kirk, no one can "…change the laws of physics." Physical constraints or hard logic exist on every project. Logical relationships such as one must construct the foundation before erecting the walls which must be completed prior to constructing the roof are examples of physical constraints. Site access may be another example of a physical constraint. If the project is being constructed on a site with only a single access road then this may mandate the manner in which the project is constructed.

2. **External constraints** – External constraints are those constraints imposed on the project by an outside party over which neither the owner nor the contractor can exert any control. Examples of external constraints may be environmental permit restrictions requiring that the work of the project may not continue past May 1st nor commence again until after September 15th in order to protect the environment on or near the project site. Noise ordinances may restrict working hours on the projects to 7:00 AM to 5:00 PM, Monday through Friday with no weekend work allowed.

3. **Contract constraints** – Contract constraints are those constraints imposed by the terms and conditions of the contract. Owners have the ability to impose numerous constraints by including them in their contracts. Contractors, once they have executed the contract, have little ability to change such constraints unless a change order is granted. A prison authority may require that "All work on Building 1 shall be completed within 270 days after issuance of Notice to Proceed ("NTP"). All work on Building 2 shall be completed within 360 days after issuance of NTP…" and so on and so forth. A municipality may require, by contract "All work on the contract shall cease, all open trenches shall be covered entirely and all roads shall be fully opened to traffic during the period between May 15th and September 15th" in order

to provide vacationers access to the area during the summer season. Such contractual requirements force the contractor to proceed in a certain manner or risk being default terminated for a material breach of contract.

4. **Resource constraints** – Resource constraints may be caused by internal and/or external situations. Some examples of external resource constraints include a shortage of skilled labor in the project area; a shortage of critical materials; available delivery periods for critical equipment if the project is in a remote location; and long lead items necessary to complete the work. If the contractor owns only one 100 ton crane and did not include the rental cost of a second 100 ton crane in its bid, this is an internal resource constraint for which the contractor bears the risk. If the contractor owns two paving machines but one is tied up on another project, which is taking longer than planned, this too may cause an internal resource constraint that must be considered in the as-planned schedule.

5. **Preferential logic constraints** – Preferential logic is defined as the "Contractor's approach to sequencing work over and above those sequences indicated in or required by contract documents. Examples include equipment restraints, crew movements, form reuse, special logic (lead/lag) restraints, etc., factored into the progress schedule instead [of] disclosing the associated float times."[8] This is frequently referred to as "soft logic" since it is not imposed by physical or contractual constraints. When this logic is used as part of the contractor's plan for prosecuting the work, to the forensic scheduler this is a constraint nevertheless. Once the contractor plans their means and methods (based upon this preferential logic) it typically commences work following this plan. The plan itself is, therefore, a constraint albeit a self-imposed one. The forensic scheduler performing schedule delay analysis must treat preferential logic as a constraint on schedule activities at least at the outset of a project simply because the initial project planning defined the logic of the activities in the field.

[8] Ibid, page 78.

Forensic Scheduling in Non-CPM Schedule Delay Analysis

This paper outlines a methodology for forensic schedule analysis of delays on a non-CPM scheduled project and discusses some of the documentation that a forensic scheduler should review in order to document that the schedule used for delay analysis is reasonable, reliable and accurately represents the schedule the contractor actually followed during prosecution of the work. It is critical that the forensic scheduler document a baseline schedule to demonstrate that the contractor had a reasonable and achievable plan to construct the project at the outset. Since U.S. Courts recognize that project schedules are dynamic in nature, then reasonably accurate schedule updates are also required in order to properly analyze project delays in litigation.[9] It is acknowledged that all of the cited cases dealt with schedule delay analysis performed on CPM schedules. However, the logic and thinking underlying these decisions makes it likely that courts and arbitration panels are likely to apply similar rules in non-CPM delay situations.

Delay Analysis – No project schedules

Perhaps the toughest challenge a forensic scheduler faces is to prepare and present a schedule delay analysis on a project which had no schedules. Since there are no schedules on the project, a baseline schedule and a series of schedule updates must be constructed in order to demonstrate schedule delay.

Methodology – It is recommended that the forensic scheduler employ the following methodology.

[9] *George Sollitt Construction Company v. U.S.*, 64 Fed. Cl. 229 (2005); *Sterling Millwrights, Inc. v. U.S.*, 26 Cl. Ct. 49, 75 (1992); *Fortec Constructors v. U.S.*, 8 Cl. Ct. 490, 505, *aff'd*, 804 F.2d 141 (Fed. Cir. 1986); *Blinderman Construction Company v. U.S.*, 39 Fed. Cl. 529 (1997).

