CDR.493

Forensic Schedule Analysis: Example Implementation, Part 2

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ABSTRACT— *Recommended Practice 29R-03—Forensic Schedule Analysis*, has aroused significant debate in the forensic scheduling community since its original publication in 2007. Now in its second revision, the RP continues to evolve in pursuit of the original goal of providing a unifying technical reference for the forensic application of the critical path method of scheduling. During the development of the original RP, there was a proposal to include example analysis implementations, in so-called "cookbook" sections. The material developed for two of those sections was presented in 2008, in a paper detailing the forensic analysis of a sample project using Method Implementation Protocols 3.3 and 3.7. This paper presents an analysis of the same project using MIPs 3.1, 3.2, and 3.8; presents a comparison of the results from all five analyses; and provides additional discussion of issues likely to be encountered in an actual implementation of the guidelines in the recommended practice.

Table of Contents

List of Tables

List of Figures

Introduction

This paper is the second in a series that presents a Forensic Schedule Analysis (FSA) example implementation, prepared to address the application of procedures described in **Recommended Practice 29R-03—Forensic Schedule Analysis** [1]. The techniques explored here, or variations on these techniques, have been commonly referred to as "As-Planned v. As-Built," "As-Planned v. Update," and "Collapsed As-Built." Those terms are not used here, in preference for the taxonomic terms presented in the RP 29R-03. This paper presents three separate analyses of the same project. The analyses are based on the Method Implementation Protocols in Sections 3.1, 3.2, and 3.8 of the Recommended Practice. The paper has five major sections:

1. Model Project to be Analyzed
2. Analysis by Comparing the As-Planned and As-Built Schedules (Observational/Static/Gross Analysis per MIP 3.1)
3. Analysis by Comparing the As-Planned and As-Built Schedules on a Periodic Basis (Observational/Static/Periodic Analysis per MIP 3.2)
4. Analysis by Removing Delay Events from the As-Built Schedule (Modeled/Subtractive Single-Simulation Analysis per MIP 3.8)
5. Comparison, Commentary, and Conclusion

Model Project to be Analyzed

The sample project referenced in this paper is the same project used in the example implementation for MIPs 3.3 and 3.7, presented in 2008 [2]. The description of the sample project presented in that paper is reiterated here for reference. The original sample project was provided for the consideration of the participants in the RP development committee and had been used previously for the comparison of various delay analysis techniques [3].

The model project is the construction of a storage building. The building will be used to store non-hazardous, dry materials. The design consists of tilt-up concrete panels with a steel-framed, metal roof. A much smaller receiving and reception area is attached. The reception area is framed with metal studs and enclosed with an exterior-insulating and finishing system (EIFS). Personnel arrive through the reception area and goods are delivered by truck to the all-weather docking unit in that area. The available information for the project includes a baseline schedule, six schedule updates, and a summary of project events based on the contractor's and owner's files.

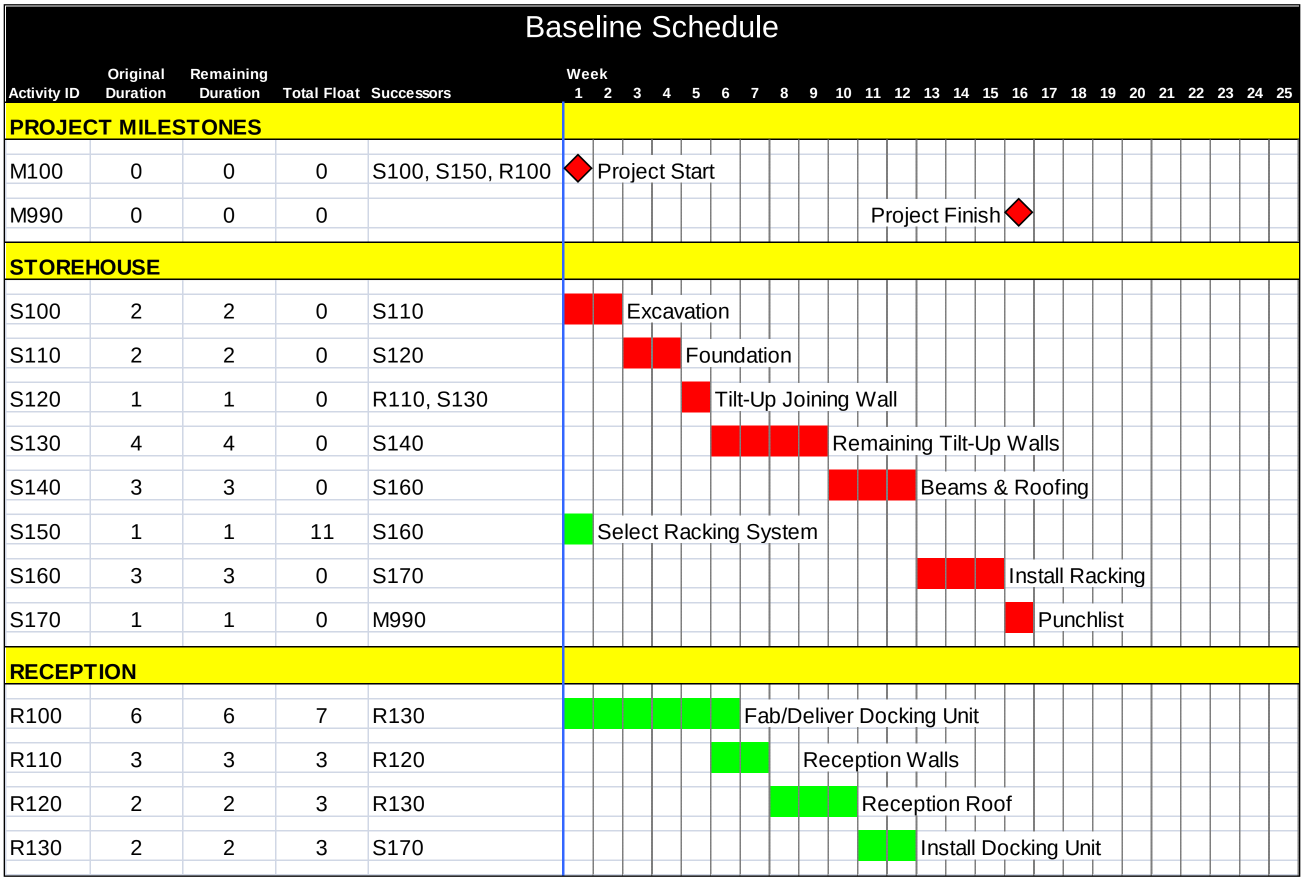


Figure 1—Baseline Schedule

Figure 1 depicts the as-planned schedule as a bar chart, and figure 2 shows the logic diagram. In the example project schedule, the project start milestone has start-to-start relationships with its successors, and the punchlist activity has a finish-to-finish relationship with the project finish milestone. All other relationships are finish-to-start, and there are no lags. Durations are in weeks, and the project is planned to take 16 weeks to complete. The baseline critical path begins with project start and proceeds through excavation, foundation, tilt-up joining wall, remaining tilt-up walls, beams and roofing, install racking, punchlist, and project finish. There are no constraints in the schedule. The following logic diagram details the relationships in the baseline schedule.

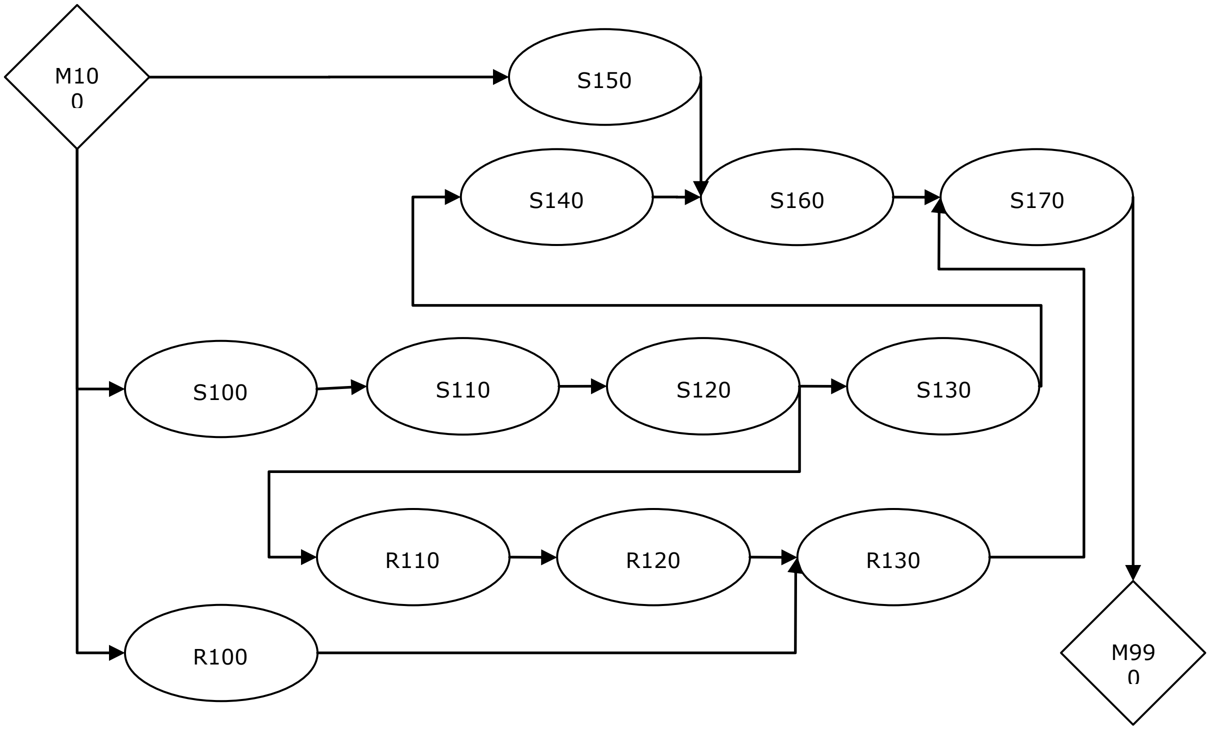


Figure 2—Schedule Logic Diagram

The following figure shows the as-built schedule for the same project.

