Out-of-Sequence Progress

Part 1: Reporting

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Introduction

This is a second technical paper [1] exploring the interesting complexities involved when a scheduler using Critical Path Method (CPM) applies status to an in-progress CPM schedule. Sometimes, the events being modeled do not proceed in reality as were planned. The manner that CPM software handles the results of that unplanned progress (or lack thereof) is a large factor in their effectiveness in modeling real-world situations.

Out-of-sequence progress is very common in construction projects and it is very important to be aware of this condition. Out-of-sequence work can happen despite physical constraints to the contrary. For example, utility work under a foundation should be installed before the foundation but if the utility is delayed, the utility work could proceed afterward, albeit with reduced overall productivity. This situation and work-around may or may not affect the schedule's critical path but there is usually a loss of productivity component involved.

Reviewing a schedule update for out-of-sequence performance is good project management practice. The schedule should be reviewed to see if the logic for the remaining work is still valid of if actual performance will continue to be performed out of sequence. [2]

Industry Surveys:

Out-of-sequence progress appears in virtually all schedule updates. [4] Just how often out-of-sequence events occur during construction is probably not well known. Out-of-sequence logic is not something that can be statistically modeled in a laboratory setting. A study of how frequently such conditions actually occur requires real-world observations. To this end, two industry surveys have been conducted using real-world schedules that were updated using actual, observed progress.

How Common is Out-Of-Sequence Logic?

Thirty-one different real-world construction schedules were randomly selected to investigate how common out-of-sequence progress was in the industry. These schedules represented a diverse set of industries over a wide range of schedule sizes. An independent analysis software [5] was used to report on out-of-sequence events in these schedules. Table 1 below details the findings:

Schedule Name	Started Acts	Ave Early (WD)	Total Events	Total Acts	% Acts OOS
0009	123	5	25	23	19%
0354	10109	66	4844	4122	41%
0575	161	33	41	35	22%
0755	1380	58	934	763	55%
0813	745	163	454	351	47%
2827	4594	162	2005	1392	30%
1027	181	106	150	102	56%
6800	353	9	55	54	15%
A031	494	50	186	140	28%
B114	2726	101	477	435	16%
BT21	714	179	394	317	44%
C000	65	29	14	10	15%
CHOP	6451	77	4607	3124	48%
COUR	4552	48	1364	1098	24%
CPWT	1004	123	520	392	39%
EKR2	35	15	25	23	66%
HQNE	130	13	69	66	51%
HQNG	3237	25	12225	945	29%
HQNS	844	77	179	163	19%
MULE	4466	20	1175	924	21%
OMVM	409	96	299	239	58%
PARK	117	12	18	18	15%
PL03	74	58	45	37	50%
PLPB	680	168	398	200	29%
POLB	218	28	179	146	67%
RT57	271	32	124	105	39%
SA11	797	63	480	409	51%
UP11	520	31	293	251	48%
VERY	12295	81	4271	3021	25%
WTPR	530	197	249	181	34%
X042	1037	35	244	214	21%
Average	1913	70	1172	623	36%
Mean	680	58	293	214	34%

Table 1, Survey of Out-of-Sequence Events

The findings are represented as the percentage of out-of-sequence activities to the number of activities with actual starts. The median of the percentage of out-of-sequence activities was 34%, indicating a fairly even distribution of outcomes to the average of 36%. The out-of-sequence activities began an average of 70 workdays early, so this was not a case of negligible results. Based on this survey, one may conclude that out-of-sequence events are quite common and widespread through most schedules. Such events occur in most every schedule and roughly one third of the activities actually start before the schedule logic would allow.

The severity of these results seem to be contrary to expectations. Many CPM experts currently believe that out-of-sequence events occur in far lower percentages than are indicated in the study. One potential reason for this disconnect is the failure to report the condition rather than the actual occurrences. With this thought in mind, an open survey of the reporting of out-of-sequence conditions was undertaken across the CPM software industry.

How Well do Software Brands Report Out-of-Sequence Progress?

Please note that this industry survey compares how thoroughly and accurately various CPM software reports out-of-sequence progress. It is not intended to be a comprehensive review of currently available CPM scheduling software. While all major CPM software companies were contacted in the researching of this paper, not all are mentioned herein. Some CPM software companies claim to eliminate out-of-sequence events from ever occurring (except from schedules imported from other software systems). Others have built-in features to automatically break-up activities and add relationships to correct out-of-sequence events[14]. Still others do not report this condition at all.

Several companies who develop CPM software were invited to test three, randomly selected real-world CPM schedules to see how well they reported instances of out-of-sequence progress. The results were quite unexpected; no software reports the same totals. Table 2 below lists the totals from the companies who responded, [11, 12, 13, 14,15]

		Schedule EKR2		Schedule PL03		Schedule RT57	
Manufacturer	Software Name	Total Events	Total Acts	Total Events	Total Acts	Total Events	Total Acts
PMA Consultants®	NetPoint©	31[A]	28	39	35	76	66
Ron Winter Consulting LLC®	Schedule Analyzer Enterprise Forensic©	25	23	45	37	124	105
Synchro Software Ltd®	Synchro Pro and Synchro Scheduler©	*25*	23	44	36	*119*	103
Spider Project Team®	Spider Project©	25	23	43	35	116	99
Primavera Inc.®	Primavera Project Planner©	5	5	9	9	14	12
Deltek®	Open Plan©	*(n/a)*	24[B]	*(n/a)*	19	*(n/a)*	12
Electrosoft®	PowerProject©	*(n/a)*	4	*(n/a)*	34	*(n/a)*	32
Oracle®	P6 Professional©	*(n/a)*	0	*(n/a)*	9	*(n/a)*	*15*

Table 2, Survey of Software Reporting Out-of-Sequence

There may be several different reasons for these reporting discrepancies between competing CPM software systems. Obvious issues include:

- Different definitions of out-of-sequence (for example, some software apparently does not report the condition if the predecessor has an actual finish date assigned),
- Different goals (such as automatic prevention),
- Different CPM calculation methods,
- Imperfect conversions of CPM backup file formats,
- Accuracy issues involving converting schedules from minutes to hours or days.

Note A: Research indicates that the correct numbers for Schedule EKR2 is 25 events and 23 activities. The high numbers from NetPoint were verified as false positives in over-reporting of Start-to-Start relationships. The lag calendar used was unusual and there probably was a conversion problem from the P6 XER file to the NetPoint native format.

Note B: The Open Plan extra activity for Schedule ERK2 was also due to an issue of a false positive reporting on an activity. In this case, the activity incorrectly identified as out-of-sequence had been statused with an actual start date later than the data date (i.e. in the future). As the predecessor was not complete in that update, this was noted as an out-of-sequence start.

It is also possible that not enough emphasis has been placed on this complex subject. CPM theory mixed with real-world status creates combinations that are difficult to predict.

Out-of-Sequence Properties

Events versus Activities

The term, Total Events in the above tables refer to the number of logical relationships that were invalidated by actual starts and the term Total Acts counts the number of activities that started early, out-of-sequence. A single activity may have started before it was logically allowed ahead of several predecessor relationships. The entries of "(n/a)" in Table 2 above, indicates that this information was not provided to the author and the feature may not be available in that software.

Just reporting which activities started before logic would allow does not sufficiently describe the condition. One activity starting earlier than logic would allow based upon multiple different logical relationships surely must be a larger departure from plan than if a single relationship was violated. Figure 1 below demonstrates this condition.

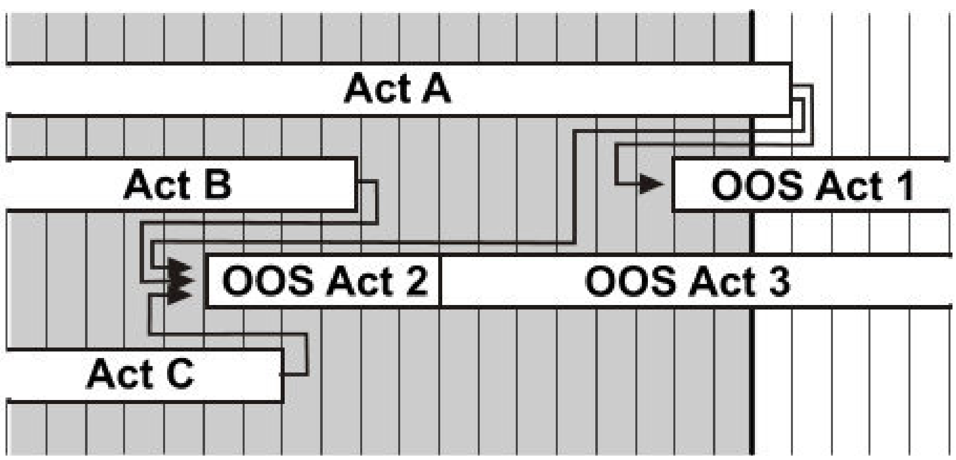

Figure 1, Out-of-Sequence Events versus Activities

In the example above, OOS Act 1 has started 2 days early, before Act A has been completed. OOS Act 2 also has started early, but has experienced events from three different predecessors; from Act A, Act B, and Act C. Clearly, OOS Act 2 has more significant out-of-sequence issues than OOS Act 1 even though they would appear the same if only the number out-of-sequence activities were reported.

The Degree of the Early Start

The amount of time that an out-of-sequence activity began before the schedule logic would allow also matters when classifying such events. It is a common construction practice to begin follow-on work a day or two prior to its scheduled start. This is modeled using OOS Act 1 in the figure above. This does not necessarily result in lower productivity for the follow-on work. Many times the logic is used as a short-cut to indicate that the follow-on work cannot be completed until the preceding work is complete.

Beginning work many days earlier than logically allowed such as shown with OOS Act 2 is more likely to cause productivity problems and other conditions common with out-of-sequence work. The fact that OOS Act 2 was also completed before Act A was finished further emphasizes this condition as problematic.

When is Out-of-Sequence not Out-of-Sequence?

A deeper out-of-sequence condition is demonstrated using OOS Act 3. It began as logic allows, immediately following the logical completion of OOS Act 2, so it would appear to not be out-of-sequence. An expanded view of the actual status compared with original logic shows that OOS Act 3 began prior to the finish of Act A and is thus logically out-of-sequence with Act A. No commercial software currently reports this condition as an out-of-sequence start.

Current versus Completed Activities

Some CPM software appear to only report on out-of-sequence conditions for “current activities”. This distinction is not discussed in their documentation. If true, one might conclude that a collection of the various updates might generate a complete list of out-of-sequence activities. This conclusion is flawed as some such conditions will never be reported regardless of which schedule updates are considered. Figure 2 below demonstrates this issue.