Baseline Schedule –

1. Review all contract documents and drawings to determine the scope of work, the conditions of the contract and determine what physical, external and contractual constraints were applicable to the work.

2. Determine how these constraints affected the plan for the work.

3. Review the contractor's bid to ascertain the activities or portions of the work bid and the cost and resources calculated for each activity or portion of the work.

4. Determine whether the bid included the full scope of work and if not, what portion(s) of the scope of work were left out.

5. Document the work left out so that it may be included in the baseline schedule the forensic scheduler will construct for analytical purposes.

6. Make a judgment on whether there were sufficient resources to accomplish the full scope of work within the contractual time of performance. Document all assumptions/bases and analyses thereof.

7. Based on availability, interview the estimator(s) who prepared the bid, the project manager and superintendent and trade foremen (the project team) to document the initial "plan" for the work.

8. Determine whether the plan was successful at least at the outset and how long the contractor was able to follow this plan.

9. If the plan was <u>not</u> successful initially, determine from interviews why not and prepare appropriate documentation.

10. Review daily, weekly and monthly reports from the first 1 to 3 months after NTP to determine if there were any changes or delays to the work during this initial period.

11. If there were none, and relying on the assumption that the initial period of the work most likely followed the initial plan, examine project documents to determine what events occurred and the duration of each event.

12. Establish a list of activities and a work breakdown structure ("WBS") coding structure.

13. Construct a computerized fully linked CPM baseline schedule based upon the information gathered in the previous steps.

14. Apply the following constraints, in order, as and if applicable –

    a. Physical constraints – First, determine what physical constraints affected the work by determining what activities physically had to be complete prior to other activities starting; what activities had to be partially completed before follow on activities can start and what percentage the activity had to be complete; etc. Once physical constraints are identified and calculated, incorporate these constraints.

    b. External constraints – Second, determine what external constraints affected the plan such as local permitting requirements, environmental restrictions, noise ordinances, etc. These constraints come second in the order of application as they are typically imposed by governmental entities over which neither the owner nor the contractor has any control. Input these constraints into the draft schedule and make appropriate adjustments as needed.

c. Contract constraints – Third, determine from the terms and conditions of the contract what constraints were imposed by the owner. Since the forensic scheduler is performing a retrospective schedule analysis, unless it can be determined from project documentation that the owner specifically waived one or more of the contract constraints, apply these constraints to the draft schedule and make appropriate changes as necessary.

d. Resource constraints – Fourth, determine from analysis of the contractor's bid and interviews with the project team what resource constraints were known prior to the commencement of the work. Was there a shortage of skilled craft labor; a shortage of critical materials; a shortage of cranes or earthmoving equipment, etc. and, if so, how did these resource constraints affect the work? Apply these constraints to the draft schedule as appropriate.

e. Preferential logic – Finally, determine from interviews and project documentation what preferential logic was considered for the schedule at the outset of the work and apply this constraint to the baseline schedule.

15. Test the baseline schedule against the information gathered earlier and have the project team validate or correct the baseline schedule to ensure only conditions known at bid/NTP were included in the baseline.

Schedule Updates –

1. Review available project documentation including meeting minutes, project status reports, project photographs, correspondence, change orders, Requests for Information ("RFI"), etc. to determine how the project actually progressed over the execution phase.

2. Interview the project team to determine what happened on the project, when it happened, who caused the event or issue, and what the impact was. Independently verify through project documents.

3. Determine what changes were made to the plan; when they were made; who caused the changes; and what the impacts of these changes were.

4. Prepare periodic schedule updates based upon the information gathered above.

5. Have key project personnel review the schedule updates to validate them.

6. Develop and maintain records to document each of the tasks performed above.

Schedule Delay Analysis –

1. Apply Method Implementation Protocol ("MIP") 3.5 – Observational / Dynamic / Modified or Recreated to document what events or activities drove the project delay.

2. From the project documentation determine whether the contractor provided actual or constructive notice of any or all of these delays. For those delays where notice was filed, incorporate the delays. For those where notice was <u>not</u> provided, include the delays in the schedule with an annotation that notice was not provided. Legal counsel will have to provide guidance at the end of the analysis on whether these delays remain in or are to be excluded from the schedule delay analysis.

3. Determine the amount of delay caused by those events or actions/inactions of the owner, its representatives or events for which the owner assumed liability.