As-Built Schedule

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Week 1–25
PROJECT MILESTONES					
M100	0	0		S100, S150, R100	Project Start
M990	0	0			Project Finish
STOREHOUSE					
S100	2	0		S110	Excavation
S110	2	0		S120	Foundation
S120	1	0		R110, S130	Tilt-Up Joining Wall
S130	4	0		S140	Remaining Tilt-Up Walls
S140	3	0		S160	Beams & Roofing
S150	1	0		S160	Select Racking System
S160	3	0		S170	Install Racking
S170	1	0		M990	Punchlist
RECEPTION					
R100	6	0		R130	Fab/Deliver Docking Unit
R110	3	0		R120	Reception Walls
R120	2	0		R130	Reception Roof
R130	2	0		S170	Install Docking Unit

Figure 3—As-Built Schedule

The project actually took 24 weeks to complete, as shown in figure 3. Relevant information from the project records is summarized in table 1, outlining the events that occurred during the project.

Week	Contractor's Records	Owner's Records
1	Mobilized excavator and crew; laid out building pad and began excavation at storehouse area; hit existing underground storage tank (UST) on Thursday that was shown on the project drawings as outside of the building footprint; material in building footprint smells contaminated and may require remediation or replacement; wrote RFI and moved crew to far side of building away from UST area for remainder of week	Contractor mobilized excavation crew on Monday; performed survey of building pad and placed E&S controls; began excavation late Monday; uncovered UST on Thursday (received RFI); called enviro. consultant; and they can be on site on Tuesday
2	Operator showed on Monday but refused to continue work without knowing what contamination was; got a new operator on Wednesday and continued excavation outside of contaminated area; completed all available excavation by Friday AM; received direction to over-excavate soil beginning on Monday	Enviro. consultant verified VOC in soil on Tuesday; submitted report on Friday stating that contamination is below hazardous threshold; soil can be over-excavated, aerated for one week, and replaced; consultant will be on site to monitor; contractor to begin on Monday and submit LS proposal for added work by Friday; will track T&M in the mean time just in case
3	Removed UST and began excavation of contaminated material as directed by enviro. consultant; stockpiling on site and pushing around as directed; not enough footings available to begin concrete work and site is a mess with stockpiles	Enviro. consultant monitoring remediation work; contractor submitted LS proposal for mitigation on Wednesday; meeting on Friday to negotiate proposal
4	Continuing excavation and mitigation of contaminated soil as directed by enviro. consultant; begin backfilling excavation with mitigated material as directed; executed change order for work; no time extension granted, but owner agreed to revisit the issue later in the job	Enviro. consultant continues to monitor ongoing remediation work; contractor submitted revised proposal on Tuesday; contract price adjustment in conformance with the revised proposal was returned to contractor; contractor also requested a two-week time extension, but that was not executed, because it is still early in the job and the delay may be recovered

Week	Contractor's Records	Owner's Records
5	On Monday, received a letter from the docking unit supplier stating that its plant is at capacity and our fabrication will start six weeks from today; told them that they would be impacting our schedule and that we cannot wait that long; completed backfill of over-excavation and restoration of all footing trenches; will proceed with footings next week	Contractor had reduced crew completing backfilling of over-excavation and footing trenches; footing rebar delivered to site on Thursday; footing bottom inspections scheduled for Monday, with placements planned on Monday and Thursday next week
6	Completed footing placements; proceeding with foundation walls; installed U/G for bathroom at reception and U/G electrical conduits for service	Footing placements completed on Monday and Thursday; contractor is forming and reinforcing foundation walls on Monday's footings; also completed underground utility work to building
7	Contacted casting yard on Monday—all tilt-up panels are ready for delivery; scheduled joining wall for next Monday; completed and backfilled all foundations	Contractor completed FRP of all foundations on Tuesday; last foundations were stripped and backfilled on Friday
8	Joining wall delivered Monday; set-up for raising; raised joining wall on Wednesday; exterior wall panels delivered on Thursday; setting up for raising next week	Tilted up joining wall on Wednesday; exterior wall panels delivered on Thursday; several panels had honeycombing; contractor followed specified repair procedures
9	All panels on site; raising began on Monday; connecting and providing temporary bracing per erection plan; also began framing steel stud walls at reception; panel erection subcontractor worked through Saturday to complete work and demobilized	Panel erection proceeding according to accepted erection plan; light-gage steel framing at reception also began; worked Saturday to finish all panel erection, but no steel or roofing materials have been delivered to site yet; noted concern to contractor as we were three weeks behind schedule according to the last schedule update and we could recover that time if we get roofing started next week
10	Continuing steel stud work at reception; cleaning up from panel erection and fine grading up to building	Light-gage framing at reception area continues and is 50% complete by the end of the week; minimal other work underway; no structural steel or joists on site

Week	Contractor's Records	Owner's Records
11	Completed framing work and exterior wall and roof sheathing at reception; installing EIFS panels and roof membrane and proceeding with interior rough-in; contacted docking unit supplier to verify start of fabrication and they said fabrication will begin next week with delivery anticipated in six weeks; this is going to be a delay	Reception area framed and sheathed; contractor is proceeding with electrical rough-in at stud walls and bathroom plumbing in reception area; note: these MEP details are not in the contractor's schedule; when asked to add them for tracking purposes, contractor indicated that they were included in the "Reception Walls" activity; still no structural steel, joists, or standing-seam materials on site
12	Completed electrical rough-in and bathroom plumbing; completed exterior panels at reception; span on installed tilt-up panels does not appear to match joist shop drawings; survey on site to verify; will field modify joists as necessary.	Surveyor on site verifying tilt-up panel installation. Contractor running conduit and plumbing in reception.
13	Steel and roof panels arrived on Monday and beam erection began, but first beam was three inches longer than bay; the steel matches the accepted shop drawings and the contract structural drawings, but the panel tie-in points do not appear to match up; survey showed that installed panels match with accepted erection drawings, but architectural drawings showing center-to-center wall dimensions and panel dimensions do not match structural drawings; erected bay is three inches shorter than shown on the structural drawings; steel and roof panels will have to be modified; submitted procedures.	Structural steel and roofing panels arrived on Monday; contractor began erection but steel did not match up with panel tie-in points; beams are three inches too long; contractor proposed field cutting steel; that can be done per spec, but full roof panels must be trimmed by manufacturer to maintain warranty; electrical and plumbing work at reception passed inspections on Wednesday.
14	Owner will not allow field modification of roof panels; panels to be returned to the supplier for modification. Proceeded with joist modifications.	Contractor did not verify all dimensions as required and contractor-fabricated tilt-up panels did not align with joists; contractor wants to field modify joists and roofing, but extensive field bending or cutting of roof panels may void warranty; directed contractor to return panels to manufacturer; joist modifications proceeded on site.
15	Completed reception framing and exterior panel erection.	Contractor working on reception panels.

Week	Contractor's Records	Owner's Records
16	Received half shipment of modified panels for storage; proceeding with roofing at reception.	Contractor working on reception roofing.
17	Reception roofing completed; docking unit to arrive next week; proceeding with joist and roofing installation at storage.	Contractor installed joists and began installing roofing panels at storage.
18	Received remaining roof panels; completed insulation and hang/tape/texture of drywall in reception area; ready for painting; docking unit arrived and installation began; have been waiting for owner to select racking system; supplier can provide multiple options, but final selection is becoming critical.	All modified roofing panels have been returned to site.
19	Began racking system installation; continuing docking unit installation.	Contractor is proceeding with racking and docking unit installation.
20	Began racking system installation; continuing docking unit installation.	Contractor is proceeding with racking and docking unit installation.
21	Began electrical installation at storage.	Racking system installation is nearing completion, but contractor is having difficulty with docking unit installation; had to reset docking unit due to misalignment.
22	Completed electrical; completing racking system and docking unit.	Contractor continues work on racking and electrical. Docking unit still incomplete. Provided contractor with punchlist.
23	Completed all work; proceeding with minor punchlist items.	Contractor completed racking and electrical; proceeding with punchlist items.
24	Completed punchlist; signed off; project complete.	Signed off on final punchlist completion.

Table 1—Summary of Project Information

The summary of project information will be used in conjunction with the project schedules. The goal of the schedule analysis will be to identify the specific activity delays that resulted in the overall eight-week delay to project completion. Including the as-built schedule, there were six updates to the baseline schedule. The updates were completed after every four weeks of work.

Analysis by Comparing the As-Planned and As-Built Schedules

Observational/Static/Gross Analysis per MIP 3.1

This analysis will be performed based on the method implementation protocol (MIP) described in Section 3.1 of the RP. The analysis is classified as *retrospective* because the analysis is performed after the delay events and the impacts of those events have occurred and the outcome is known. The analysis is *observational* because no activities are added or subtracted from the schedule to model delays or changes to the plan; the progress from the as-built schedule is simply compared to the original as-planned schedule. The analysis is *static* because the critical path of the as-planned schedule is used as the basis for identifying critical delays throughout the project. The analysis is *gross* because the as-built schedule is compared directly to the as-planned schedule. Interim updates are not analyzed as these reflect only a subset of the information that is ultimately captured in the final as-built schedule.

According to the RP, MIP 3.1 recommends the implementation of the Source Validation Protocols (SVPs) as follow: SVP 2.1 (baseline validation); SVP 2.2 (as-built validation) or SVP 2.3 (update validation); and SVP 2.4 (delay identification and quantification). There are no additional SVPs recommended for an enhanced implementation.

Other recommendations from the RP include: (1) recognize all contract time extensions granted, (2) identify the critical path activity that will be used to track the loss or gain of time for the overall network, and (3) separately identify activities that will be used to track intra-network time losses and gains, such as on interim milestones. For the purpose of this example implementation, all of the information sources have been evaluated based on the SVPs and deemed to be reliable sources of project information for the analysis. There have been no contract time extensions granted. The activity that will be used to track delays to the overall network will be Activity M990. There are no intermediate milestones on the project [2].

The analysis begins with a direct comparison of the as-planned and as-built schedules. Figure 4 shows an activity-by-activity comparison of the data from the two schedules.