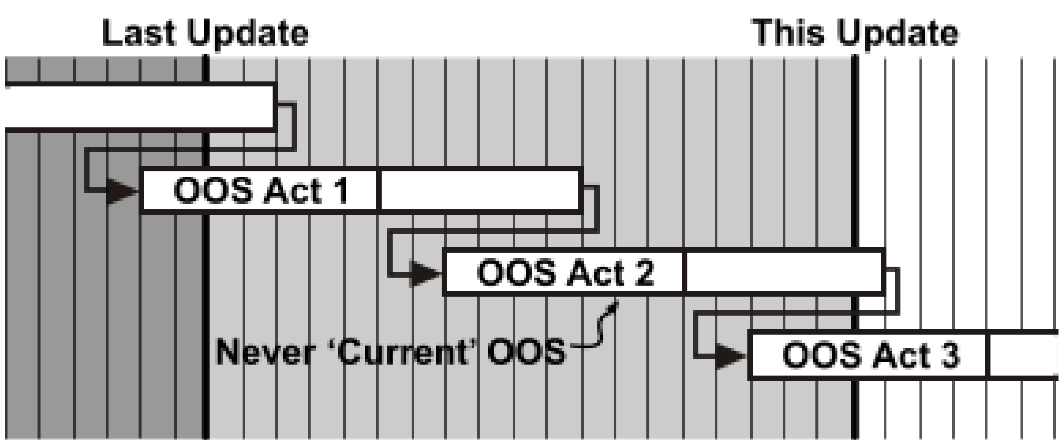

Figure 2, Underreporting Non-Active Out-of-Sequence Activities

Out-of-sequence Activity 1 is reported as active in last update and out-of-sequence Activity 3 is reported as active in this update. The problem with this active-only reporting method is that activity 2 is never reported as out-of-sequence, as it was never active at the time of a data date.

Type of Logic Involved

Some of the software products fail to catch out-of-sequence conditions in the case of activities with a Finish-to-Finish constraint. This is partly due to a matter of technical definition. One popular definition identifies the actual start as occurring earlier than logic allowed. The fact that the finish logical constraint was not out of sequence is not relevant to this definition. The other definition only looks at whether any particular logic was violated.

Figure 3 below demonstrates this technical issue. In Figure 3, planned Activity 1 is scheduled to start late so that it will satisfy the Finish-to-Finish constraint from Activity 2.

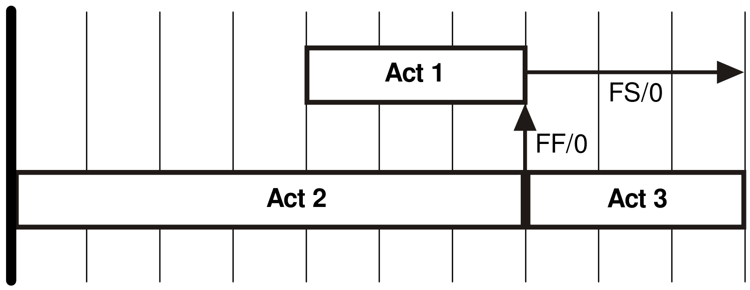

Figure 3, Planned Finish-to-Finish Relationship

Figure 4 shows that, when statused, Activity 1 actually began 3 days early, or earlier than the finish constraint would allow.

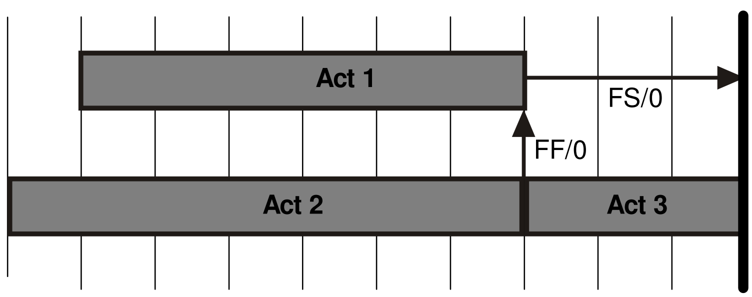

Figure 4, As-Built Finish-to-Finish Relationship

The earlier definition of out-of-sequence only concerned itself with whether the activity started before logic allowed. In this second case, an out-of-sequence condition occurred because the activity actually started too early to allow for the activity to continue to progress uninterrupted to meet the Finish-to-Finish constraint. However, the second definition argues that if the succeeding activity finished on or later than preceding activity, that the schedule logic has not been violated. This issue is based on a technical definition of what is out-of-sequence progress.

Other Issues

The severity, or degree of out-of-sequence progress may vary widely in a schedule. The condition may be minimal, arising from an actual lag between activities being less than scheduled. It may be a simple matter of the sequence of several resource-constrained activities[3] being re-arranged for convenience. On the other hand, it may indicate the point in a schedule where disruption or even critical project delays have occurred. Understanding the reason behind an early start is the key to classifying out-of-sequence events.

Categorizing Out-of-Sequence Work

The key to understanding out-of-sequence conditions is to classify the type of issues involved and to categorize these types onto like groups.

Types of Out-of-Sequence Work

Some out-of-sequence events are benign and do not cause disruption. Others are not. Out-of-sequence progress may be categorized into four major categories for out-of-sequence work, [4]

1. **Scheduler's 'Short-Cut'**: Instances where a simple linear execution of the work is not possible are simpler to schedule it as if they were linear as long as the differences are minor and the work does not represent a locational overlap. The succeeding work may begin early as long as it does not interfere or overtake the preceding work.

2. **Rearrangement of Repetitive Work**: Long work plans are often broken into pieces to better manage and monitor the work. If the area to be worked next is not available, many times the contractor will shift their resources to simply work in a different area. One industry observer distinguishes this as "Out-of-Logic" work as opposed to Out-of-Sequence.[21]

3. **In Response to an Unexpected Event**. Sometimes work that would have been more efficiently performed earlier is delayed for physical reasons, causing follow-on work to begin early as resources or crews are shifted to another area. This is sometimes due to a faulty plan and other times due to an unpredicted event.

4. **In Response to an Earlier Delay**: Work that would more efficiently be performed later may be accomplished sooner in order to regain lost time from previous (delayed) work on the critical path. This can reflect either a "doubling up" of resources if it is the same trade and crew(s), or it could be a different trade/crew starting earlier than planned. In both instances there is an overlap of activities that had not been scheduled concurrently in the baseline.

Out-of-Sequence Technical Categories

It is possible to categorize out-of-sequence events into discrete issues. [6][7] The reported problem statements and their meanings, based on relationship type, are as follows:

1. **Activity started, predecessor has not finished**. This is used for Finish-to-Start (FS) and Finish-to-Finish (FF) relationships, with or without a lag, where the lag factor was not an issue.
2. **Activity started before its predecessor's lag would allow**. This is used for FS and Start-to-Start (SS) relationships with lag where the lag factor, when reduced to zero, would not have also caused the successor activity to have started early.
3. **Activity started too early to allow it to finish on time**. Activity started too early to allow it to finish on or after its predecessor's finish. This is used for FF relationships without a lag.
4. **Activity with lag started too early to allow it to finish on time**. Activity started too early to allow it to finish after expiration of its predecessor's lag. This is used for FF relationships with a lag factor. This would not be reported as out-of-sequence if the lag factor were zero.
5. **Activity started, predecessor has not started**. The successor activity started but the predecessor has not started. This is used for SS relationships with or without a lag.
6. **Activity started before its predecessor's lag would allow**. The activity started before its predecessor's lag would allow. This is used for FS and SS relationships with lag factor that would not have been out-of-sequence if the lag were zero.
7. **Activity started too early to allow the predecessor to finish on time**. The activity started too early to allow it to finish on or after its predecessor's start. This is reported for Start-to-Finish (SF) relationships without a lag.
8. **Activity started too early to allow the lag to finish on time**. The activity started too early to allow it to finish after expiration of its predecessor's lag. This is used for SF relationships with lag that would not have been reported as out-of-sequence if the lag were zero.
9. **Activity finished, predecessor not started**. This would further differentiate between disruptions that skip to the next activity after a disruption occurs from those that just skip over the entire activity altogether.
10. **Activity has that had an Actual Finish without an Actual Start date**. This condition was quite common with CPM software where one could just click on an Actual Start checkbox without supplying an Actual Start date.
11. **Problem with Lag**. If a lag exists with an out-of-sequence situation, it is beneficial to consider whether the out-of-sequence condition would still exist if the lag factor was changed to zero. Perhaps the issue is with the lag and not the logical relationship.

In addition to the primary out of-sequence events described above, there are additional problems that can occur,

A. **Activity finished, predecessor has not finished**. The successor activity has not only started early, but it has also finished before the predecessor activity finished. This is a complete breaching of the FS relationship and indicates that the logical relationship described was a ”soft” preferential relationship.

B. **Activity finished before its predecessor's lag**. The activity finished before its predecessor's lag would allow. This is used for FF relationships with a lag that would not have been finished out-of-sequence if the lag were zero.

These additional problems involve the completion of the out-of-sequence activity rather than its start. It is a much more severe condition to finish an activity out-of-sequence that it is to start it out-of-sequence. This may indicate that the condition only reflected a ”soft” preferential or resource-driven choice and not a ”hard” physical one.

Special Case: Linear Scheduling

Location Based Construction Scheduling Software (LBMS) has four special cases for out-of-sequence work. [8] These cases include:

1. **Subcontractors working simultaneously in multiple locations** instead of working in sequence. A central tenant in LBMS projects is that trades cannot ”collide” or work in the same location. Having a single trade spread out over multiple locations at the same time denies other trades access to that location.

2. **Workers not completing 100% of the work** before moving on. Leaving a small amount of work in several locations requires that the trade crews return and complete the job at a later date. What with material logistics, start-up costs, and learning curve considerations, this is inefficient and time consuming. Often this type of catch-up work is ignored until it is too late due to lack of management oversight.

3. **Crowding** that results from starting with too many workers at the same time. This type of production control is inefficient and prone to disruption. Crews using different laydown areas for the same material tend to become unbalanced, causing a lot of search time to locate material.

4. **Overlapping work areas**. Even if two different tasks are not technically dependent, having two or more crews share the same area has been shown to cause inefficiencies. Sometimes this is caused by beginning a follow-on task early while the predecessor work is still on-going. “It has been empirically shown that overlapping work can result in 30%+ productivity decreases (for both the predecessor and the successor).”[8] Studies show that it is more efficient to wait until the successor work can proceed to 100% without hindrance from predecessor work.