Delay Analysis – Bar Chart/Gantt Chart Schedules

A Bar Chart is defined as a "Graphic representation of a project that includes the activities that make up the project and placed on a time scale. Bar charts are time scaled, show activity numbers, description[s], duration[s], start and finish dates, and an overall sequencing of the flow of work. Bar charts do not generally include the logic ties between activities."[10] Bar Charts are sometimes referred to as Gantt Charts which are defined as "A time scaled bar chart named after Henry L. Gantt"[11], the early 20th Century mechanical engineer who created this scheduling technique.

In this situation the forensic scheduler has a schedule to work with. The Bar Chart should show at least the major activities required to complete the work; provide activity descriptions; set forth start and finish dates for all activities; and may provide activity numbers. If activity numbers are not provided the forensic scheduler needs to create a numbering system in order to track activities during the delay analysis. Generally, a Bar Chart is time scaled and shows the flow of work from the upper left to the lower right of the schedule sheet.

The problem with Bar Charts with respect to schedule delay analysis is that a delay to Activity 100 does <u>not</u> mean that any following activities were delayed or even impacted. The challenge for the forensic scheduler in this situation is to construct appropriate logic ties between activities. Many activities on Bar Charts are <u>not</u> planned in a finish to start relationships; that is, there is often overlap between activities without explanation. Therefore the forensic scheduler has to construct logic ties with leads and lags based on the constraints applicable to the project. Additionally, the forensic scheduler must create well documented schedule updates for the duration of the work.

Methodology – It is recommended that the forensic scheduler employ the following methodology.

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[10] AACE Recommended Practice 10S-90 – Cost Engineering Terminology, page 10.
[11] Ibid, page 49.

Baseline Schedule –

1. Assuming the baseline Bar Chart provided was not rejected by the owner this initial submittal is the best starting point for forensic scheduling. If the schedule was not accepted by the owner determine whether the contractor followed the schedule from the outset. If the contractor did follow the schedule then this schedule should be used. If the contractor did not follow the schedule submitted then the forensic analyst should follow the steps outlined above – Delay Analysis – No Project Schedule.

2. Review all contract documents and drawings to determine the scope of work, the conditions of the contract and what physical, external and contractual constraints impacted the work.

3. Determine how these constraints affected the work.

4. Review the contractor's bid to ascertain the activities or portions of the work bid and the cost and resources calculated for each activity.

5. Determine whether the bid included the full scope of work and if not, what portion(s) of the scope of work were left out.

6. Document the work left out so that it may be included in the baseline schedule the forensic scheduler will construct for analytical purposes.

7. Make a judgment on whether there were sufficient resources planned to accomplish the full scope of work within the contractual time of performance. Document all assumptions and bases/analyses thereof.

8. Interview the project team to gain its understanding of the baseline schedule and determine whether and how long the contractor was able to follow the plan set forth in the Bar Chart.

9. Determine from these interviews the leads and lags that had to physically occur in the field in order to efficiently prosecute the work. For example, how much framing on each floor had to be in place before the rough-in of mechanical, electrical and plumbing ("MEP") could start; how much of the MEP on each floor had to be in place before the sheetrocking on the floor could start; and so on and so forth.

10. If the Bar Chart plan was <u>not</u> initially successful, determine from these interviews why not.

11. Construct the revised baseline schedule by inserting the required logic leads and lags in order to create a network based upon the information gathered.

12. Apply the following constraints as discussed above, in order, as and if applicable –

    a. Physical constraints
    b. External constraints
    c. Contract constraints
    d. Resource constraints
    e. Preferential logic

13. Revise the baseline schedule appropriately to account for the applicable constraints.

14. Test the revised baseline schedule against the information gathered earlier and have the project team validate or correct the baseline schedule as needed.

15. Determine the delay, if any, caused by events that necessitated revision of the baseline schedule.

Schedule Updates –

1. Review available project documentation to determine how the project actually progressed on a period by period basis.

2. Interview the project team and document what happened on the project, when it happened, who caused the event or issue, and what was the resulting impact. Independently verify through project documents.

3. Determine what changes were made to the schedule; when they were made; who caused the changes; and what the impacts of the changes were.

4. Prepare periodic schedule updates based upon the information gathered above.

5. Have key project personnel review the schedule updates to validate them.

Schedule Delay Analysis –

1. Apply MIP 3.5 – Observational / Dynamic / Modified or Recreated to document what events or activities drove the project delay.