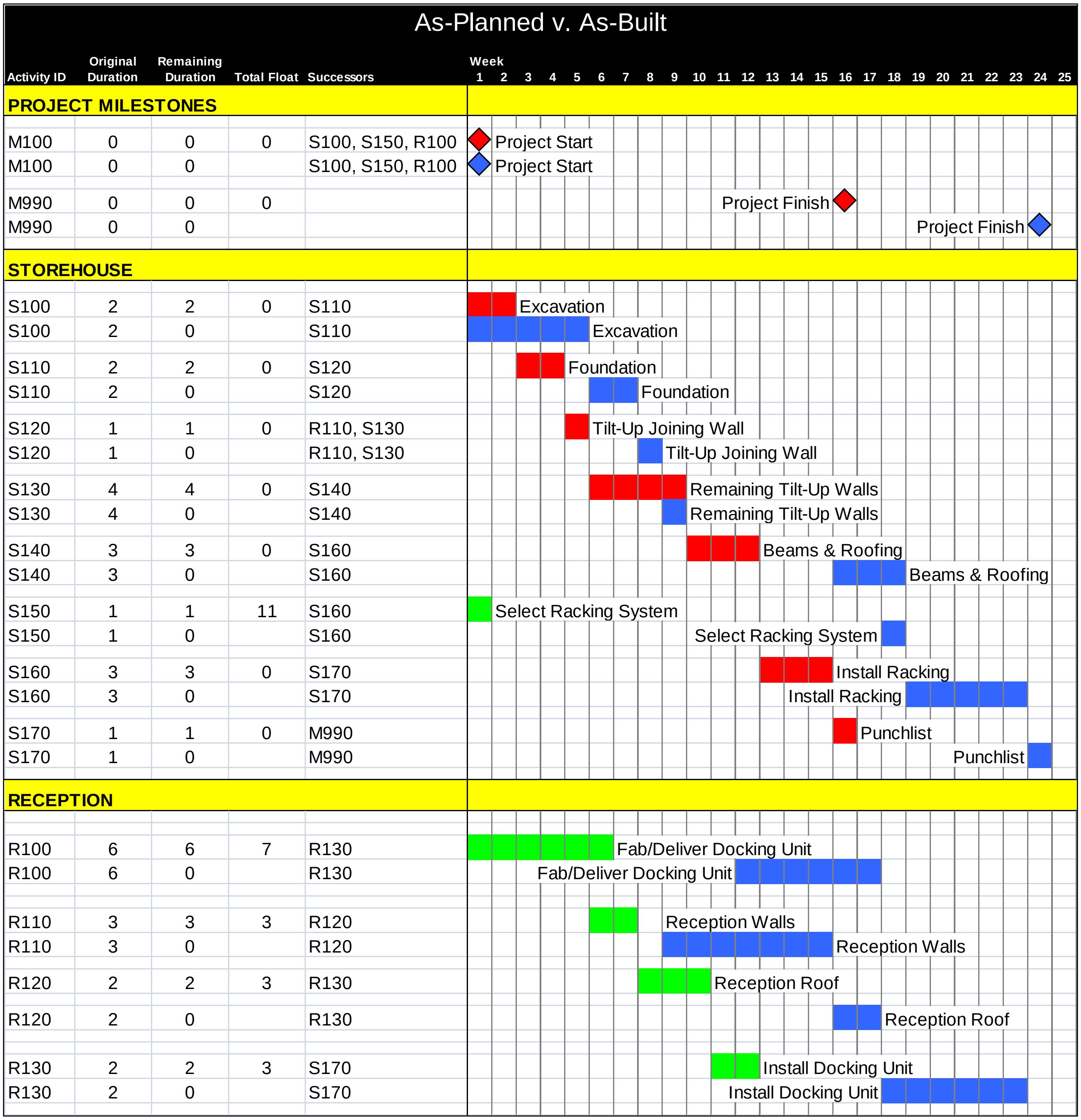


Figure 4 —As-Planned v. As-Built

Figure 4 includes the "raw" data from the as-planned and as-built schedules. The original durations shown are the same, as they would be in the schedule files. The remaining durations are the same as the original durations in the as-planned schedule, and are all zero in the as-built schedule. As the relevant information for the purpose of this analysis can be read directly from the bar chart on the right side of the figure, the columns on the left side will not be included in further figures. The planned and actual dates and durations can be observed on the bar chart. Using this information, the analyst might begin to identify and quantify delays from Figure 4.

SVP 2.4 recommends identifying activity-level variances (ALVs). These variances can be identified by comparing the planned and actual dates for all activities. The variances are summarized in table 2.

Activity-Level Variances		Planned Start	Planned Finish	Actual Start	Actual Finish	Start Variance	Finish Variance	Duration Variance
PROJECT MILESTONES								
M100	Project Start	1		1		0		N/A
M990	Project Finish		16		24		8	N/A
STOREHOUSE								
S100	Excavation	1	2	1	5	0	3	3
S110	Foundation	3	4	6	7	3	3	0
S120	Tilt-Up Joining Wall	5	5	8	8	3	3	0
S130	Remaining Tilt-Up Walls	6	9	9	9	3	0	(3)
S140	Beams & Roofing	10	12	16	18	6	6	0
S150	Select Racking System	1	1	18	18	17	17	0
S160	Install Racking	13	15	19	23	6	8	2
S170	Punchlist	16	16	24	24	8	8	0
RECEPTION								
R100	Fab/Deliver Docking Unit	1	6	12	17	11	11	0
R110	Reception Walls	6	7	9	15	3	8	5
R120	Reception Roof	7	9	16	17	9	8	(1)
R130	Install Docking Unit	10	11	18	23	8	12	4

Table 2 — Activity-Level Variances for MIP 3.1

The information in table 2 shows the extent to which each activity in the schedule started late and finished late. By comparing those variances, it also shows the extent to which each activity's duration exceeded its original duration. In the case of the Remaining Tilt-Up Walls and Reception Roof, the activities actually took less time than planned. The information in table 2 is useful but not conclusive, because variances are cumulative as the project progresses. In addition, table 2 does not indicate whether the delays noted were critical. Further investigation is required.

Based on the project records, there were delays associated with an underground storage tank that impacted excavation; delivery of the docking unit; and design issues that affected roof joists and panels. At one point, the contractor also noted that selection of the racking system was "becoming critical," but selection did not appear to delay procurement, based on the project records. In any case, Install Racking was on the critical path in the as-planned schedule, and its finish was delayed by eight weeks, so the analysis will begin there.

Figure 5 is an initial attempt to associate the overall eight-week project delay with the individual activity delays shown in table 2. By initial inspection, it is clear that there was a total eight-week delay to the completion of Install Racking. Racking installation started six weeks later than originally planned, and its duration was two weeks longer than planned. These appear to be critical delays, because of the fact that Install Racking was on the critical path in the as-planned schedule, and it was driving the start of Punchlist, which was driving Project Finish, in the as-built schedule. The project documentation discusses the fact that racking installation was proceeding from Weeks 19 through 23, which was two weeks longer than planned. The documentation also indicates that the owner had an electrical contractor working during Weeks 21 and 22, and that racking installation was suspended during that period.

Predecessor activities will be investigated to determine what caused the delay to the start of Install Racking. As can be seen from the activity level variances in table 2, Beams and Roofing was delayed by six weeks, and it was a predecessor to Install Racking. In addition, we can see that there was a three-week delay to excavation at the start of the project. Those delays are plotted on the project schedule in the next step of the analysis.

Based on the project records, there was a delay to Excavation because of a UST that was found within the building footprint. In addition, there was a delay to the beams and roofing because of a dimensional discrepancy between the structural and architectural drawings. These delays are plotted on the as-planned v. as-built comparison in figure 6. A portion of the roofing delay overlaps with the racking delay noted previously. As the roofing delay occurred first, the overlapping portion of the racking delay is marked as 'concurrent,' as the delays appear to be concurrent in figure 6.

Figure 6 now shows a total of 14 weeks of non-concurrent delay, and the actual project was only delayed by eight weeks. Some simple presentations might stop here, having identified at least enough delay to explain the total project delay. If a presentation is to be made on behalf of the contractor, as part of a request for waiver of liquidated damages, it might include the following statements:

- We were delayed by three weeks because of unforeseen underground conditions associated with the UST.
- We were delayed by an additional six weeks because of a dimensional design error between the structural and architectural drawings.
- We started the racking later than planned; therefore, we were not able to complete it prior to the mobilization of the owner's electrical contractor. Racking installation had to be suspended for two weeks during that contractor's work.
- We are due a time extension of at least 11 weeks, so we should not be assessed liquidated damages for finishing eight weeks late.

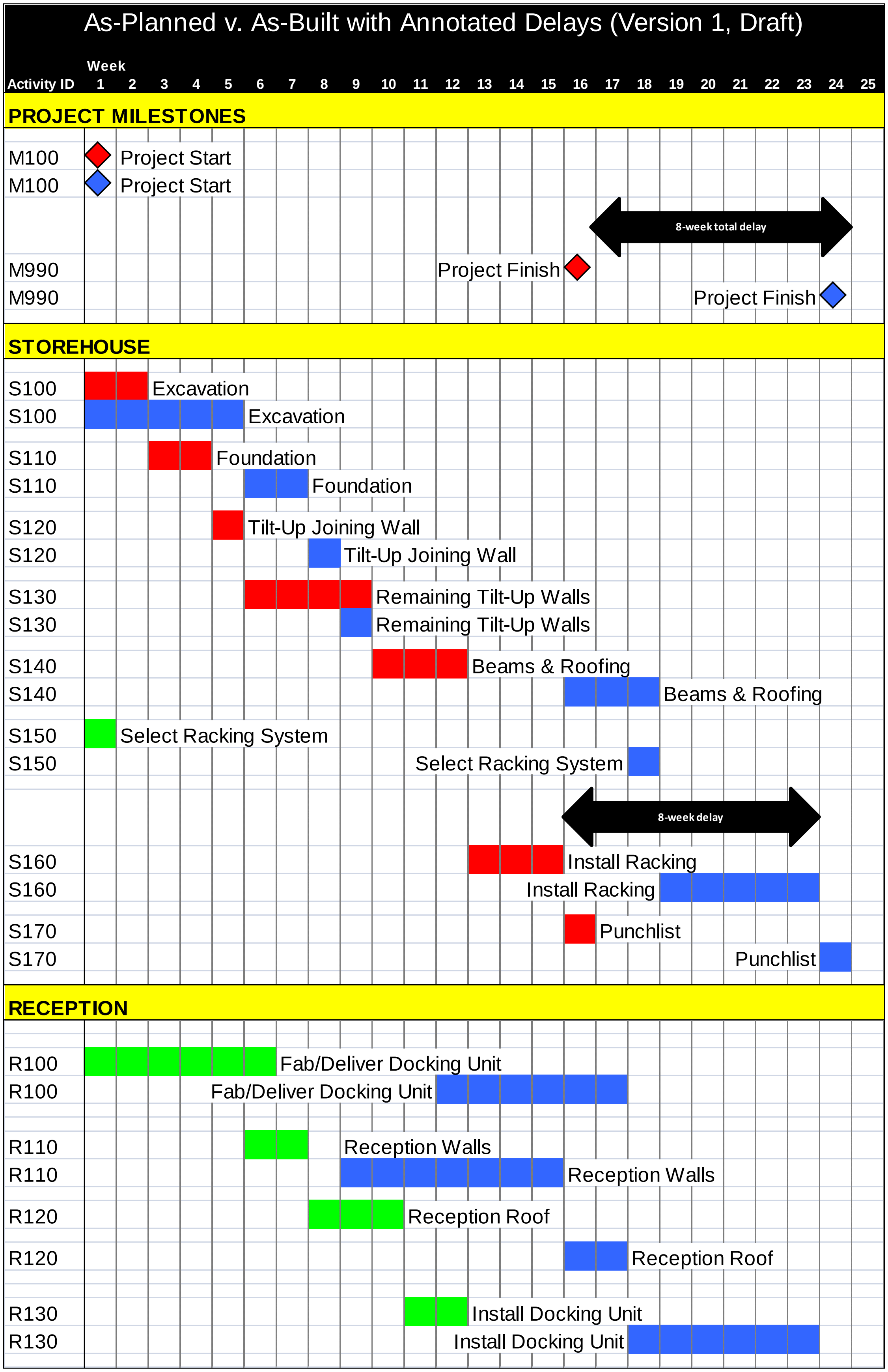


Figure 5 — As-Planned v. As-Built with Annotated Delays (Version 1, Draft)