Definition of Out-of-Sequence Progress

Part of the problem with different results between CPM software platforms may be different definitions of what is an out-of-sequence condition. AACE International defines out-of-sequence progress as,

> "OUT-OF-SEQUENCE PROGRESS: Progress that has been reported even though activities that have been deemed predecessors in project logic have not been completed." [9]

The Oracle Online P6 Professional Help defines out-of-sequence progress as,

> Out-of-sequence progress: "Work completed for an activity before it is scheduled to occur. In a conventional relationship, an activity that starts before its predecessor completes shows out-of-sequence progress."[10]

Neither of these definitions offer technical specifications on how to detect such occurrences. The technical definition of out-of-sequence work is surprisingly difficult to define. First off, the definition should include CPM logic as a required qualifier. Out of planned sequence is different from out of <u>logical</u> sequence. Resource allocations and uneven progress can easily cause unrelated events to occur in a different chronological order. The true definition of out-of-sequence progress must include an analysis of logic within the definition.

There are other technical issues to consider. This definition should include milestones (even though they have limited logical relationships) and exclude hammock activities such as Level of Effort and WBS Summary activities.

There are two similar but different technical definitions for out-of-sequence progress as used in the CPM software industry. The first definition uses actual start as the trigger for out-of-sequence occurrences, [4,7]

> Out-of-sequence Progress occurs when an activity is statused as actually starting earlier than the schedule says it is logically allowed to start (or actual finish for a finish milestone).

Other CPM software documentation does not use the actual start date as the definition of an out-of-sequence event. [10, 11, 12, 13, 14] One can consider this out-of-sequence analysis as looking for what various CPM software companies call, "Busted Links"[11], "Unscheduled Links"[12], "Unsatisfied Logic" [13], or "Breached Gaps"[14]. This paper will describe this type of measurement as, "broken links".

> "Broken Links" occur when any actual date (whether actual start or actual finish) is statused as occurring earlier than predecessor status and logic would allow.

Many CPM software companies differentiate between out-of-sequence activities that are complete and those that are not complete. They label the activities that are still underway as out-of-sequence activities and use a variation of the term, "broken links" to report all other out-of-sequence activities.

There should be a technical definition that determines whether an out-of-sequence condition is ”active”. Is it the predecessor, or the successor, or both, or just the logical relationship that is out-of-sequence? There does not appear to be published documentation describing this.

We propose a straightforward definition of an active out-of-sequence activity: A predecessor to an activity that has started out-of-sequence and that has not had an actual finish established. An active predecessor to an out-of-sequence activity would have an expected finish date later than the current data date. Likewise, a report on last month’s out-of-sequence activities would include those whose predecessor has an early or actual finish later than the data date of the month prior to the current data date.

Using this definition of active out-of-sequence events, we surmise that some of the CPM software were reporting only the “active” out-of-sequence instead of all the out-of-sequence events. This distinction is not documented in their literature, but it makes sense when we revisit the comparisons using this criteria. Table 3 below lists the totals for the three test schedules considering only active out-of-sequence events as reported by eForensic Out-of-Sequence.[5]

		Schedule EKR2		Schedule PL03		Schedule RT57	
Manufacturer	Software Name	Total Events	Total Acts	Total Events	Total Acts	Total Events	Total Acts
Ron Winter Consulting LLCⓇ	Schedule Analyzer Enterprise Forensic©	9	8	10	10	22	15
Primavera Inc.Ⓡ	Primavera Project Planner©	5	5	9	9	14	12
OracleⓇ	P6 Professional©	*(n/a)*	0	*(n/a)*	9	*(n/a)*	*15*

Table 3, Survey of Software Reporting Active Out-of-Sequence Events

While still incomplete, the results of this test confirm that Oracle/Primavera products were most-likely reporting on only active out-of-sequence events.

Does Reporting of Out-of-Sequence Matter?

Some analysts believe that out of planned sequence progress has very little impact on forensic analysis. This is believed because it does not impact the critical path due to float considerations.[4] Forensic analysis looks at the late calculated dates and not the early. Still, each of the analysis methodologies are impacted by the degree of discretionary logic.

Others are not so sanguine about the issue of out-of-sequence progress. Issues involved with out-of-sequence progress include:

- An error in statusing of earlier work,
- The progress was not as predicted,
- May be caused by delays or disruption of the work,
- Indicates possible lack of planning or field management following the schedule,
- May indicate low productivity, and
- Negates ability to use this activity for Measured Mile productivity calculations.

The first thing an analyst should do when investigating out-of-sequence progress is to confirm the correct statusing of earlier work causing the current condition. Frequently, reports of out-of-sequence work are merely the result of failing to properly status preceding work as complete. This is commonly manifests itself as a long-forgotten procurement item.

Tracking out-of-sequence events can provide a useful metric for measuring project health. Along with other metrics such as bottleneck identification, risk hot spots, task density, and duration validation, tracking and reporting out-of-sequence events can help to maintain a quality, reliable schedule.[17]

There is little doubt that out-of-sequence progress can be disruptive to a project. Disruption causes inefficiencies and additional expenses. In some cases, the causes for having to work out-of-sequence may be compensable. [5]

Recovery from disruptions includes methods such as compression of planned durations, work performed out-of-sequence, work performed in parallel that was planned to be performed in sequence, stacking of trades, as well as other acceleration issues. [16]

There are several reasons to track disruptions in a project. First the disruption might have delayed the project. Not all disruptions are project disruptions that extend project completion but the ones that do may result in additional contractual expenses. Secondly, in many cases, disruptions cause inefficiencies and additional production costs over the cost of performing the work as planned. These disruption costs may be small and inconsequential, or they may be the basis for a request for compensation.

Analysis of out-of-sequence conditions can also work against a disruption claim. Before the contractor can prove a disruption claim, one has to first show that prior to the disruption that the schedule was under control and proceeding as planned. It is more difficult to prove the assertion that ”but for the disruption we would have been on-time” if the project was already chaotic before the disruption occurred. Various methods for demonstrating an out-of-control schedule include:

- If the schedule was not used,
- If work proceeded out-of-sequence,
- If progress was not linear,
- If work was frequently interrupted,

- If status was not taken on a regular basis.

All or some of the above listed conditions occurring would suggest that the schedule purporting to describe the planned work was not under control. It is wise to make sure that the schedule was considered under control before possible situations where a third-party causes disruption.

Additionally, one needs a well-functioning work schedule with similar periods of non-disrupted work in order to provide a basis for a Measured Mile evaluation. Selecting work that was proceeding out of the planned sequence is a poor choice for comparing progress to later-claimed disruptive work.

What to Do About Out-of-Sequence Activities

What can or should a scheduler do when faced with a schedule containing activities performed out of logical sequence? After confirming the actual status and acknowledging the existence of out-of-sequence work, the logic should be questioned.

When identifying the out-of-sequence activity, one needs to revisit the original assumptions used to create the plan. Does changing the order of execution introduce more risk into the plan? Will the contractor be assuming more risk in an effort to work around a problem that was possibly caused by another party? [17] If so, then might that increased risk be compensable?

If a schedule specification says that the contractor must submit a schedule update that reflects last period's progress, does this mean that the logic (as well as activity progress) should be updated to reflect how the project was built? If so, then the schedule logic must be updated to reflect any out-of-sequence progress.

In acknowledging that out-of-sequence work commonly occurs, the U.S. Government Accountability Office (GAO) [18] recommends either (1) revising the logic or (2) counting on the CPM software to accommodate the issue. Revising the logic is the preferred method and should be performed on the next month's schedule update. This can lead to a cycle of "continually re-baselining" the project that makes tracking actual progress inaccurate.

The alternative to monthly revisions to logic is to depend upon software settings to compensate. The GAO directive highlight's the Oracle P6's Retained Logic CPM setting to correct the minor discrepancies. This calculation procedure is fairly accurate at maintaining a proper schedule completion forecast without making any adjustments to the schedule's original logic. [4] It does fail to automatically re-sequence the work plan in favor of maintaining the correct project completion forecast. This second method is problematic if the actual logic sequence is substantially different than what was planned.

The Retained Logic CPM calculation setting frequently fails to correctly schedule the current work involved in out-of-sequence progress as it assumes that the work started out-of-sequence will be immediately suspended until the remaining predecessor work has been completed. Even though this assumption may not be correct, the overall time to complete the combined, aggregate work is accounted for.

Most out-of-sequence logic conditions can be resolved by either deleting the logic, changing the logic, or doing nothing. There are instances where it cannot or more importantly, where it should not be revised. Whenever a logic change is made, the condition and the reason for the resulting change should be communicated to all parties involved. The deviation from the current baseline plan and any schedule revisions performed to correct this should be noted in the monthly schedule narrative. It is important to caution that if the baseline plan is repeatedly revised over several update periods, then it is reasonable to consider whether a re-baselining plan is needed. [19]

Another idea has been proposed to ”automatically” adjust for some types of out-of-sequence progress [7]. This is performed by replacing any early starting activity's Finish-to-Start relationship with a Finish-to-Finish one instead. This would allow the logic to still constrain the completion of the out-of-sequence activity while still allowing the early start and reported progress to proceed concurrently. This proposal does not cover all situations that can arise, however.

There are situations where no adjustment for out-of-sequence activities should be made. One such situation involves the project close-out period. At this time, it is typical for many activities to be performed out-of-sequence to meet an aggressive deadline. [20] It is typical to abandon the CPM schedule in favor of completion lists as the work proceeds from finishes to punchlist work, even on a normal, non-accelerated project. Near the end of a project, it may be said that all activities are critical.

Out-of-Sequence Progress

Part 2: Analyzing

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Introduction

This is a third technical paper [22,23] exploring the complexities derived from using Critical Path Method (CPM) to apply status to an in-progress schedule. Sometimes, the events being modeled do not proceed in reality as planned. It is important to report and then analyze such occurrences. Industry surveys suggest that out-of-sequence early starts occurs approximately one-third of the time on nearly every major construction project. Analyzing the out-of-sequence events and their accumulative impact on the project and the costs of construction should be considered for all projects.

The planned schedule is an excellent method for documenting the contractor's intended workplan. [24] Unhindered, it should theoretically guide the contractor toward construction of the objective in the least-cost method considering the time constraints and planned resource usage. Any changes to this workplan should be analyzed for additional risks and costs. Any changes caused by other parties should be assessed for their contributions to increases in risk and cost. Contractually, some or all of these increases may be compensable.

Why Analyze Out-of-Sequence Events?