2. From the project documentation determine whether the contractor provided actual or constructive notice of any or all of these delays. For those delays where notice was filed, incorporate the delays. For those where notice was <u>not</u> provided, include the delays in the schedule with an annotation that notice was not provided. Legal counsel will have to provide guidance at the end of the analysis on whether these delays remain in or are to be excluded from the schedule delay analysis.

4. Determine the amount of delay caused by those events or actions/inactions of the owner, its representatives or events for which the owner was contractually liable.

Delay Analysis – Milestone Schedules

A Milestone Schedule is defined as "A schedule comprised of key events or milestones selected as a result of coordination between the client's and the contractor's project management. These events are generally critical accomplishments planned at time intervals throughout the project and used as a basis to monitor overall project performance. The format may be either a network or bar chart and may contain minimal detail at a highly summarized level."[12]

The forensic scheduler in this situation has an agreed upon baseline schedule and most likely has some schedule updates to work with. If the project's Milestone Schedule is in the form of a network or logic diagram, forensic scheduling should be performed in accordance with RP29R-03. If the Milestone Schedule is in the form of a Bar Chart, then forensic scheduling should be performed in accordance with the previous discussion. (See "Delay Analysis – Bar Chart/Gantt Chart Schedules" above.) There is a third form of Milestone Schedules not mentioned in the AACE definition cited above. This third form is a list of Milestone events showing the milestones on the vertical axis on the left side of the schedule. The completion dates on for each milestone are simply shown as asterisks to the right of each milestone description (example: * M/S 16 – May 11, 2012).

The problem with this type of Milestone Schedule is that it does not show logical relationships between milestones nor does it show the planned start dates and durations of each of the activities required to complete each milestone. The challenge for the forensic scheduler is to flesh out the as-planned Milestone Schedule by calculating and documenting the starting dates and durations of each set of activities leading to each milestone date and then determining logic ties and leads and lags between sets of activities. Subsequently, the forensic scheduler must revise the periodic schedule updates performed on the work to take into account the logic defined for the baseline schedule.

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[12] Ibid, page 68.

Methodology – It is recommended that the forensic scheduler employ the following methodology.

Baseline Schedule –

1. Assuming the baseline Milestone Schedule was agreed to this should be the starting point for forensic scheduling.

2. Review all contract documents and drawings to determine the scope of work, the conditions of the contract and what physical, external and contractual constraints were applicable to the work.

3. Determine how these constraints affected the work.

4. Review the contractor's bid to ascertain the activities or portions of the work bid and the cost and resources calculated for each activity or portion of the work leading to each milestone.

5. Determine whether the bid included the full scope of work or what portion(s) of the scope of work were left out, if any.

6. Document the work left out so that it may be included in the baseline schedule the forensic scheduler will construct for analytical purposes.

7. Make a judgment on whether there were sufficient resources planned to accomplish the full scope of work for each milestone by the milestone date. Document all assumptions/bases and analyses thereof.

8. Interview the project team to gain its understanding of the baseline schedule and determine whether and how long the contractor was able to follow the plan set forth in the baseline.

9. Determine from these interviews the activity relationships and leads and lags that had to physically occur in the field in order to efficiently prosecute the work. For example, how long did each deck have to be cured before the shoring and forming could be jumped to the next elevation.

10. If the Milestone Schedule missed all or most of the initial as-planned dates, determine from these interviews why this occurred.

11. Construct the revised baseline Milestone Schedule by inserting the required relationships and leads and lags in order to define a logic network.

12. Apply the following constraints as set forth earlier, in order, as and if applicable –

    a. Physical constraints
    b. External constraints
    c. Contract constraints
    d. Resource constraints
    e. Preferential logic

13. Revise the baseline Milestone Schedule appropriately to account for applicable constraints.

14. Test the revised baseline Milestone Schedule against the information gathered earlier and have the project team validate or correct the adjusted revised baseline schedule.

Schedule Updates –

1. Review available project documentation to determine how the planned milestone dates were actually accomplished on a period by period basis.

2. Interview the project team and document what happened on the project, when it happened, who caused the event and what was the resulting impact. Independently verify through project documents.

3. Determine what changes were made to the schedule; when they were made; who caused the changes; and what the impacts of the changes to the plan were.

4. Prepare periodic schedule updates based upon the information gathered above.

5. Have key project personnel review the schedule updates to validate them.

Schedule Delay Analysis –

1. Apply MIP 3.5 – Observational / Dynamic / Modified or Recreated to document what events or activities drove the project delay.

2. From the project documentation determine whether the contractor provided actual or constructive notice of any or all of these delays.

3. Determine the amount of delay caused by those events or actions/inactions of the owner, its representatives or events for which the owner was liable under the contract.