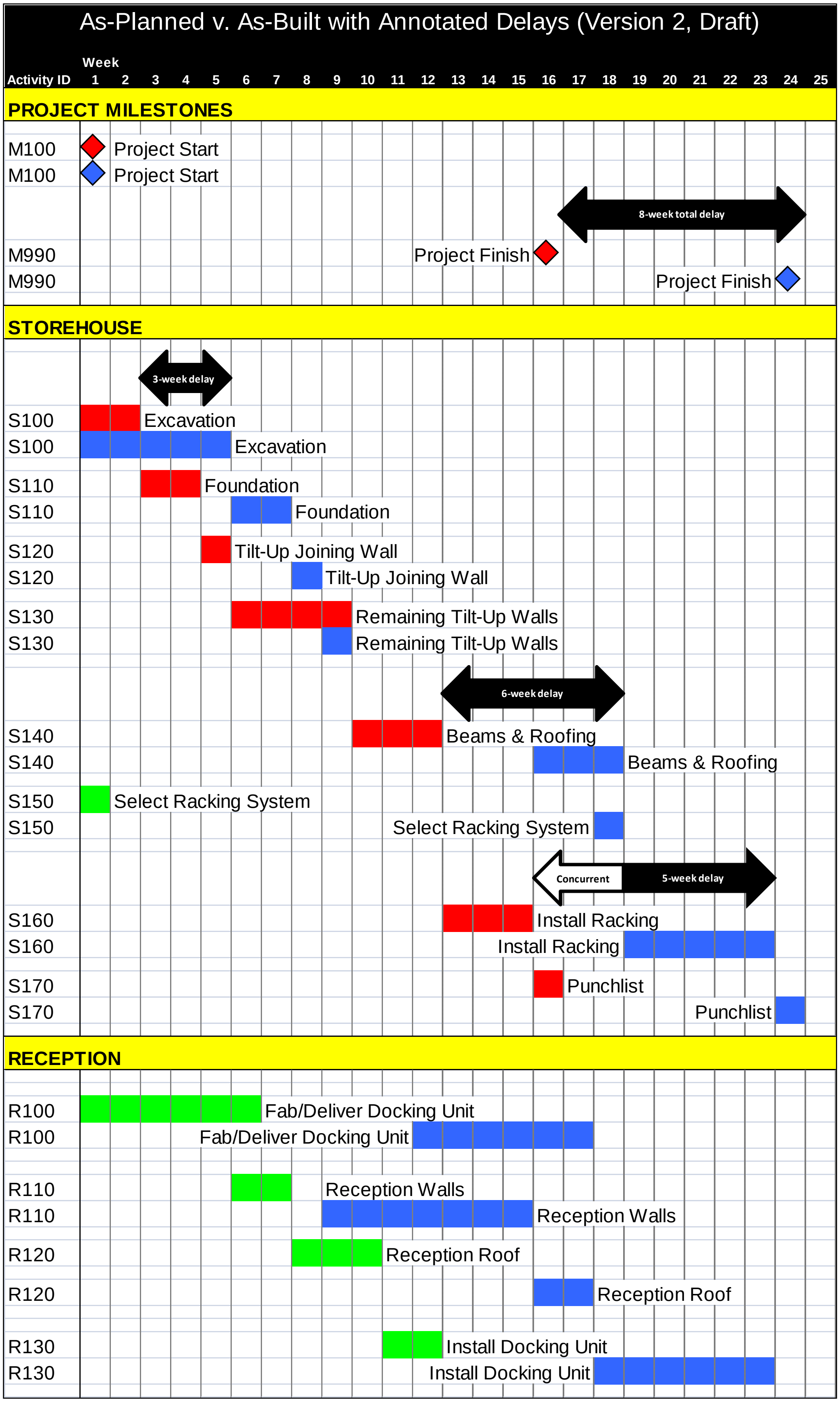


Figure 6 — As-Planned v. As-Built with Annotated Delays (Version 2, Draft)

Depending on the owner, this presentation might be sufficient to obtain a release from liquidated damages. However, some owners might require a more detailed analysis. Certainly, if a presentation is to be made before an arbitration panel or in a courtroom, the contractor would likely want to have a much more thorough presentation. If presented as an expert opinion, a presentation such as the preceding one runs the risk of being dismissed entirely for not meeting the standards for expert testimony. Therefore, in an attempt to add more detail—while staying within the analysis techniques outlined in MIP 3.1—the analysis will continue. As we have identified the major delays of interest, the sub-critical activities that have not been associated with project delays at this point are removed from the figures for simplicity.

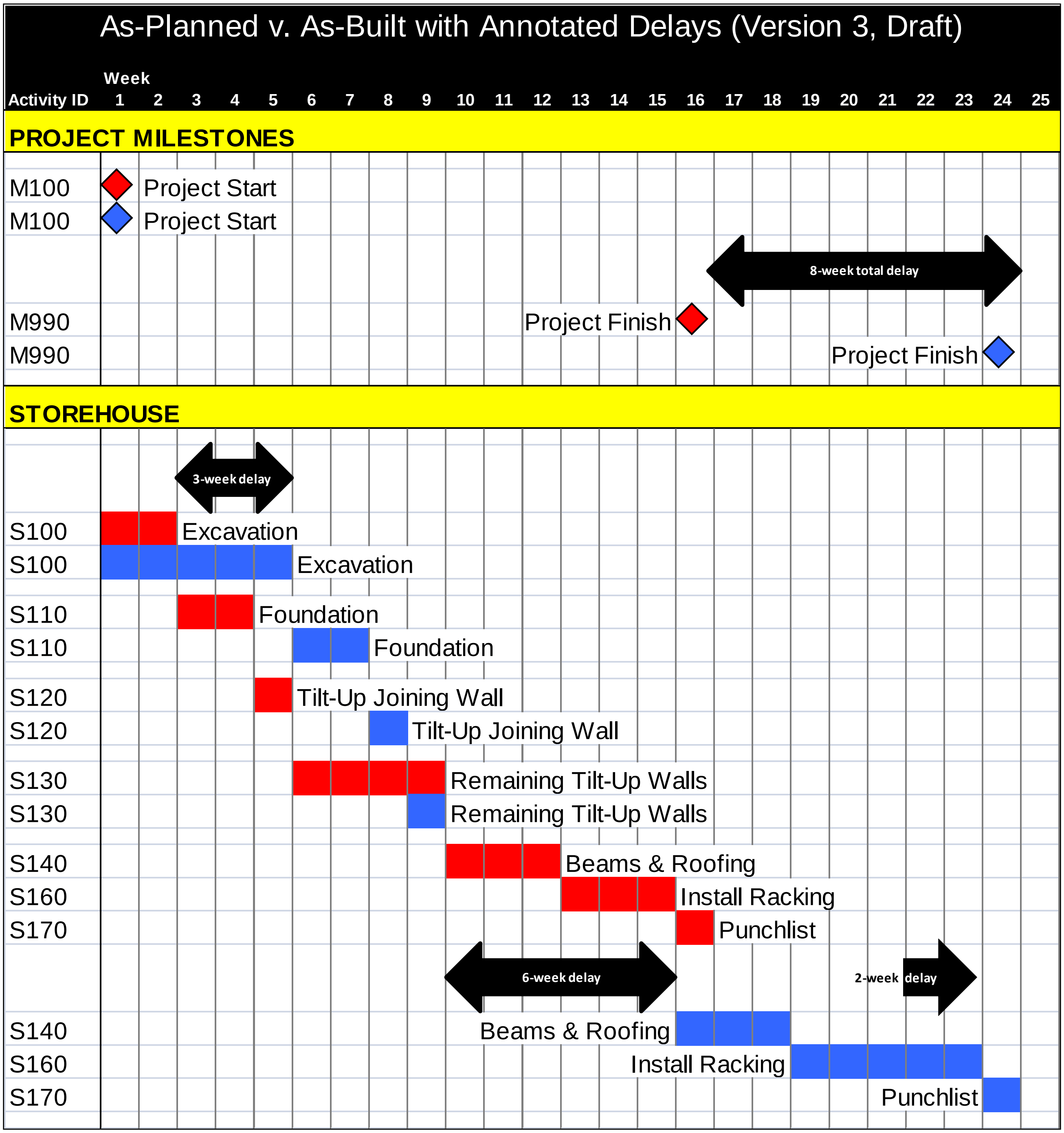


Figure 7 — As-Planned v. As-Built with Annotated Delays (Version 3, Draft)

Figure 7 shows that the entire six-week delay to Install Racking could be associated with the late finish of Beams and Roofing. This leaves a two-week delay associated with the extended duration of Install Racking, and eliminates the concurrent delay noted in Figure 6. As can be seen in figure 7, Beams and Roofing and Install Racking were planned sequentially and actually proceeded sequentially. They were not concurrent activities, and there was no concurrent delay. Instead, the delays were sequential. Still, figure 7 shows a total of 11 weeks of delay. As the overall project was only delayed by eight weeks, further investigation is required to resolve the discrepancy.