Schedule analysis begins with answering the question of whether the original project plan was reasonable and capable of implementation. [25] Analysis of out-of-Sequence events may answer several important questions such as,

- How good was the schedule? A CPM schedule that that is not logic driven limits the types of analyses that can be performed. [28] For example, the traditional As-Planned/As-Built Traditional Daily Delay Measure (APAB/DDM) forensic analysis procedures will not provide an accurate evaluation of delays when there is substantial-out-of-sequence work. [26]
- Did the logic reflect how the project was actually built? Analyzing a schedule that was never consulted nor followed may very well be a waste of time.
- What percent of the activities were started out-of-sequence? If the ratio is high, then this suggests that the published schedule was not being followed in the field.
- What was the average time that activities were started early? The higher the figure, the less likely the claim that the schedule represented the workplan.

Hidden Change Orders

Change Orders[27] are typically issued to reconcile the current project changes. The logic, durations, and even the work to be performed may be adjusted that this time. This contractual adjustment should also be accompanied with a cost adjustment so that the project can re-start anew without contractual issues left unresolved. This reconciliation effort can inadvertently be overlooked if 'minor' delays and disruptions are ignored.

Most projects require periodic status updates to monitor progress and ensure the correct understanding of what work is currently critical and the projected project completion. Many scheduling experts recommend updating the logic every schedule update to reflect how the project is currently proceeding. This procure should be questioned as the update process may make proving cases of disruption more difficult.

Sometimes contractors 'hurt' their ability to present their disruption or delay issues by adapting their schedules to meet and recover from these events without considering the possibility of assuming additional costs and risks in the process. This can be thought of as Hidden Change Orders. Updates to the schedule that include logic changes in response to out-of-sequence occurrences may hide the effects of the disruption from analysis.

One possible analytical 'solution' to this problem is to create a 'Half-Step Schedule'. [28,29] The process involves transferring the update's schedule's As-Built dates and status to a copy of the earlier schedule without the logic changes. The analyst would then use this statused, As-Planned schedule to look for out-of-sequence conditions for further study. This method will remove any adjustments made to schedule updates that would otherwise hide or reduce the reported effects.

Trace the Out-of-Sequence Logic

If the analyst is using Oracle Primavera P6© software and only has the schedule log of currently out-of-sequence activities to reference, then the first step is to identify the still-active predecessor activity that is causing the reported activity to be out-of-sequence. This is not always the immediate predecessor of the reported out-of-sequence activity.

The easiest method of tracing the predecessor activity in question is to add two new columns to the Predecessor Tab on the Activity View Window in P6.[30] These new columns should be the predecessor's Early Start and Early Finish dates.

If the relationship involves the predecessor activity's finish (Finish-to-Start or Finish-to-Finish relationships) then look through the Early Finish dates in the Predecessor Tab for any that are later than the effective[1] data date. This indicates that the predecessor is a part of the out-of-sequence logic chain. Multiple predecessors with Early Finish dates later than the data date indicate that there are multiple predecessor events causing this one activity to be out-of-sequence. Perform this same search technique using the Early Start date instead of the Early Finish if the predecessor activity's relationship involves its start date (Start-to-Start or Start-to-Finish relationships).

[1] The effective data date is the first available working moment after the current (set) data date for that activity's calendar. Usually the effective data date is the same as the current data date. The two can be different if the current data date was set to be a non-working period.

On the Predecessor Tab, click on the identified predecessor activity in the out-of-sequence chain and then click on the 'Go To' button below it to have P6 'jump' to display the predecessor's activity information. This activity may or may not be complete. If it is not complete, then this is the driving predecessor.

If the activity is complete, then the analyst must continue searching for the inevitable uncompleted predecessor by repeating the process of jumping to the next predecessor of that activity with an early date later than the effective data date. Figure 5 below is an example of such an arrangement showing how to trace an out-of-sequence occurrence.

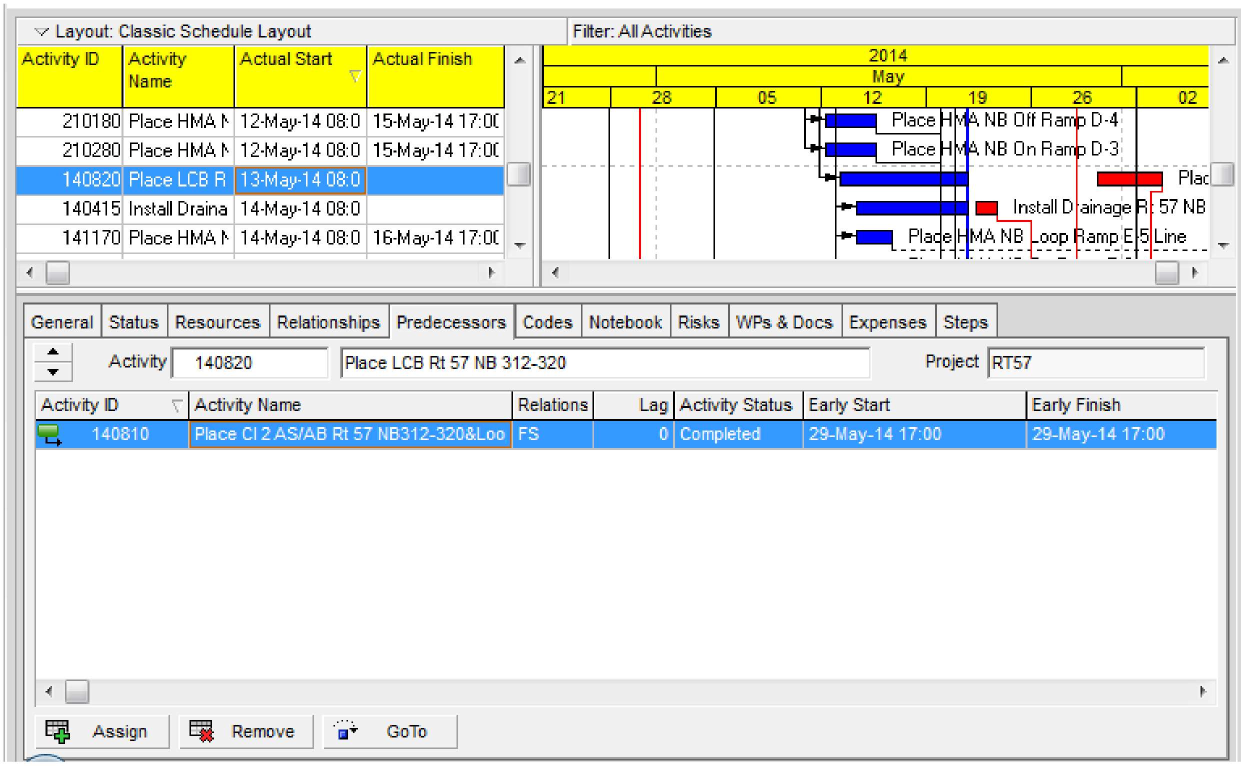

Figure 5, Tracing Out-of-Sequence using P6

Highlighted Activity 140820 has an actual start and a large gap of more than a week before it can resume progress after the data date (shown as a blue vertical line). This activity does not show up on any out-of-sequence report. We call this an Indirect Out-of-Sequence activity.

We note that only one predecessor relationship is listed with an Early Finish later then the 21MAY14 20:00 data date. Had there been other predecessors, we would have clicked on the predecessor with the latest finish date. Then we click on the 'Go To' button below to see the completed predecessor activity displayed as shown in Figure 6 below,

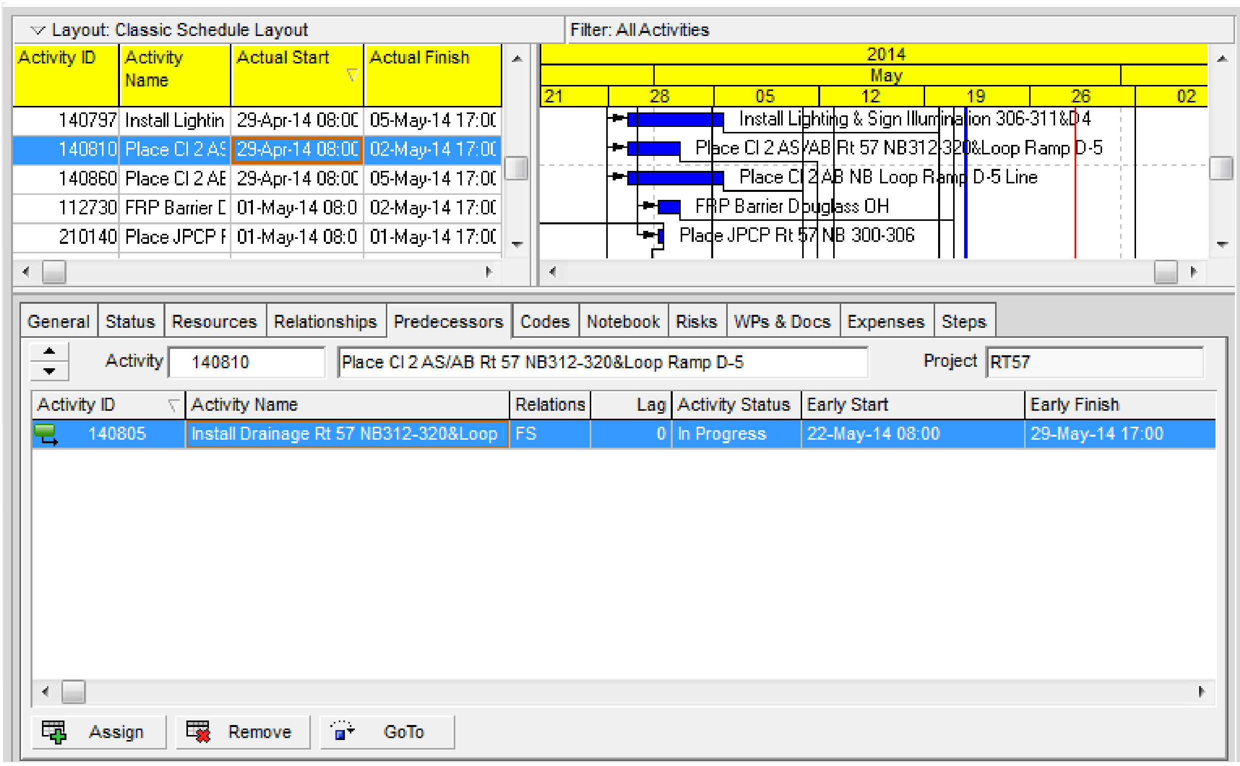

Figure 6, Completed Predecessor Activity Example

Again, we follow the controlling predecessors to Activity 140810, clicking on the relationship with an Early Finish date later than the 12MAY14 20:00 data date and then the Go To button to reveal Activity 140805, as displayed in Figure 7 below. This uncompleted activity is causing the out-of-sequence condition to Activity 140820.