<u>Delay Analysis – S-Curves</u>

An S-Curve "is a graphic display of cumulative costs, labor hours, progress or other quantities plotted against time."[13] S-Curves are also known as Cumulative Distribution Charts, Velocity Diagrams and S-Plots. According to Recommended Practice 55R-09

[13] AACE Recommended Practice 55R-09 – Analyzing S-Curves, AACE International, Morgantown, W.V., November 10, 2010, page 1.

> "Prior to developing an S-Curve, a project baseline schedule needs to be developed. The baseline schedule should employ best scheduling practices … The baseline schedule should also contain cost and/or quantity data information if that type of S-Curve is desired. The S-curve produced from the baseline early dates is often referred to as the 'target S-Curve' which reflects projected or planned progress on the project if all tasks are completed on their original early finish dates."[14]

If a forensic scheduler is retained to work on a project where an S-Curve has been developed from a CPM network (as is implied by RP 55R-09) then all forensic schedule analysis should be performed on the underlying CPM schedules in accordance with RP 29R-03. Having said this, S-Curves on linear projects, for example, earthmoving projects, and the like are often created by spreadsheet analysis only – <u>not</u> by the calculation of resource loaded CPM schedules. In this event, the guidance offered in RP 29R-03 is insufficient to perform a forensic analysis on this type of S-Curve.

The challenge for the forensic scheduler in a situation such as a linear project is to locate and document the underlying calculations that supported the baseline S-Curve; identify and document events on the project which drove the schedule late; and analyze those events for liability, causation and damages.

Methodology – It is recommended that the forensic scheduler employ the following methodology.

Baseline Schedule –

1. Assuming that the baseline S-Curve provided was agreed to at the outset of the project this is the starting point for forensic scheduling.

[14] Ibid, page 1.

2. Review all contract documents and drawings to determine the scope of work, the conditions of the contract and what physical, external and contractual constraints were applicable to the work.

3. Determine how these constraints affected the work plan.

4. Review the contractor's bid to ascertain the activities or portions of the work bid and the cost and resources calculated for each activity or portion of the work.

5. Determine whether the bid included the full scope of work or what portion(s) of the scope of work were left out, if any.

6. Document the work left out so that it may be included in the baseline schedule the forensic scheduler will construct for analytical purposes.

7. Make a judgment on whether there were sufficient resources to accomplish the scope of work by the contract completion date. Document all assumptions/bases and analyses thereof.

8. Interview the project team who prepared the S-Curve to determine their understanding of what was required to complete work in accordance with the S-Curve. Determine whether and how long the contractor met the S-Curve numbers.

9. If the contractor missed the initial as-planned S-Curve quantities, determine from these interviews why this occurred and document these findings.

10. Apply the following constraints as discussed above, in order, as and if applicable –

    a. Physical constraints
    b. External constraints
    c. Contract constraints

d. Resource constraints
e. Preferential logic

11. Revise the baseline S-Curve appropriately, if needed, to account for the applicable constraints.

12. Test the revised baseline S-Curve against the information gathered earlier and have the project team validate or correct the revised baseline S-Curve.

Schedule Updates –

1. As projects using S-Curves typically are routinely updated based on actual progress, valid schedule updates should be available for the forensic scheduler to review.

2. Each updated S-Curve should be reviewed to determine actual progress recorded. Earned value analysis as discussed in RP 55R-09 should be performed on each update including Earned Schedule analysis to determine what variances occurred during the performance of the work and in what time periods these variances occurred.

3. Review available project documentation to determine how the S-Curve schedules actually progressed on a period by period basis.

4. Interview the project team and document what happened on the project, when it happened, who caused the event or issue, and what was the resulting impact. Independently verify through project documents.

Schedule Delay Analysis –

1. Apply MIP 3. – Observational / Dynamic / Contemporaneous As-Is to document the events or activities drove the project delay.

2. From the project documentation determine whether the contractor provided actual or constructive notice of any or all of these delays.

3. Determine the amount of delay caused by those events or actions/inactions of the owner, its representatives or events for which the owner was liable.

Delay Analysis – Linear Schedules

AACE defines the Linear Scheduling Method ("LSM") as a "Scheduling method that may be used on horizontal projects (pipelines, highways, etc.). Highly repetitive tasks make up the majority of the work. LSM schedules use 'velocity' diagrams representing each activity. LSM scheduling is not widely used."[15] Another author wrote that "The Linear Scheduling method has been developed to meet highway construction's demands for improved planning, scheduling and management. Linear Scheduling is a simple diagram representing the location and time at which a given crew will be performing a given operation. Graphic symbols are used to represent construction operations and visually communicate the construction plan and schedule."[16]

Methodology – It is recommended that the forensic scheduler employ the following methodology.