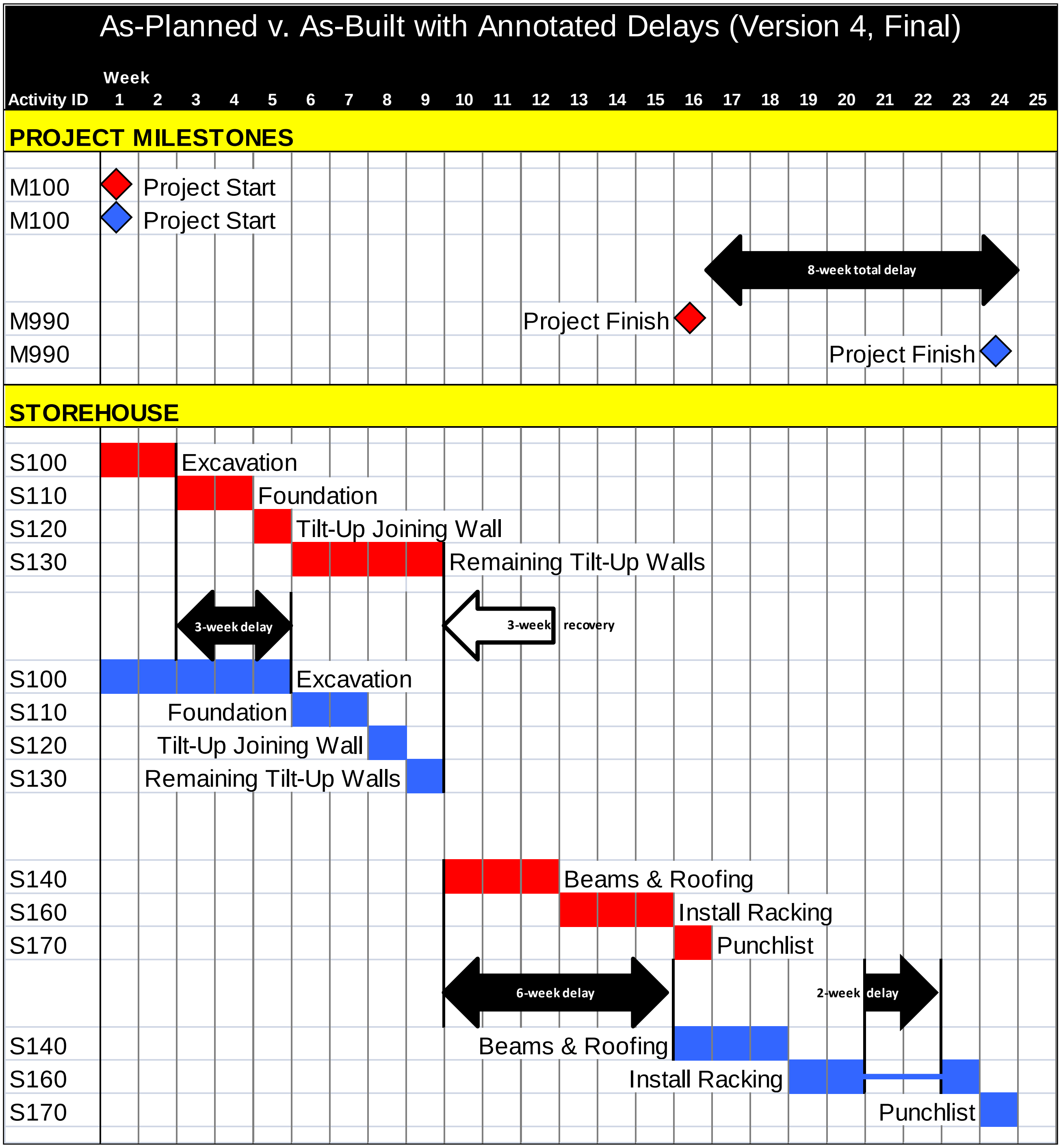


Figure 8 — As-Planned v. As-Built with Annotated Delays (Version 4, Final)

Figure 8 recognizes the fact that the delay to Excavation was recovered by Week 9, and the Remaining Tilt-Up Walls activity was completed in the same week as originally planned. The three-week recovery is shown to highlight that fact. Subsequently, the project experienced a six-week delay to the start of Beams and Roofing and a two-week delay due to the extended duration of Install Racking. This figure will be used in the final presentation of the analysis. The total project delay is determined to include the following:

- Three-week delay to Excavation
- Three-week savings to Remaining Tilt-Up Walls
- Six-week delay to Beams and Roofing
- Two-week delay to Install Racking

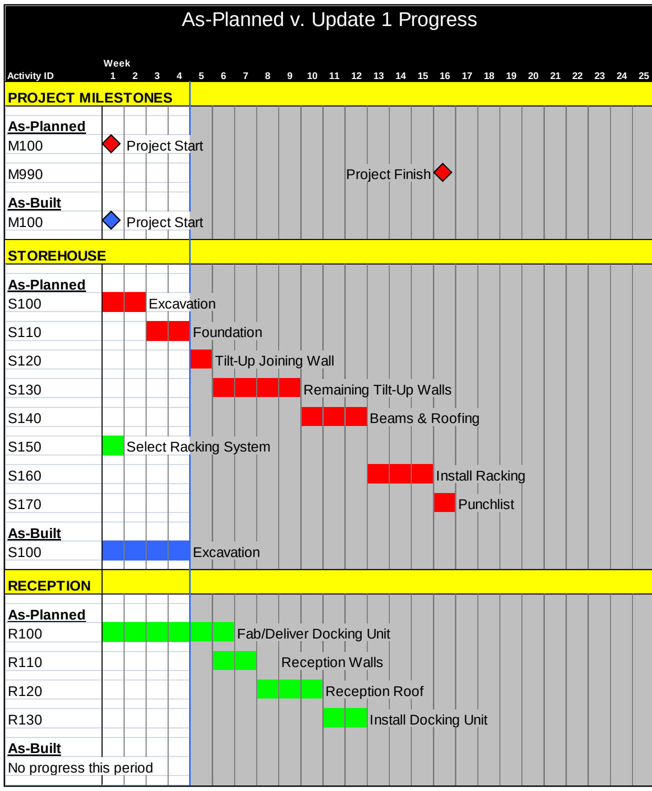
Analysis by Comparing the As-Planned and As-Built Schedules on a Periodic Basis

Observational/Static/Periodic Analysis per MIP 3.2

This analysis will be performed based on the method implementation protocol (MIP) described in Section 3.2 of the RP. The analysis is classified as *retrospective* because the analysis is performed after the delay events and the impacts of those events have occurred and the outcome is known. The analysis is *observational* because no activities are added or subtracted from the schedule to model delays or changes to the plan; the progress from the as-built schedule is simply compared to the original as-planned schedule. The analysis is *static* because the critical path of the as-planned schedule is used as the basis for identifying critical delays throughout the project. The analysis is *periodic* because the progress in each schedule update is compared sequentially to the as-planned schedule, and delays are identified during each update period.

It is notable that MIP 3.2 is still considered a static analysis technique, even though the updates will be used in the analysis. This is because the analysis will proceed based on the critical path from the as-planned schedule. There is an inherent assumption that the parties had an agreed-upon plan with which to execute the work, and the contractor based its pricing and performance on that plan. The contractor prepared the plan; the owner reviewed it, provided comments, and ultimately approved it. Both the contractor and owner agreed that the critical path shown in the plan was the critical path of the project.

MIP 3.2 recommends the implementation of the same SVPs as MIP 3.1. Again, for the purpose of this analysis, assume that all of the source documentation provided has been reviewed and determined to be valid. The analysis begins with a comparison of the as-planned schedule to the first update, as shown in figure 9.



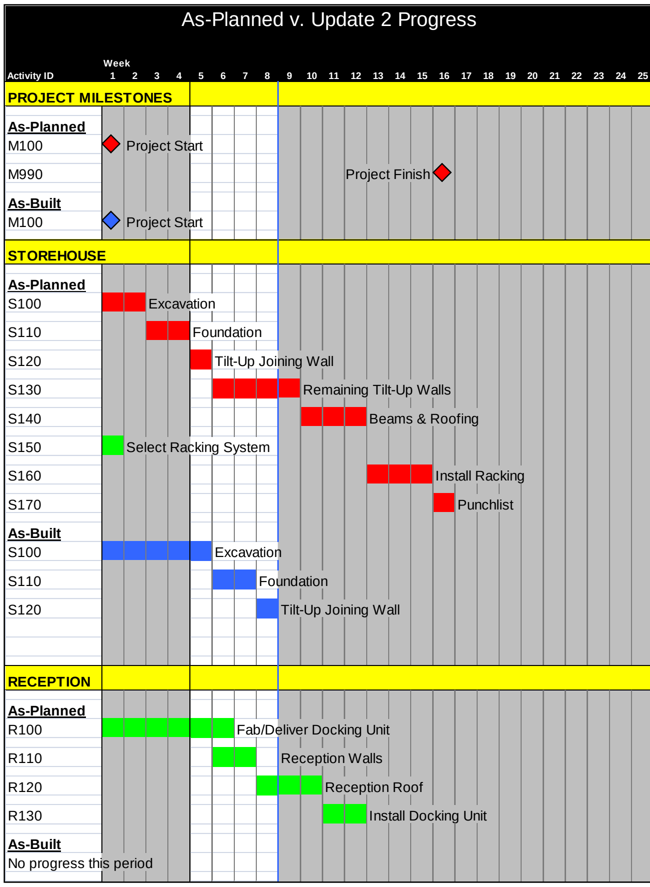
Activity-Level Variances

Activity ID	Activity	Planned Start	Planned Finish	Actual Start	Actual Finish	Start Variance	Finish Variance	Period Duration Variance	Total Duration Variance
PROJECT MILESTONES									
M100	Project Start	1		1		0		N/A	N/A
M990	Project Finish		16		TBD		TBD	N/A	N/A
STOREHOUSE									
S100	Excavation	1	2	1	TBD	0	TBD	2	TBD
S110	Foundation	3	4	TBD	TBD	TBD	TBD	TBD	TBD
S120	Tilt-Up Joining Wall	5	5	TBD	TBD	TBD	TBD	TBD	TBD
S130	Remaining Tilt-Up Walls	6	9	TBD	TBD	TBD	TBD	TBD	TBD
S140	Beams & Roofing	10	12	TBD	TBD	TBD	TBD	TBD	TBD
S150	Select Racking System	1	1	TBD	TBD	TBD	TBD	TBD	TBD
S160	Install Racking	13	15	TBD	TBD	TBD	TBD	TBD	TBD
S170	Punchlist	16	16	TBD	TBD	TBD	TBD	TBD	TBD
RECEPTION									
R100	Fab/Deliver Docking Unit	1	6	TBD	TBD	TBD	TBD	TBD	TBD
R110	Reception Walls	6	7	TBD	TBD	TBD	TBD	TBD	TBD
R120	Reception Roof	7	9	TBD	TBD	TBD	TBD	TBD	TBD
R130	Install Docking Unit	10	11	TBD	TBD	TBD	TBD	TBD	TBD

Figure 9 — As-Planned v. Update 1 Progress with ALVs for Period

In reviewing each period, the analyst can identify any ALVs that occur during the period. Those values are tabulated on the right side of figure 9. Values determined in this step of the analysis are highlighted in yellow in the table. During the first period, the Project Start milestone occurred, and Excavation began. The milestone began as planned, so the ALVs is zero. Duration variances are not applicable to milestone activities, and are marked “N/A” on the right side of figure 9.