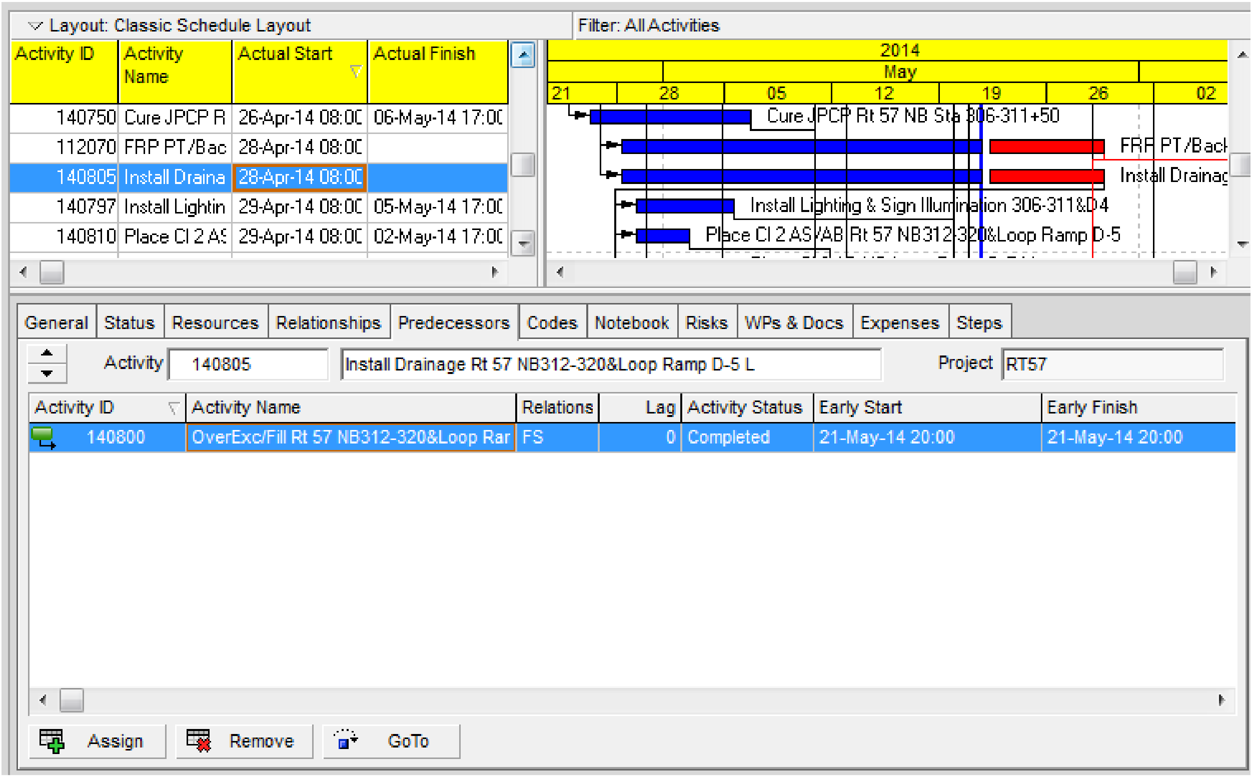

Figure 7, Activity Causing the Out-of-Sequence Condition

In this example, another type of sort allows for a summary of the out-of-sequence analysis, as shown in Figure 8. Activity 140805 is not complete. The short gap between the data date line and the remaining start of Activity 140805 is due to the difference between the current and the effective data date.

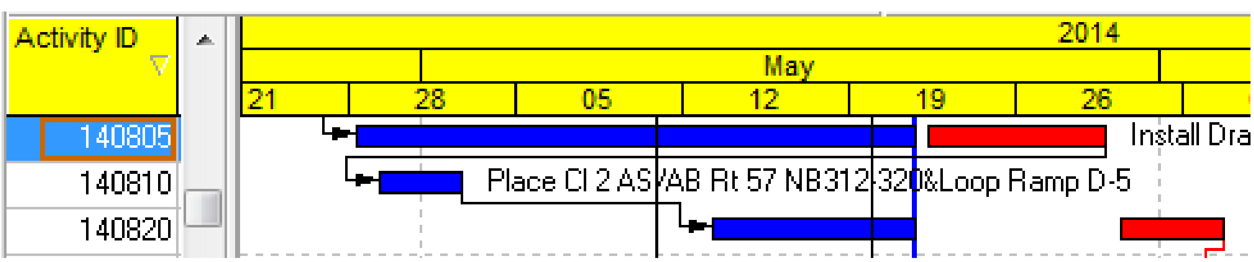

Figure 8, Summary of Out-of-Sequence Example

The successor, Activity 140810 has started out-of-sequence and is complete. The successor to the completed activity, Activity 140820 started in logical sequence to Activity 140810 but still displays the characteristic Retained Logic gap in the work plan due to indirectly starting out-of-sequence to Activity 140805.

It is interesting to note that the P6 Out-of-Sequence Log does list the middle Activity 140810 as being out-of-sequence but it does not list the final Activity 140820. This is due to the fact that Activity 140820 started later than middle Activity 140810 and is not technically out-of-sequence to its predecessor. Activity 140820 displays a ‘gap’ where no planned work is anticipated due to the Retained Logic computational mode delaying its re-start by incomplete Activity 140805, working through Activity 140810.

Statistical Analysis

Out-of-sequence events have properties that can be used for analysis to catalogue and rate these events. If a baseline or statistical norms are recognized, then such statistics can be used to highlight occurrences particularly outside of standard, acceptable variations.

Statistical Measurement

When analyzing out-of-sequence events, the proper course of action is to ask what are undesirable or unacceptable outcomes and how would we would measure them.

Percent of Occurrence of Out-of-Sequence Events

One such outcome would be if the planned schedule was not followed. The percent of activities with actual starts that began earlier than logic would allow compared to the total number of activities that registered actual starts would be an excellent indicator of the extent of the performance of the plan. A very low percentage would suggest a well-run project and a very high percentage would indicate problems with executing the plan.

If a very large percentage of the activities in a CPM schedule were performed out-of-sequence, one could make a fairly convincing case against using that unadjusted schedule as the basis of a judgment. There must be some statistical limit that would greatly bolster the argument that adjustments to the schedule were warranted.

Degree of Out-of-Sequence Overlaps

The degree of overlap of out-of-sequence events also determines the severity of the condition. The larger a percentage of the total duration of the activity that comprise out-of-sequence starts, the more necessary it becomes to correct the conditions. The greater the duration of overlap, the less likely the schedule network represents the planned work. This would, in turn make the schedule less reliable in displaying the actual results of the status. Project-controlling events are more likely to be hidden from the analyst if the CPM results are not reflective of the actual project status. The mean of the duration of early starts makes an excellent measurement for this condition.

These two measurements can be combined into a statistical trigger event. If a significant portion of the work started earlier than the schedule allowed and if the average early start was of a significant amount of time, then one can reasonably assume that the schedule did not adequately describe the actual workplan for this task. This can be a significant gauge of program disruption

Industry Survey

An industry study [23] performed on 31 diverse and unrelated schedules suggests that activities typically start out-of-sequence with a mean of 34% of the time and a standard deviation of 16%. While this seems a very large percentage, it is a reasonable number to use as a basis for determining a standard baseline.

With this figure in mind, readings outside one standard deviation, or 50% would form a justifiable cut-off for determining a schedule's reasonableness for representing a schedule that displayed the actual work plan. Any schedule receiving a number greater than 50% of the started activities as starting out-of-sequence would fall out of the range of acceptable logic. In our industry survey, 5 schedules out of 31 or 19% of the schedules exceeded this limit.

In the same industry study, the mean of the amount of overlap (i.e. days started early) was 58 days with a standard deviation of 56. Any mean value greater than one standard deviation would be a reasonable first look at identifying a schedule outlier. Thus any schedule with a mean of 114 days in the duration of early starts of out-of-sequence activities could be said to have excessively severe out-of-sequence events. In our industry survey, 6, or 19% of the schedules exceeded this amount.

Schedules that have both a combined percentage of greater than 50% of out-of-sequence starts and a mean greater than an average of 114 days starting early should be identified as candidates for a poor plan and schedule disruptions. In our industry survey, none of the schedules exceeded both criteria.

Enhance CPM Software Reporting

Even if a particular CPM software does not fully identify all out-of-sequence activities (or does not provide a method to use this information in advanced reporting), one can use external sources to do so and import this information back into the schedule. Oracle P6© has the ability to create user-defined fields and activity codes. They can be loaded via a spreadsheet or other methods and then this field can be selected to create specialty reports.

Time scaled logic diagrams is one type of report that can take advantage of this process. If the software supports activity coloring by an activity code, then the analyst can create a code for out-of-sequence events and populate it from the outside report for this property. The activities that started early will then be easy to locate and observe if any related events appear to be causal. Further analysis can be made from there.

Out-of-Sequence History Profile

A profile of when out-of-sequence activities occurred can prove to be insightful. The analyst would create this by totaling the number of out-of-sequence activities that were active for every day that the project was progressing. Then the analyst could plot this curve along with the total number of activities that were active for that day. Figure 9 below illustrates the process by summing the out-of-sequence working days (shown in blue) per day,

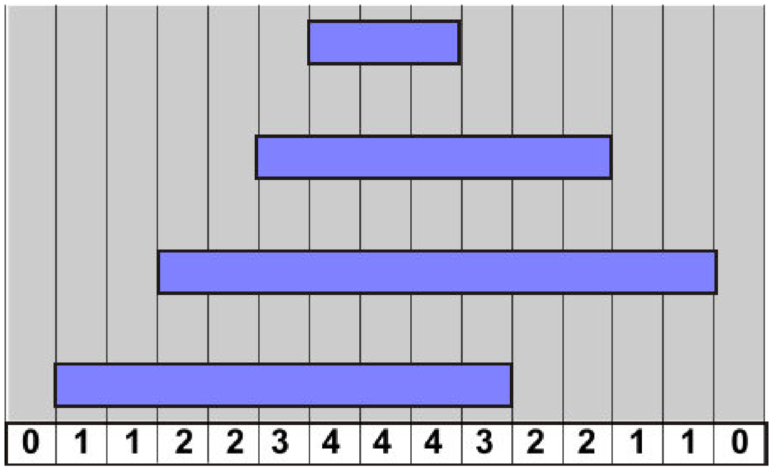

Figure 9, Out-of-Sequence Activity Profile

Disruption due to dilution of management, crowding, or interference is more likely on days that have more active out-of-sequence activities occurring than those where all activities are proceeding as originally planned.