Baseline Schedule –

1. Assuming the baseline Linear Schedule was agreed to at the outset of the project, then this schedule is the starting point for forensic analysis.

[15] AACE Recommended Practice 10S-90, page 61.
[16] Parvin, Cordell M. and Dr. Michael C. Vorster, Linear Scheduling: Visual Project Planning & Management, P&W Publications, Inc., Richmond, VA, 1993.

2. Review all contract documents and drawings to determine the scope of work, the conditions of the contract and what physical, external and contractual constraints were applicable to the work.

3. Determine how these constraints would have or should have affected the plan for the work.

4. Review the contractor's bid to ascertain the activities or portions of the work bid and the cost and resources calculated for each activity or portion.

5. Determine whether the bid included the full scope of work or what portion(s) of the scope of work were left out, if any.

6. Document the work left out so that it may be included in the baseline schedule the forensic scheduler will construct for analytical purposes.

7. Make a judgment on whether there were sufficient resources to accomplish the full scope of work by the planned dates. Document all assumptions/bases and analyses thereof.

8. Interview the project team who prepared the baseline Linear Schedule to determine their understanding of what was required to complete work in accordance with the baseline schedule.

9. Determine whether and how long the contractor met the velocity diagrams.

10. If the contractor missed the initial as-planned velocity diagrams determine from these interviews why this occurred.

11. Apply the following constraints as discussed above, in order, as and if applicable –

a. Physical constraints
b. External constraints
c. Contract constraints
d. Resource constraints
e. Preferential logic

12. Revise the baseline Linear Schedule appropriately, if needed, to account for the applicable constraints.

13. Test the revised baseline Linear Schedule against the information gathered earlier and have the project team validate or correct the revised baseline.

Schedule Updates –

1. Projects using Linear Schedules typically have routine updates. Thus reasonably valid schedule updates should be available for the forensic scheduler to review.

2. Each updated schedule should be reviewed to determine actual progress recorded.

3. Review available project documentation to determine how the planned velocity diagrams actually progressed on a period by period basis.

4. Interview the project team and document what happened on the project, when it happened, who caused the event or issue, and what was the resulting impact. Independently verify through project documents.

Schedule Delay Analysis –

1. Apply MIP 3.3 – Observational / Dynamic / Contemporaneous As-Is to document what events or activities drove the project delay.

2. From the project documentation determine whether the contractor provided actual or constructive notice of any or all of these delays.

3. Determine the amount of delay caused by those events or actions/inactions of the owner, their representatives or events for which the owner was liable under the contract.

Delay Analysis – Critical Chain Schedules

The Critical Chain Method is defined in the following manner. "Differentiated from the critical path method, this project planning and management technique considers resources that constrain the work, not only the precedence of activities. The method determines the longest duration sequence of resource constrained activities through a project network – thus the shortest possible project duration – the critical chain. Algorithms for application of the method are both deterministic and stochastic. Time buffers are included to protect completion dates and provide adequate solutions, since contingency is removed from durations of individual activities."[17] Thus, the Critical Chain is "That set of tasks which determines the overall duration of a project, after considering resource capacity. It is typically regarded as the constraint or leverage point of a project."[18] The Critical Chain Method was developed by Dr. Eliyahu M. Goldratt in his books, Critical Chain[19] and The Goal[20]. It is suggested that the Forensic Scheduler review these texts to familiarize himself with the techniques before attempting any forensic analysis of these types of schedules.

The forensic scheduler working on a project using the Critical Chain Method may have less of a challenge than some of the earlier project situations discussed, assuming the schedules are good. A Critical Chain Method schedule is a time scaled, logic network

[17] AACE Recommended Practice 10S-90, page 30.
[18] Ibid, page 30.
[19] Goldratt, Eliyahu M., Critical Chain, North River Press, Great Barrington, MA, 1997.
[20] Goldratt, Eliyahu M., The Goal, North River Press, Great Barrington, MA, 1984.

but one driven by resource constraints rather than estimates of activity durations. Thus, the forensic scheduler will likely have an approved baseline and a series of schedule updates available for analytical purposes.

Methodology – It is recommended that the forensic scheduler employ the following methodology.

Baseline Schedule –

1. Since a Critical Chain Method schedule is a time scaled logic diagram, based on resource planning and allocation the forensic scheduler may have a thorough and well thought out baseline schedule to work with.