Excavation began as planned, and its actual start date is reported on the right side of figure 9. The start variance is reported as zero. Excavation had a planned duration of two weeks, and it had an actual duration of four weeks by the end of the period. Therefore, its duration variance for the period is reported as two weeks. The activity was incomplete at the end of the period, so its total duration variance is to be determined and is marked “TBD” in the table. No other activities made progress during the period analyzed in figure 9.

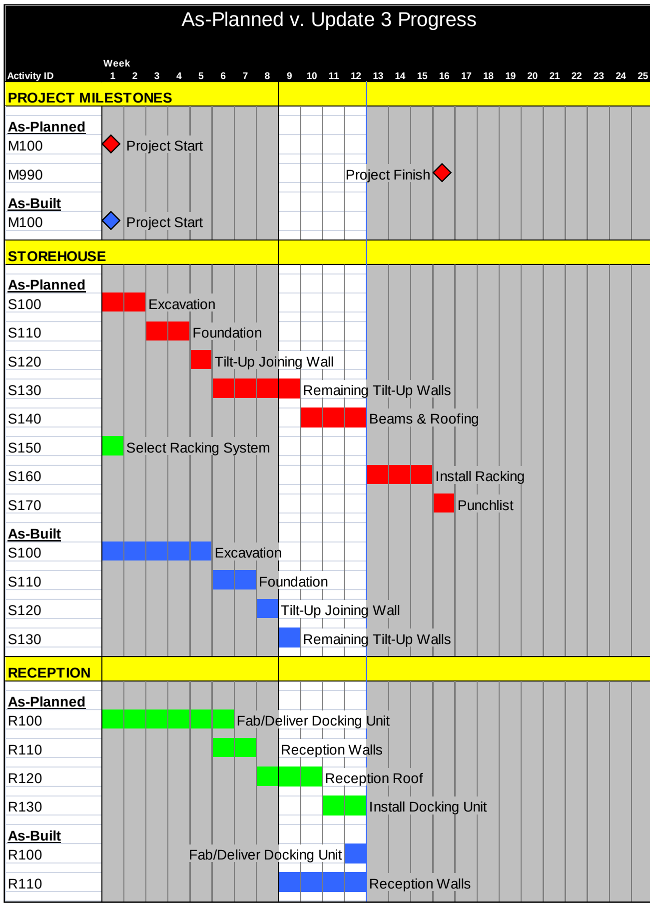


Activity-Level Variances

Activity ID	Activity	Planned Start	Planned Finish	Actual Start	Actual Finish	Start Variance	Finish Variance	Period Duration Variance	Total Duration Variance
PROJECT MILESTONES									
M100	Project Start	1		1		0		N/A	N/A
M990	Project Finish		16		TBD		TBD	N/A	N/A
STOREHOUSE									
S100	Excavation	1	2	1	5	0	3	1	3
S110	Foundation	3	4	6	7	3	3	0	0
S120	Tilt-Up Joining Wall	5	5	8	8	3	3	0	0
S130	Remaining Tilt-Up Walls	6	9	TBD	TBD	TBD	TBD	TBD	TBD
S140	Beams & Roofing	10	12	TBD	TBD	TBD	TBD	TBD	TBD
S150	Select Racking System	1	1	TBD	TBD	TBD	TBD	TBD	TBD
S160	Install Racking	13	15	TBD	TBD	TBD	TBD	TBD	TBD
S170	Punchlist	16	16	TBD	TBD	TBD	TBD	TBD	TBD
RECEPTION									
R100	Fab/Deliver Docking Unit	1	6	TBD	TBD	TBD	TBD	TBD	TBD
R110	Reception Walls	6	7	TBD	TBD	TBD	TBD	TBD	TBD
R120	Reception Roof	7	9	TBD	TBD	TBD	TBD	TBD	TBD
R130	Install Docking Unit	10	11	TBD	TBD	TBD	TBD	TBD	TBD

Figure 10 — As-Planned v. Update 2 Progress with ALVs for Period

In the second period, Excavation is finished, and the Foundation and Tilt-Up Joining Wall activities both started and finished. Figure 10 shows the as-built schedule for the completed Excavation activity and the two additional activities. The associated ALVs are tabulated on the right. There is an additional one-week delay in this period associated with the extended duration of Excavation. Its original planned duration was two weeks. That duration had already been overrun by two weeks in Period 1. The additional one week in Period 2 brings the cumulative duration variance to a total of three weeks. This appears to be the same three weeks associated with the start and finish variances on the Foundation and Tilt-Up Joining Wall activities.

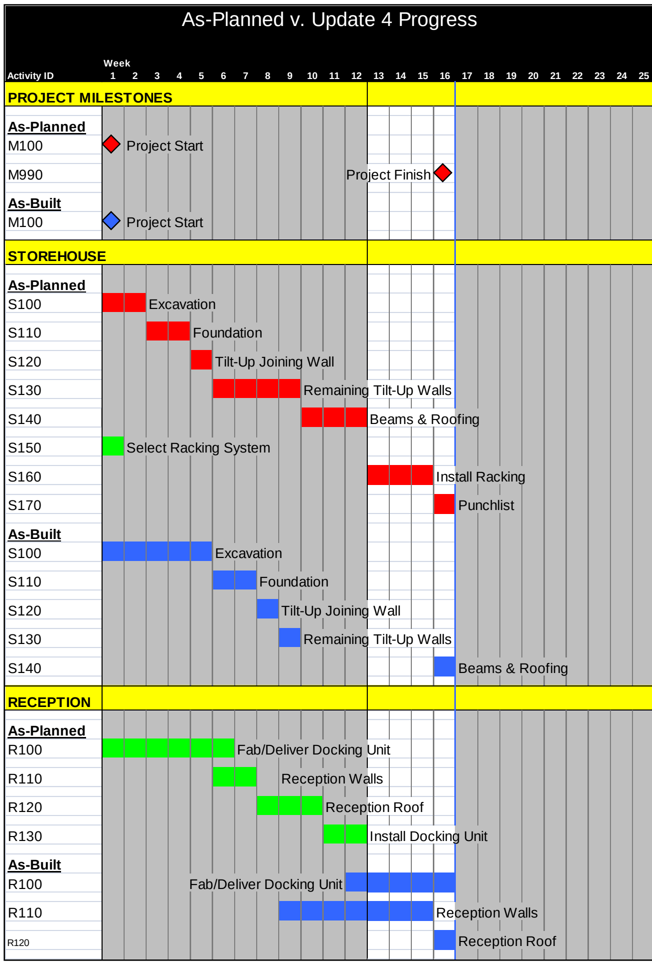


Activity-Level Variances

		Planned Start	Planned Finish	Actual Start	Actual Finish	Start Variance	Finish Variance	Period Duration Variance	Total Duration Variance
PROJECT MILESTONES									
M100	Project Start	1		1		0		N/A	N/A
M990	Project Finish		16		TBD		TBD	N/A	N/A
STOREHOUSE									
S100	Excavation	1	2	1	5	0	3	0	3
S110	Foundation	3	4	6	7	3	3	0	0
S120	Tilt-Up Joining Wall	5	5	8	8	3	3	0	0
S130	Remaining Tilt-Up Walls	6	9	9	9	3	0	(3)	(3)
S140	Beams & Roofing	10	12	TBD	TBD	TBD	TBD	TBD	TBD
S150	Select Racking System	1	1	TBD	TBD	TBD	TBD	TBD	TBD
S160	Install Racking	13	15	TBD	TBD	TBD	TBD	TBD	TBD
S170	Punchlist	16	16	TBD	TBD	TBD	TBD	TBD	TBD
RECEPTION									
R100	Fab/Deliver Docking Unit	1	6	12	TBD	11	TBD	0	TBD
R110	Reception Walls	6	7	9	TBD	3	TBD	2	TBD
R120	Reception Roof	7	9	TBD	TBD	TBD	TBD	TBD	TBD
R130	Install Docking Unit	10	11	TBD	TBD	TBD	TBD	TBD	TBD

Figure 11 — As-Planned v. Update 3 Progress with ALVs for Period

Figure 11 shows the three weeks of recovery achieved by completing the Remaining Tilt-Up Walls more quickly than originally planned. Comparing the as-planned critical path to the as-built path in the Storehouse, the analyst can see that the critical path is back on schedule by the end of Week 9. Work has also started in the Reception area, which was not on the critical path in the baseline schedule. The project records indicated that there was some concern regarding the fabrication of the docking unit, but they also indicated that the contractor was working with the supplier to expedite delivery. In any event, the project is not ready for the docking unit. More importantly, the critical Beams and Roofing activity did not begin immediately after the finish of Remaining Tilt-Up Walls. The magnitude of the delay associated with the start of roofing will be assessed in the next period, when work on that activity begins.