What would an actual out-of-sequence profile look like? Figure 10 below shows the profile for an actual project showing the daily totals for all started activities (in red) compared to activities that began out-of-sequence (shown in blue). This is an actual project with 12,295 activities having actual starts.

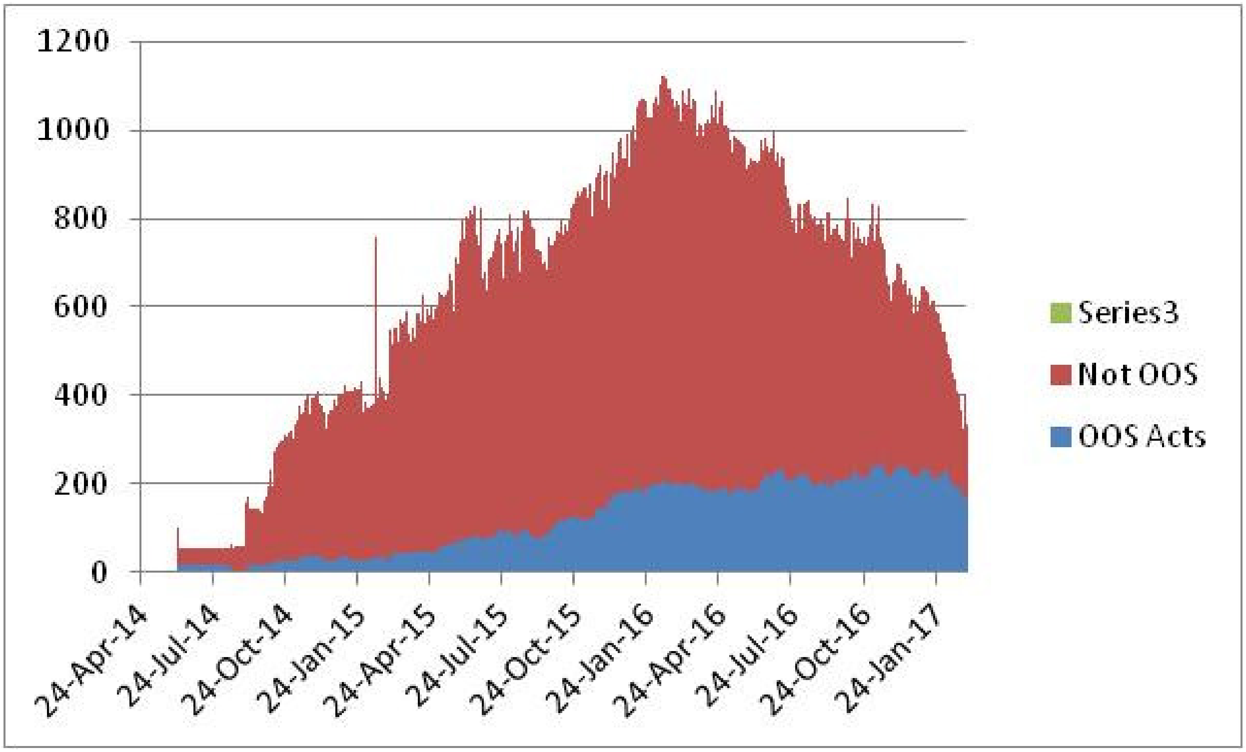

Figure 10, Total Activities with an Actual Starts versus Out-of-Sequence Profile

There are several insights to be gained by creating a timeline of out-of-sequence activities. This profile can be used to indicate a history of possible disruption occurrences. The timeline can be correlated with a list of known disruptions to form a framework for discussing disruptions over the course of a project. This profile can also possibly connect activities that were physically but not logically related.

When the curves are high, this may indicate periods of project stress, especially if this occurred at the same time as a project delay. This may help to tie delays on one activity to the interference and dilution of supervisory control over other non-critical activities that shared supervision and locality.

Even non-critical disruption can influence the critical path delays through dilution of supervisory control. Non-critical disruption can also result in blockage of laydown areas and the access to the work for critical personnel. A profile of disruptive activities helps to tie critical path issues to 'non-critical' disruptive activities.

Disruptions and project stress have forensic analysis considerations. A time of project stress is a poor standard to use for a Measured Mile [28] process. The work productivity being measured should have limited or no negative influence arising from disruption events. [31] Perhaps all other crafts were being interrupted in order to allow the Measured Mile work to proceed artificially fast, creating an exaggerated productivity rate that would not have been achieved under normal circumstances?

A further refinement to this analysis is comparing the number of out-of-sequence events to the number of out-of-sequence actual starts. A single out-of-sequence activity can be started earlier than several different logical constraints would allow, not just one. An activity experiencing multiple events of out-of-sequence action would more likely prove to be disruptive to the project than just a single event. Figure 11 below relates how the multiple events per out-of-sequence activity dramatically increased around October 2015. After this time, the schedule increasingly became more out of control.

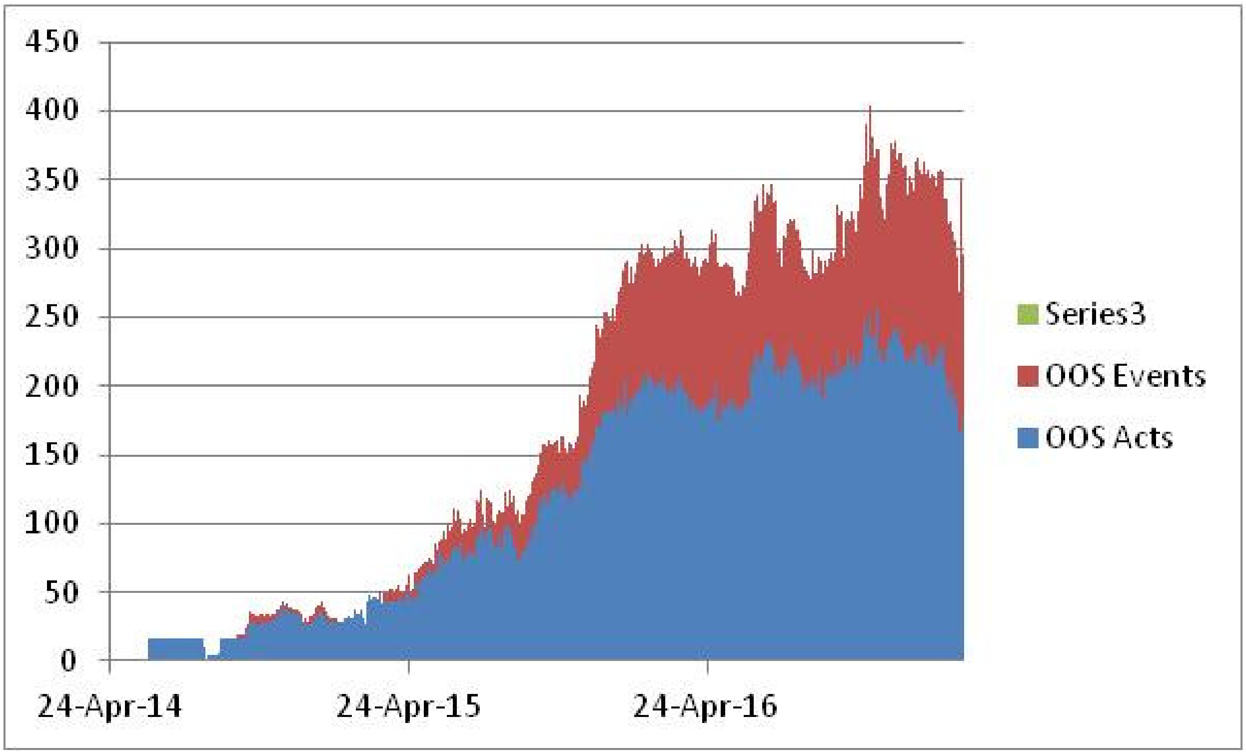

Figure 11, Total Out-of-Sequence Events versus Activities Profile

From a claims perspective, it would be useful to be able to focus on one particular contractor or subcontractor. Filtering the report to only include a particular responsibility value in the appropriate activity code will help focus the analysis to contractual issues. Figure 12 below shows such a curve from the same project, only showing the out-of-sequence events from the responsibility field setting for (re-named[2]) “SGM Contractors”.

2 The actual name of the sub-contractor has been changed here in order to maintain anonymity.

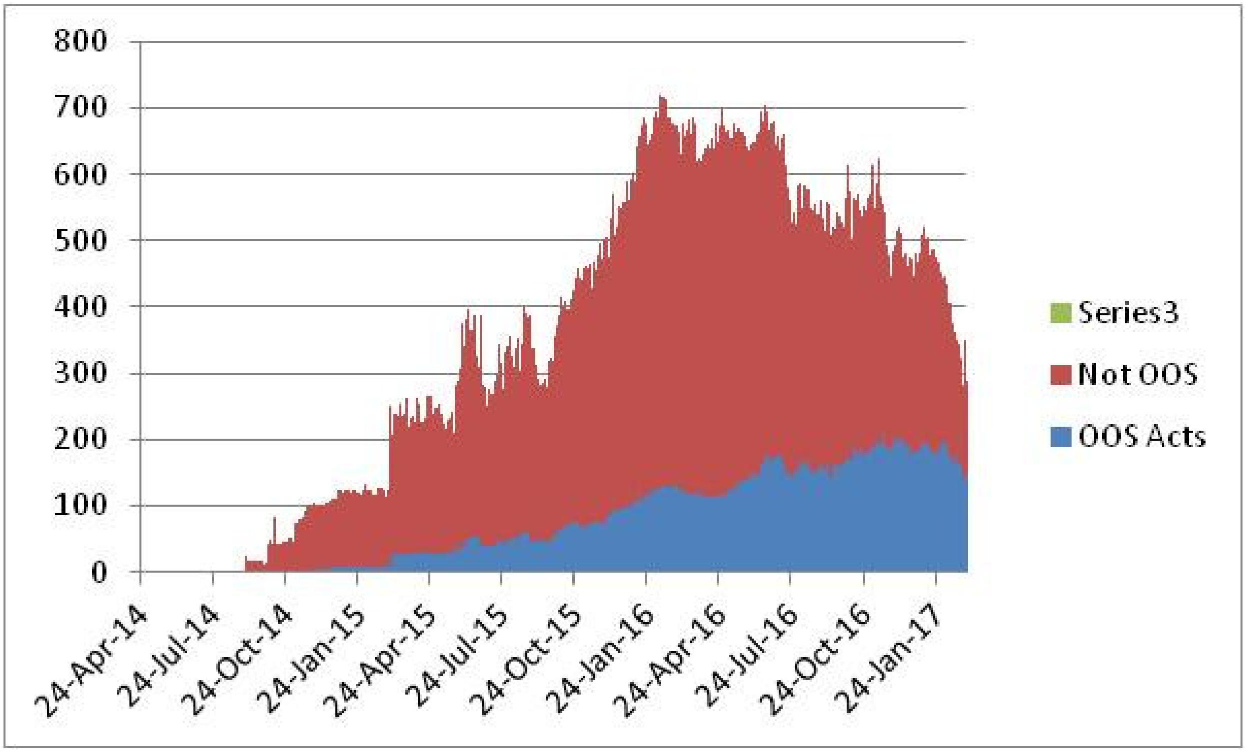

Figure 12, SGM Contractors Activities with Actual Starts versus Out-of-Sequence Profile

As can be seen by comparing project totals to SGM Contractor totals, this subcontractor experienced a lion's share of the project's logically early starts. Figure 13 below displays the out-of-sequence events as compared to the activities for this same contractor.