2. Assuming that the baseline schedule was agreed to at the outset of the project, then this schedule is the starting point for forensic scheduling.

3. Review all contract documents and drawings to determine the scope of work, the conditions of the contract and what physical, external and contractual constraints were applicable to the work.

4. Determine how these constraints would have or should have affected the work plan.

5. Review the contractor's bid to ascertain the activities or portions of the work bid and the cost and resources calculated for each activity or portion of the work.

6. Determine whether the bid included the full scope of work or what portion(s) of the scope of work were left out, if any.

7. Document the work left out so that it may be included in the baseline schedule the forensic scheduler will construct for analytical purposes.

8. Make a judgment on whether there were sufficient resources to accomplish the full scope of work. Document all assumptions/bases and analyses thereof.

9. Interview the project team who prepared the baseline Critical Chain schedule to determine its understanding of what was required to complete work in accordance with the baseline schedule.

10. Determine whether and how long the contractor met the planned schedule.

11. If the contractor missed the initial as-planned schedule determine from these interviews why this occurred.

12. As a Critical Chain schedule is already based on an analysis of resources constraints, apply the following constraints as discussed above, in order, as and if applicable –

    a. Physical constraints
    b. External constraints
    c. Contract constraints
    d. Preferential logic

13. Revise the baseline Critical Chain Schedule appropriately, if needed, to account for the applicable constraints.

14. Test the revised baseline Critical Chain Schedule against the information gathered earlier and have the project team validate or correct the revised baseline schedule.

Schedule Updates –

1. As projects using Critical Chain schedules typically have routine updates of the schedule, reasonably valid schedule updates should be available for the forensic scheduler to review.

2. Each updated schedule should be reviewed to determine actual progress recorded.

3. Review available project documentation to determine how the project actually progressed on a period by period basis.

4. Interview the project team and document what happened on the project, when it happened, who caused the event or issue, and what was the resulting impact. Independently verify through project documents.

Schedule Delay Analysis –

1. Apply MIP 3.3 – Observational / Dynamic / Contemporaneous As-Is to document the events or activities drove the project delay.

2. From the project documentation determine whether the contractor provided actual or constructive notice of any or all of these delays.

3. Determine the amount of delay caused by those events or actions/inactions of the owner, its representative or events for which the owner was liable.

Delay Analysis – Line of Balance Schedules

A Line of Balance ("LOB") schedule is defined as "A graphical display of scheduled units versus actual units over a given set of critical schedule control points on a particular day. The line of balance technique is oriented towards the control of production activities."[21] An LOB schedule is similar to a Linear Schedule and thus analysis of the baseline and schedule updates is the same.

Methodology – It is recommended that the forensic scheduler employ the following methodology.

[21] AACE Recommended Practice 10S-90, page 60.

Baseline Schedule –

1. Assuming that the baseline LOB Schedule was agreed to at the outset of the project, this schedule is the starting point for forensic scheduling.

2. Review all contract documents and drawings to determine the scope of work, the conditions of the contract and what physical, external and contractual constraints were applicable to the work.

3. Determine how these constraints would have or should have affected the work plan.

4. Review the contractor's bid to ascertain the activities or portions of the work bid and the cost and resources calculated for each activity or portion of the work.

5. Determine whether the bid included the full scope of work or what portion(s) of the scope of work were left out, if any.

6. Document the work left out so that it may be included in the baseline schedule the forensic scheduler will construct for analytical purposes.

7. Make a judgment on whether there were sufficient resources to accomplish the full scope of work for each LOB activity by the dates required. Document all assumptions/bases and analyses thereof.

8. Interview the project team who prepared the baseline LOB Schedule to determine their understanding of what was required to complete work in accordance with the baseline schedule.

9. Determine whether and how long the contractor met the LOB planned dates.

10. If the contractor missed the initial as-planned LOB dates determine from these interviews why this occurred.

11. Apply the following constraints as discussed above, in order, as and if applicable –

    a. Physical constraints
    b. External constraints
    c. Contract constraints
    d. Resource constraints
    e. Preferential logic

12. Revise the baseline LOB Schedule appropriately, if needed, to account for the applicable constraints.

13. Test the revised baseline LOB Schedule against the information gathered earlier and have the project team validate or correct the revised baseline schedule.

Schedule Updates –

1. Projects using LOB Schedules typically have routine updates. Therefore, reasonably valid schedule updates are likely to be available for the forensic scheduler to review.