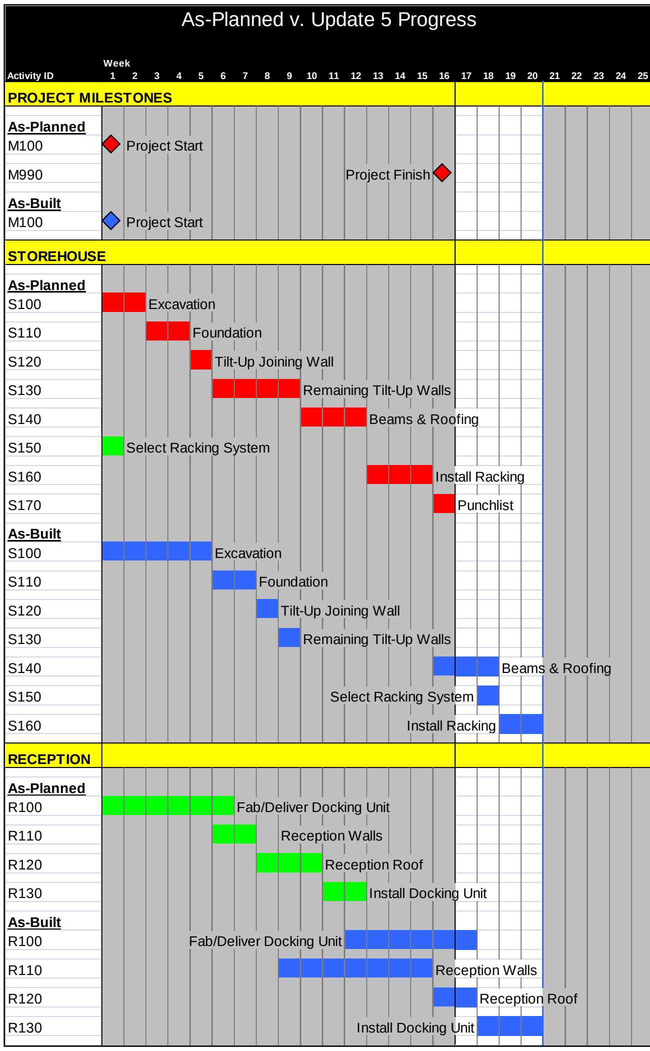


Activity-Level Variances

Activity ID	Activity	Planned Start	Planned Finish	Actual Start	Actual Finish	Start Variance	Finish Variance	Period Duration Variance	Total Duration Variance
PROJECT MILESTONES									
M100	Project Start	1		1		0		N/A	N/A
M990	Project Finish		16		TBD		TBD	N/A	N/A
STOREHOUSE									
S100	Excavation	1	2	1	5	0	3	0	3
S110	Foundation	3	4	6	7	3	3	0	0
S120	Tilt-Up Joining Wall	5	5	8	8	3	3	0	0
S130	Remaining Tilt-Up Walls	6	9	9	9	3	0	0	(3)
S140	Beams & Roofing	10	12	16	TBD	6	TBD	0	TBD
S150	Select Racking System	1	1	TBD	TBD	TBD	TBD	TBD	TBD
S160	Install Racking	13	15	TBD	TBD	TBD	TBD	TBD	TBD
S170	Punchlist	16	16	TBD	TBD	TBD	TBD	TBD	TBD
RECEPTION									
R100	Fab/Deliver Docking Unit	1	6	12	TBD	11	TBD	0	TBD
R110	Reception Walls	6	7	9	15	3	8	3	5
R120	Reception Roof	7	9	16	TBD	9	TBD	0	TBD
R130	Install Docking Unit	10	11	TBD	TBD	TBD	TBD	TBD	TBD

Figure 12 — As-Planned v. Update 4 Progress with ALVs for Period

Figure 12 shows the analysis of the fourth period. The start of Beams and Roofing was delayed six weeks, and this appears to be a critical path delay. Meanwhile, progress in Reception continued, and delivery of the docking unit appears to be imminent. Based on the project records, the dimensional issues that caused the delay to Beams and Roofing have been resolved through modifications to the roof structure and panels, and installation of the roof system began in Week 16, as shown.

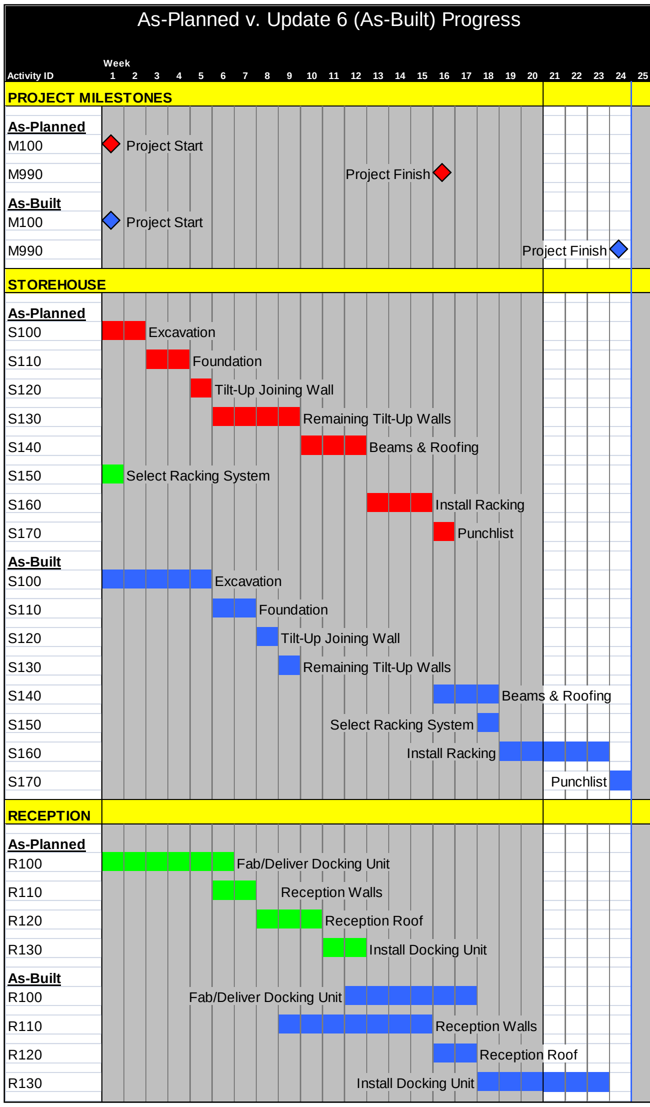


Activity-Level Variances

Activity ID	Activity	Planned Start	Planned Finish	Actual Start	Actual Finish	Start Variance	Finish Variance	Period Duration Variance	Total Duration Variance
PROJECT MILESTONES									
M100	Project Start	1		1		0		N/A	N/A
M990	Project Finish		16		TBD		TBD	N/A	N/A
STOREHOUSE									
S100	Excavation	1	2	1	5	0	3	1	3
S110	Foundation	3	4	6	7	3	3	0	0
S120	Tilt-Up Joining Wall	5	5	8	8	3	3	0	0
S130	Remaining Tilt-Up Walls	6	9	9	9	3	0	0	(3)
S140	Beams & Roofing	10	12	16	18	6	6	0	0
S150	Select Racking System	1	1	18	18	17	17	0	0
S160	Install Racking	13	15	19	TBD	6	TBD	0	TBD
S170	Punchlist	16	16	TBD	TBD	TBD	TBD	TBD	TBD
RECEPTION									
R100	Fab/Deliver Docking Unit	1	6	12	17	11	11	0	0
R110	Reception Walls	6	7	9	15	3	8	0	5
R120	Reception Roof	7	9	16	17	9	8	(1)	(1)
R130	Install Docking Unit	10	11	18	TBD	8	TBD	1	TBD

Figure 13 — As-Planned v. Update 5 Progress with ALVs for Period

Figure 13 shows that the Beams and Roofing activity was completed within its planned duration. Meanwhile, work in Reception continued, and the roof in that area was completed in one week less than its planned duration. The docking unit was delivered, and installation is under way. Installation has overrun its duration by one week, but that week appears to have been mitigated by the better-than-planned progress on Roofing. Both areas of the project are complete except for Install Racking, Install Docking Unit, and Punchlist. The project is already four weeks past its planned completion date. Based on project documentation, the project is expected to finish in another two weeks.



Activity-Level Variances

Activity ID	Activity	Planned Start	Planned Finish	Actual Start	Actual Finish	Start Variance	Finish Variance	Period Duration Variance	Total Duration Variance
PROJECT MILESTONES									
M100	Project Start	1		1		0		N/A	N/A
M990	Project Finish		16		24		8	N/A	N/A
STOREHOUSE									
S100	Excavation	1	2	1	5	0	3	1	3
S110	Foundation	3	4	6	7	3	3	0	0
S120	Tilt-Up Joining Wall	5	5	8	8	3	3	0	0
S130	Remaining Tilt-Up Walls	6	9	9	9	3	0	0	(3)
S140	Beams & Roofing	10	12	16	18	6	6	0	0
S150	Select Racking System	1	1	18	18	17	17	0	0
S160	Install Racking	13	15	19	23	6	8	2	2
S170	Punchlist	16	16	24	24	8	8	0	0
RECEPTION									
R100	Fab/Deliver Docking Unit	1	6	12	17	11	11	0	0
R110	Reception Walls	6	7	9	15	3	8	0	5
R120	Reception Roof	7	9	16	17	9	8	(1)	(1)
R130	Install Docking Unit	10	11	18	23	8	12	3	4

Figure 14 — As-Planned v. As-Built Progress with ALVs for Period

As shown in figure 14, it actually took four weeks to complete the project, instead of two as forecast in the project documentation available from Week 20 (and the schedule update from Week 20.) The additional two weeks of delay appear to be because of the extended duration of the Install Racking and Install Docking Unit activities, concurrently. Both activities were completed in Week 23. Then Punchlist work was completed within its planned one week duration, and the project was completed in Week 24. All periods have now been analyzed; the ALV table has been fully populated; all available project documentation has been reviewed; and the analyst is now ready to summarize the results of the analysis.

Activity-Level Variances		Planned Start	Planned Finish	Actual Start	Actual Finish	Start Variance	Finish Variance	Duration Variance
PROJECT MILESTONES								
M100	Project Start	1		1		0		N/A
M990	Project Finish		16		24		8	N/A
STOREHOUSE								
S100	Excavation	1	2	1	5	0	3	3
S110	Foundation	3	4	6	7	3	3	0
S120	Tilt-Up Joining Wall	5	5	8	8	3	3	0
S130	Remaining Tilt-Up Walls	6	9	9	9	3	0	(3)
S140	Beams & Roofing	10	12	16	18	6	6	0
S150	Select Racking System	1	1	18	18	17	17	0
S160	Install Racking	13	15	19	23	6	8	2
S170	Punchlist	16	16	24	24	8	8	0
RECEPTION								
R100	Fab/Deliver Docking Unit	1	6	12	17	11	11	0
R110	Reception Walls	6	7	9	15	3	8	5
R120	Reception Roof	7	9	16	17	9	8	(1)
R130	Install Docking Unit	10	11	18	23	8	12	4

Table 3 — Completed Activity-Level Variance Table for MIP 3.2

The completed ALV table created in MIP 3.2 consolidates the variances identified in all periods. In fact, it is identical to the ALV table created for MIP 3.1. It was simply populated through a step-by-step process in MIP 3.2. With the project records and the analysis of each period, initial conclusions can be presented as to the delays that occurred during each period. For example:

- Period 1—Critical Excavation began, but progress was delayed by two weeks because of unforeseen underground site conditions associated with the removal and remediation of a UST.