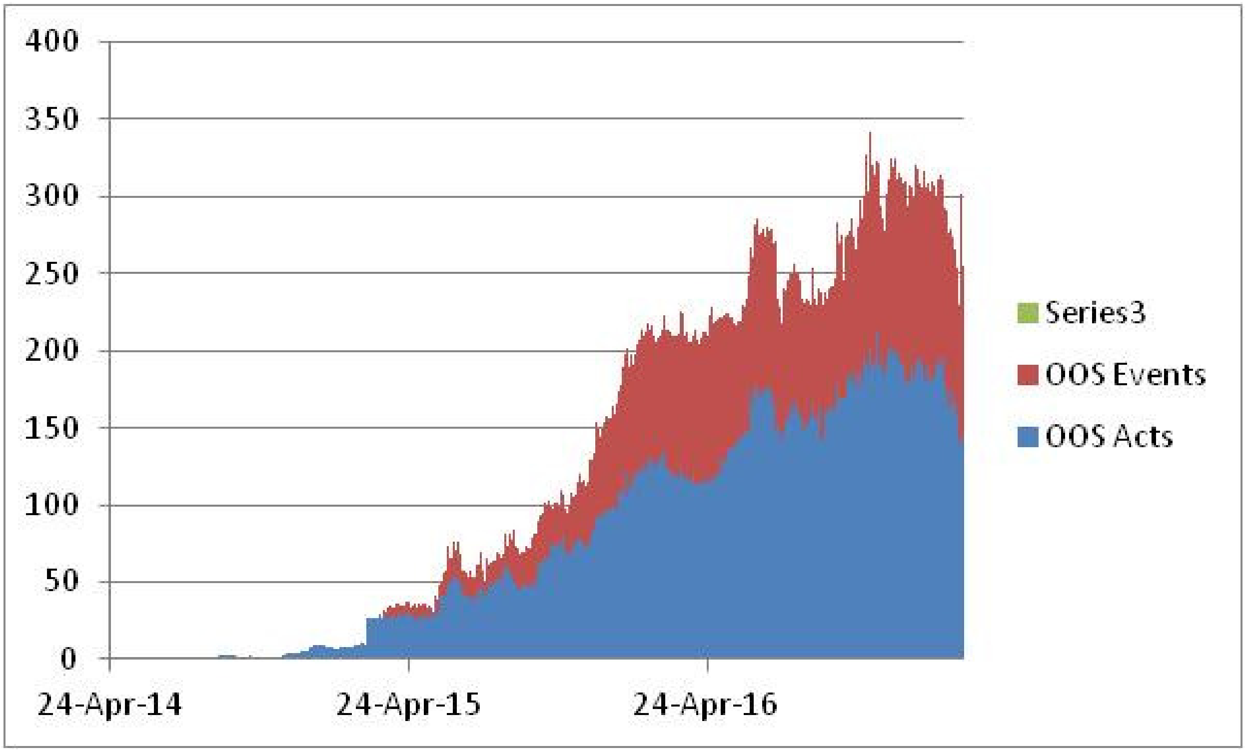

Figure 13, SGM Contractors Out-of-Sequence Events versus Activities Profile

October 2015 is again noteworthy from a disruption viewpoint showing the number of events as opposed to just the out-of-sequence activities count dramatically increased at this time. Activities were starting earlier than planned to multiple predecessor activities instead of just one, suggesting a deepening confusion on the field.

'Normal' Early Starts

Many CPM analysts allow that activities starting one or two days earlier than planned are rarely disruptive and in many cases the practice was planned beforehand. Sometimes a simple Finish-to-Start relationship without a lag is a scheduler's 'short-cut' [32] for using a 1 or 2 day negative lag. Sometimes follow-on successor work can begin before the predecessor work is complete as long as they do not overlap in the exact same location. Including this type of work in the statistics might 'over report' the out-of-sequence work that is indicative of disruption.

The simple 'fix' to this problem is to exclude reporting on out-of-sequence events that start 2 days or less from the report. This change eliminated the reporting on 1436 activities and 2357 events, or roughly half of the original totals. Figure 14 below shows such an adjustment from the previous figure. As you can see on this particular project, eliminating out-of-sequence activities with small early start overlaps had only a small effect on the profile curve.

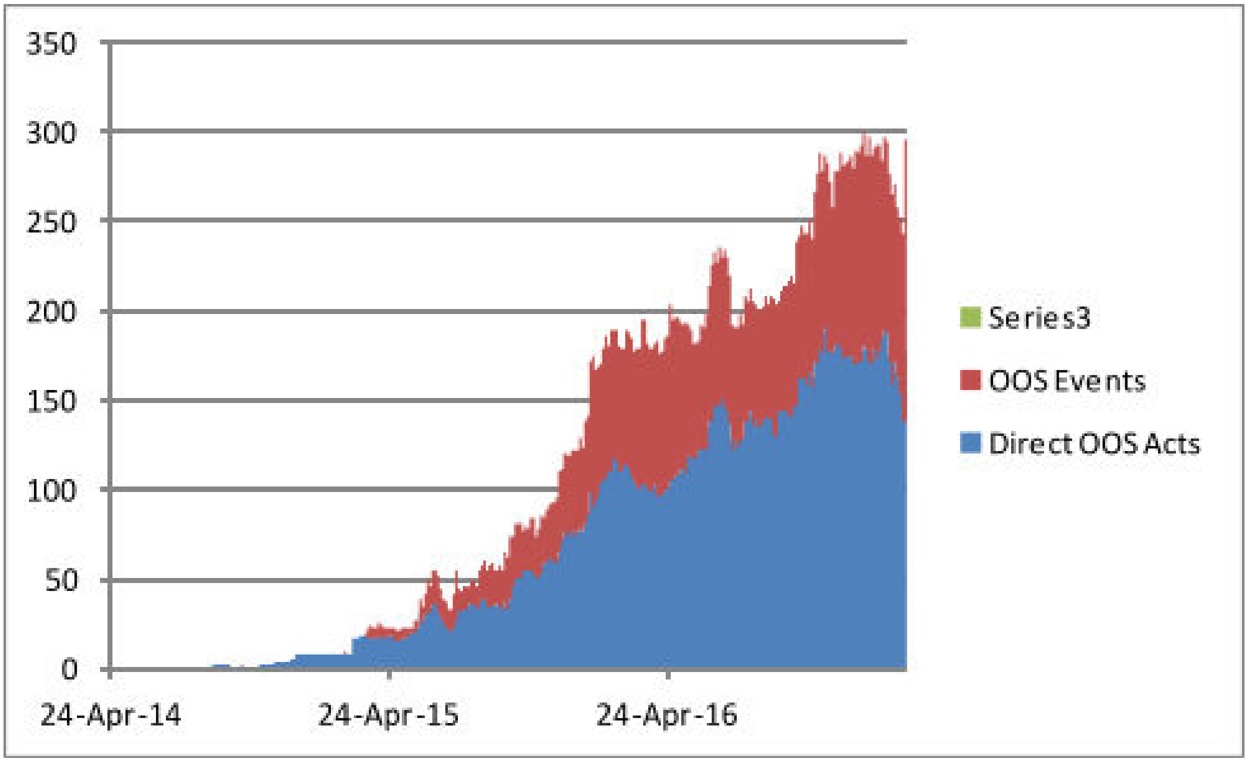

Figure 14, SGM Contractors Out-of-Sequence Events Greater than 2 Work Days Profile

Histogram of Early Start Frequency

Analysts would want to understand what eliminating the 1-2 day early starts did to the resulting early starts. Figure 15 below shows a histogram of the totals for the number of days the various out-of-sequence activities started early for SGM Contractors. To better illustrate the results, the extreme outliners were 'trimmed' with the top of the chart cut-off (trimming the 1-2 day lines that reached 632) and the right of the chart was cut-off at 153 days early (eliminating the outliers that reached 533). This allows the viewer to note that the remaining chart displays a fairly evenly distributed, standard near-parabolic distribution.

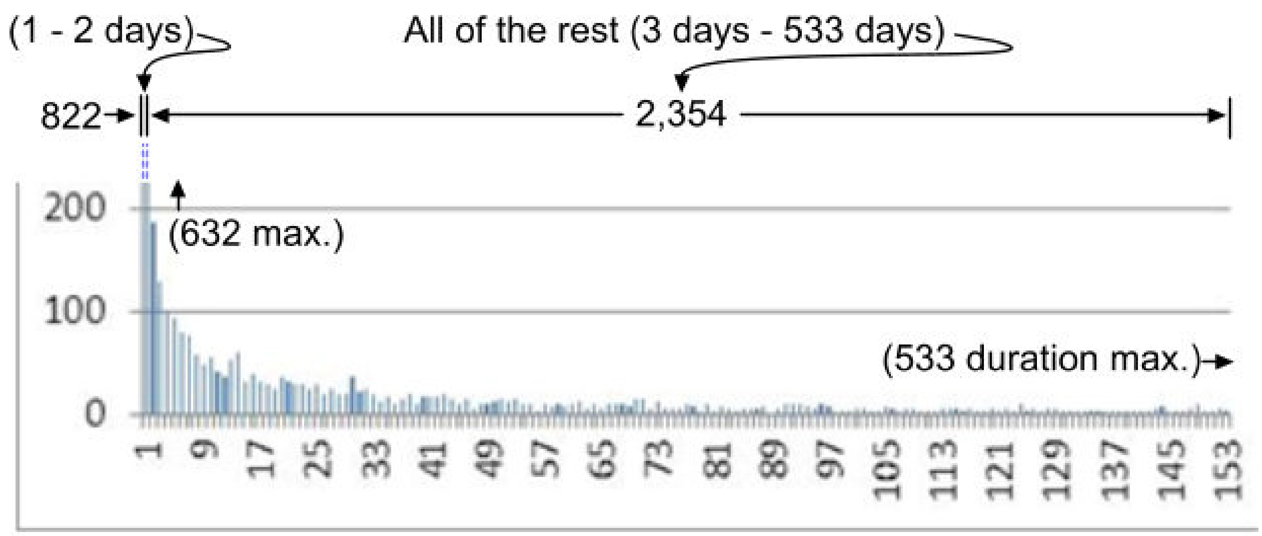

Figure 15, Histogram of SGM Contactors Early Workday Starts

The number of such activities that started 1 to 2 days early totaled 822 while the there were a total of 2,354 activites that started much earlier and were more likely disruptive to the workflow. Of the 3,176 early starts, the mean was 25 and the standard devuiation was 31. One can reasonably observe that the out-of-sequence events were significant and pervasive for SGM Contractors on this project.