2. Each updated schedule should be reviewed to determine actual progress recorded.

3. Review available project documentation to determine how the work actually progressed on a period by period basis.

4. Interview the project team and document what happened on the project, when it happened, who caused the event or issue, and what was the resulting impact. Independently verify through project documents.

Schedule Delay Analysis –

1. Apply MIP 3.3 – Observational / Dynamic / Contemporaneous As-Is to document the events or activities drove the project delay.

2. From the project documentation determine whether the contractor provided actual or constructive notice of any or all of these delays.

3. Determine the amount of delay caused by those events or actions/inactions of the owner, its representative or events for which the owner assumed liability under the contract.

Delay Analysis – Pull Planning/Location Based Schedules

Pull Planning or Location Based Scheduling[22] has been described as "the marriage of CPM and Lean Construction".[23] Pull Planning has been described by one advocate of this scheduling system as

> "…a tool that has been adapted to lean projects from the Toyota Production System and evolved from the research of Greg Howell and Glenn Ballard of the Lean Construction Institute. In general, it starts planning with the proposed finished product (the completed project or some series of milestones) as goals on the right end of the schedule and pulls backward (left) to discover and incorporate all the steps that get to the finished product. Instead of 'pushing' a project through production,

[22] Kenley, Russell and Olli Seppanen, Location-Based Management for Construction Planning, Scheduling and Control, Spon Press, London, 2010.
[23] Huber, Bob and Paul Reiser, "The Marriage of CPM and Lean Construction", Proceedings, 11th Annual Conference, International Group for Lean Construction, Blacksburg, VA, 2003.

pull planning establishes what is necessary to pull it towards completion."[24]

In a private telephone interview with the author of the above quotation during the preparation of this paper the question was posed concerning how one performs a forensic schedule analysis on a project using Pull Planning? The response was that Pull Planning by itself cannot be used for schedule delay analysis. However, the author went on to explain that Pull Planning is only a part of what he termed "Three Wall Scheduling" which is comprised of the following –

CPM Scheduling – Which tells the project team what has to be done and when.

Line of Balance Scheduling – This tells the project team where things have to be done.

Pull Planning – Which tells the project team how things have to be done (that is, what resources are needed to accomplish the above – labor, materials and construction equipment).

The author concluded that the value of the weekly Pull Planning charts in the context of forensic scheduling is that these weekly (or more frequent at times) documents are very detailed daily reports (agreed to by all parties on the project) but with a great deal more detailed information and credibility than typical daily reports.

Since Pull Planning always has an underlying CPM schedule the analysis of the baseline schedule and all schedule updates and the forensic schedule analysis can rest upon the Pull Planning charts as documentation when the forensic scheduler is employing any of the MIP's from RP 29R-03.

[24] A discussion of Pull Planning on the ReAlignment Group, Ltd. Website by Dan Fauchier, President. www.projectrealign.com/pull-planning.php.

Delay Analysis – Rolling Wave Scheduling

Rolling Wave Planning has been defined as a "cost and schedule planning method where details are developed for near term and general or summary allocations are made for out periods. Detail is developed for the out periods as information becomes available to do so."[25] Rolling Wave scheduling is more common in Engineer-Procure-Construct ("EPC") or Design Build ("D/B") projects than in the classic design/bid/build project. This is because at the outset of a typical EPC or D/B project there is less information available to prepare and issue a fully developed schedule in comparison to design-bid-build projects for which design is fully developed at the project outset. Rolling Wave schedules may be either CPM schedules or detailed Bar Charts. In the situation where a project was constructed using a Rolling Wave schedule based on CPM scheduling the forensic scheduler should apply RP 29R-03. If the Rolling Wave schedule was prepared and maintained as a Bar Chart the forensic scheduler can apply the procedure outlined previously for Bar Chart/Gantt Chart Schedules.

Conclusion

It is well known that many projects proceed and complete without any CPM schedules. Industry studies indicate that many projects complete later than planned. Therefore, it is safe to conclude that time extension requests, delay claims and assertions of liquidated damages are common on these projects. When this happens, forensic schedulers need to perform schedule delay analysis. At the present time, there is no guidance for performing forensic schedule analysis on non-CPM schedules. Such guidance is needed. The intent of this paper is to outline procedures for performing forensic schedule analysis on non-CPM scheduled projects. The authors believe that this paper can serve as the basis or starting point for Chapter 2 of RP 29R-03 which should address, in more detail, how to perform schedule delay analysis on those projects with no CPM schedule.

[25] AACE Recommended Practice 10S-90, page 94.