Target the Early Portions of Out-of-Sequence

An addition qualification can be made to make the history profiles even more targeted. This can be done by only tracking the dates that the out-of-sequence activities were actually early instead of tracking the entire activity. Figure 16 below demonstrates this refinement by only profiling the red (early) periods in the out-of-sequence activities,

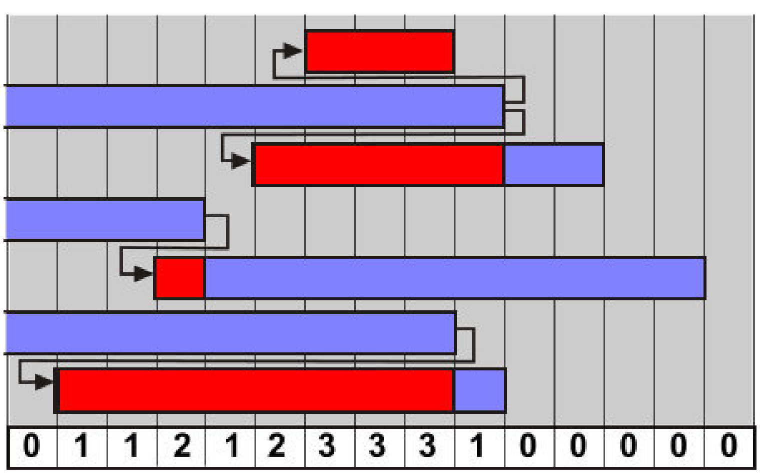

Figure 16, Out-of-Sequence Activity Early Profile

In the sample case shown in Figure 17 below, the profile looks much like the original. On this project, most of the out-of-sequence activities were completely performed out-of-sequence.

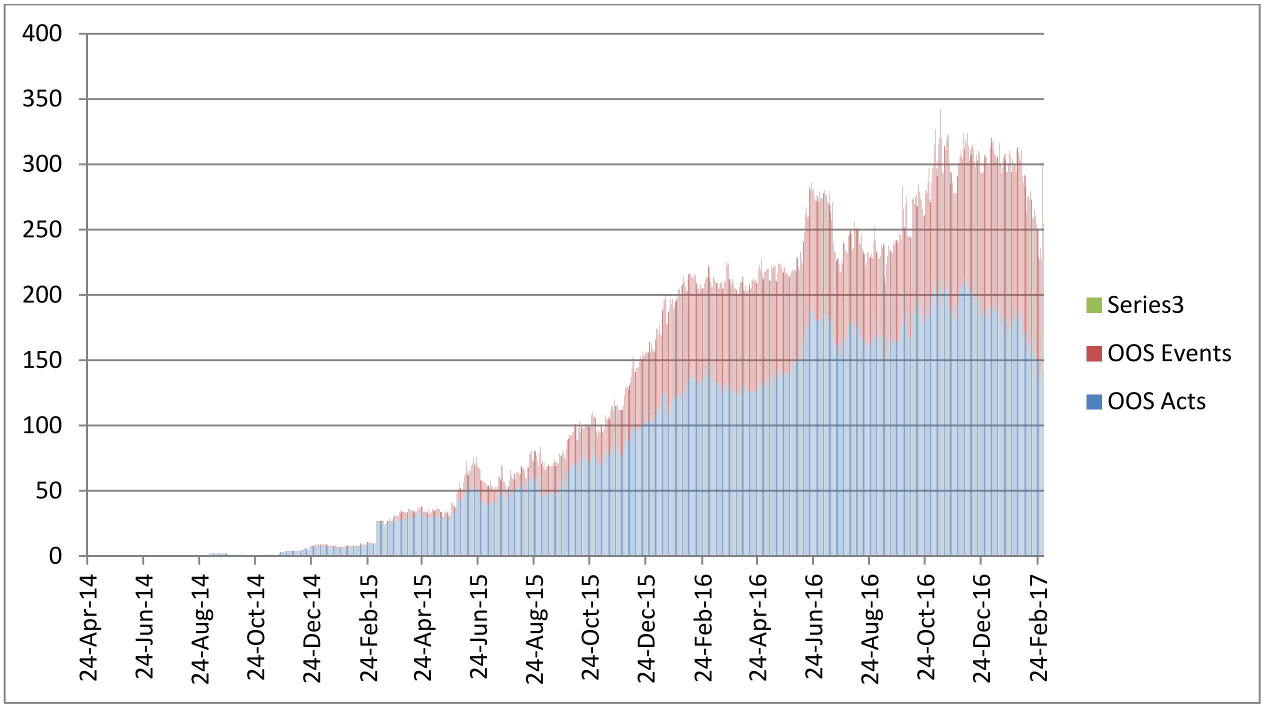

Figure 17, SGM Contractors Out-of-Sequence Events vrs. Activities Profile Using Only Early Periods

The fact that this matches so closely with the profile that tracked the entire out-of-sequence activity indicates that in this instance, there was very little time when the planned sequence was being executed.

Cost and Labor Profiles

Even if the software used does not completely or distinctly identify the intended class of out-of-sequence activities, in many cases user-defined fields, activity codes, or resources can be set up and the identified activities can be annotated using an import procedure. Once the out-of-sequence activities are identified in a manner that the software can use for filtering in reports and graphics, then additional analyses such as cost and labor profiles can be created and compared to their post-disruption values.

This process can be used to evaluate the cost of inefficiencies over the project life-cycle. The knowledge of the cost of out-of-sequence progress can be compared against the cost of prevention to better refine future operation plans. It is much easier to justify prevention costs if the current costs are well understood.

Conclusion

CPM schedule models combined with real-world progress may create logical sequences that are difficult to predict using just theory. Industry surveys indicate that out-of-sequence events may habitually occur in most schedules, roughly one third of the time. Tests on a small sample of those schedules amongst the various CPM software manufacturers reveal a wide variance in identifying out-of-sequence events and activities.

Many schedule analysts may not be aware of the extent of out-of-sequence events in their schedule updates and thus fail to realize the magnitude of the problem. Some well-known CPM software has been found to significantly underreport such occurrences. The CPM software reviewed herein appear to ignore secondary out-of-sequence events; ones that occur as downstream successors to the first activity in the chain that was reported.

Out-of-sequence occurrences have numerous properties that can be used to evaluate the impact and severity of the event on the CPM schedule. Reporting on out-of-sequence events in addition to just the activities involved, noting the severity of the early start, reporting current or active occurrences versus all such events, and the type of logic that was broken are among the properties worth noting in any time impact analysis. Labeling the problem category as well as classifying the event further documents the nature and potential impact of out-of-sequence events.

The technical definition of an out-of-sequence event varies between the various CPM software companies and seems to fall into two camps; actual early start or broken logic link. Out-of-sequence reporting also varies as to listing all affected activities or just currently active (uncompleted) activities.

It is important to identify all out-of-sequence events in a schedule in order to validate the accuracy of the schedule plan against actual project execution. Disruption events should be noted and documented. The possibility of the reduction of schedule accuracy at predicting project completion as well as the current work schedule can be obfuscated by out-of-sequence events. The question of whether the scheduler should correct the logic and how that would be done is not a clear or simple matter. There are problems and issues on all sides of the question.

Clearly, more research and coordination on establishing guidelines for reporting and responding to out-of-sequence events is warranted. Some of the most popular CPM software appears to significantly underreport this condition. Although many schedule analysts may have been incorrectly led to believe that this is a relatively small, isolated issue when this apparently is not the case.

CPM theory mixed with real-world status creates logical combinations that are difficult to predict using just theory. Industry surveys indicate that out-of-sequence events may habitually occur in most schedules with one third of all activity actual starts being made before logically permitted. Because out-of-sequence events are more common and numerous than many analysts think, the sheer number of the events opens up many new avenues for analysis and display.

Analyzing of out-of-sequence events uncovers several deficiencies. A simple, common practice of correcting the schedule logic during updates may inadvertently hide instances of disruption experienced. These disruptions might have turned into compensable change orders, had the corrections not obfuscated the effects in the schedule. A Half-Step Schedule can help fix this issue.

The analyst can trace the ruling logic from out-of-sequence activities to the delaying cause using the P6 Predecessor Tab and predecessor activity early dates. This process can logically span several completed activities before uncovering the activity whose completion is delaying the original activity's re-start. This delay causes a gap in activity's planed execution when using the P6 Retained Logic computational mode.

New methods for statistically analyzing and quantifying out-of-sequence events exist. The percentage of out-of-sequence activities in a schedule and the degree that they were out-of-sequence are important factors. Based upon an industry survey, statistical limits of 'normal' occurrences can be used to evaluate the level of out-of-sequence events in other schedules.

Enhanced graphical methods can profile disruption across the project. Project disruptions can in-turn cause disruption to individual sub-contractors. The history profile of the number of working days of concurrent out-of-sequence activities can be used to illustrate this issue. This analysis is further refined by eliminating 1 or 2 day 'normal' early starts from the analysis.

Histograms of the frequency of the amount of early starts also provide insight into the severity and extent of the phenomena. From the industry survey, it appears that activities starting hundreds days early on projects occur fairly often.

Analyzing the effects of out-of-sequence activities in a CPM environment has the potential to be able to explain disruptions in the field in a quantitative and even graphical manner. The techniques presented here may prove to be an excellent claims and dispute resolution tool.

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