- Period 2—Critical Excavation was delayed by one additional week; critical Foundation and Tilt-Up Joining Wall activities were delayed by the extended duration of Excavation, but once they started, they were completed with no additional delay.
- Period 3—Critical Remaining Tilt-Up Walls were expedited to recover the prior delay. Reception Walls were also proceeding. Critical Beams and Roofing did not begin as planned. No critical path work was performed during the last two weeks of the period. However, work in the Reception area proceeded.
- Period 4—The delay to Critical Beams and Roofing because of dimensional errors continued until Week 16. As that work should have started in Week 10, this was a total six-week delay by the end of Period 4. Work in the Reception area continued.
- Period 5—Beams and Roofing work was completed within its planned duration. Final details regarding the racking system were resolved with the owner in the same week that roof work was completed, so that Racking Installation could proceed the following week. The Reception area was completed, except for the Docking Unit.
- Period 6—Install Racking took two weeks longer than originally planned, and Install Docking Unit took four weeks longer than originally planned. Those were the last two activities to be completed prior to punchlist. They were both completed in Week 23, but the extended durations caused an additional two weeks of delay. While Install Docking Unit was not on the as-planned critical path, everything was critical at this point, because the project should have been completed in Week 16. Therefore, the delays associated with the racking system and docking unit were considered to be concurrent. In fact, a review of the project documentation shows that both activities were delayed by electrical work, which was performed by another contractor. Once they were completed, Punchlist was completed as planned, and the project was completed in Week 24.

Some analysts might disagree with some of these statements based on critical path concepts. They might argue that there is nothing in the analysis that justifies the determination of which activities are critical. In fact, they might argue that the analysis does not take into account the "dynamic nature of the critical path," even though it is divided into periods and presented in a manner that might be called a "windows analysis" by some practitioners. It is true that the analysis does not take the dynamic nature of the critical path into account. It is a static analysis, based on the concept presented at the beginning of this section—the owner and contractor had an understanding as to what was critical on the project, and they documented that understanding at the beginning of the project through their development, review, and agreement on the project schedule.

One party might argue that the analysis did not address significant delays to some activities in Reception; and the other party might argue that the Reception work was never critical, and could have been expedited if it had become critical. If this analysis were to be presented in a legal forum, the analyst would likely want to consult with counsel as to whether there exists precedent that requires an analyst to recognize the critical path as dynamic in an analysis such as this one. However, in a forum where a contract time extension is to be negotiated (as opposed to litigated), this analysis may be compelling if presented by persons knowledgeable of the events that occurred during each period of the project.

Another criticism of this analysis might be based on the fact that the remaining work from the as-planned schedule should be pushed to the right as each periodic analysis begins. From one perspective, it is confusing to compare the as-built schedule to the original as-planned schedule once delays have occurred. Rescheduling incomplete work at the end of each period would classify this as a dynamic analysis, and critical path shifts would need to be considered each time the remaining work is rescheduled. That technique is covered under MIP 3.3 in the RP, and an analysis of this project using the technique was presented in 2008 [2].

Analysis by Removing Delay Events from the As-Built Schedule

Modeled/Subtractive Single-Simulation Analysis per MIP 3.8

This analysis will be performed based on the method implementation protocol (MIP) described in Section 3.8 of the RP. The analysis is classified as *retrospective* because the analysis is performed after the delay events and the impacts of those events have occurred and the outcome is known. The analysis is *modeled* because activities modeling the delay events are inserted into the as-built schedule. Then they are subtracted to collapse the as-built schedule. The analysis is a *single-simulation* because the delays are extracted in one period—between the as-planned and as-built schedules. Although the delays may be extracted in a particular order, no specific effort is made to divide the analysis into periods or reproduce the status of the project as it was shown in the intermediate updates.

MIP 3.8 recommends the implementation of SVPs 2.2 (as-built validation) and 2.4 (delay ID and quantification). For the purpose of the analysis, the as-built has been validated. Delays will be identified and quantified in the initial steps of the analysis. MIP 3.8 states that SVPs 2.1 (baseline validation) and 2.3 (update validation) can be performed in an "enhanced implementation." Similar to the other MIPs covered for this example, assume that all data sources have been validated and deemed to be reliable.

After listing the relevant SVPs, MIP 3.8 lists a series of six points under the heading "Recommended Implementation Protocols" and three more points under "Enhanced Implementation Protocols. All of these points were taken into consideration in performing the example analysis. One point was determined not to be relevant to the example. Namely, no calendar was incorporated into the as-built schedule to model actual weather conditions. For the purpose of the analysis, weather conditions have been determined to be "normal" and had no impact on the project during its 24-week duration.

The analysis begins with the as-built schedule shown in figure 3. Network fragments ("fragnets") are then created to model each of the delaying events on the project, and these fragnets are inserted into the as-built schedule and logically tied so that the delay activities are linked to the activities that they affected. Based on a review of the project documents, the delays are identified and the fragnets created. The fragnets are similar to those that were used in the presentation of MIP 3.7 in 2008 [2]. One key difference is that all activities in the fragnets in MIP 3.8 are added to the schedule in the as-built condition. Another key difference is that the durations have been extended in some cases (as compared to the fragnets used in MIP 3.7) to facilitate collapsing the schedule.

Delay A—*Discovery of UST (differing site condition), testing, removal, and mitigation*— Excavation began as planned in Week 1. However, at the end of the week, an underground storage was discovered in the building footprint. Excavation proceeded, but was suspended in the area of the storage tank. One week was spent testing the surrounding soil for contamination and developing appropriate remediation efforts. Then, two weeks were spent removing the UST and contaminated soil before completing excavation activities. Fragnet A was developed to model the work associated with the UST, as shown in figure 15. Activities that are added are highlighted in the figures (light blue). The other activities shown in the fragnet graphics are included to show logical ties between the fragnet activities and existing schedule activities. That information is noted in the Successors column.

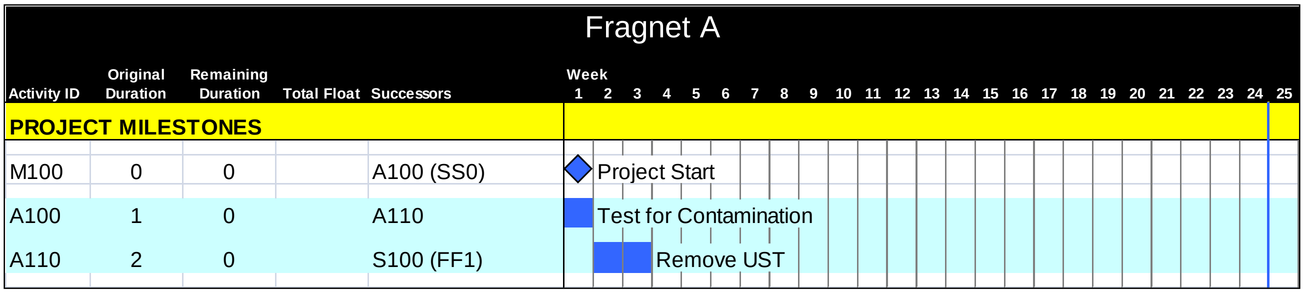


Figure 15 — Fragnet A

Delay B—*Docking unit supplier delay*—Fabrication of the docking unit was initially scheduled to begin in Week 1. Based on review of project documentation, the contractor's supplier indicated that it would not begin fabricating the docking unit until Week 11 because its factory was operating at capacity on other projects. The supplier wrote a letter to the contractor detailing the delay at the start of Week 5. Through continued communications with the supplier, the contractor learns that the fabricator actually begins work in Week 12. Fragnet B was developed to model the delay, as shown in figure 16. Although the supplier's letter indicated that it would delay the start of fabrication from Week 1 to Week 11, the supplier did not actually begin fabrication until Week 12. Therefore, the delay is modeled as continuing through Week 11.

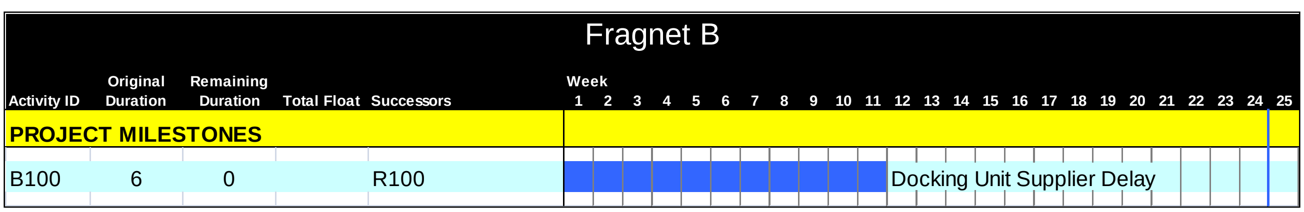


Figure 16 — Fragnet B

Delay C—*Drawing dimension discrepancies and field modifications of roof system*—Based on project documentation, structural steel arrived on site at the start of Week 13. The steel was fabricated in accordance with the contract drawings and the accepted shop drawings. However, when the erected tilt-up panels were surveyed, it was determined that there was an error in the contract drawings that caused numerous roof members and metal roof panels to be fabricated too long. The specifications contain a pre-approved procedure for cutting the steel members in the field. However, the specifications do not allow metal roof panels to be field cut or bent, and the owner will not waive that requirement because it would void the roof warranty. Thus, the panels will be returned to the supplier for modification. The field cutting of structural steel is expected to take one week, but the panel modifications are expected to take four weeks. The panels will be shipped in two partial deliveries in order to minimize the delay. The first half will be returned to the project site at the end of the second week, and the second half will be returned at the end of the fourth week. Fragnet C was developed to model the delay, as shown in figure 17.

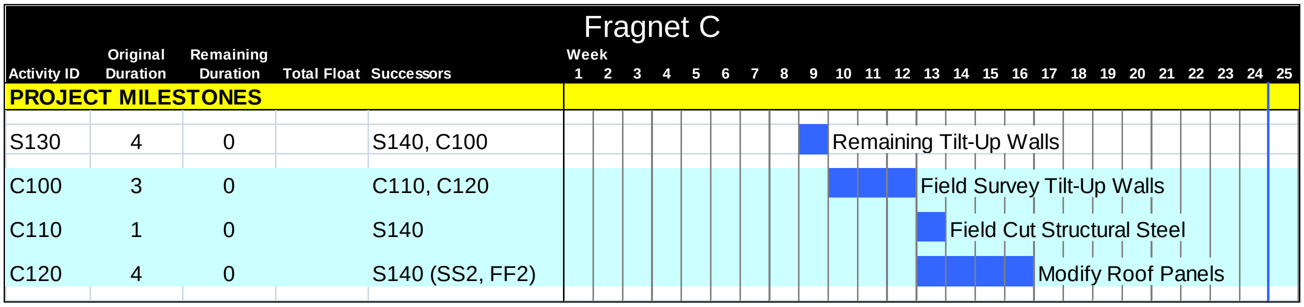


Figure 17 — Fragnet C

Delay D—*Installation of electrical and inventory systems for racking system*—At the start of Week 21, the owner informed the contractor that it had expected general contract work to be complete by now. The owner had scheduled an electrical contractor to install a computerized receiving and inventory system during Weeks 21 and 22. The electrical contractor will occupy the majority of the docking area and storehouse during that time. Fragnet D was developed to model the delay, as shown in figure 18.

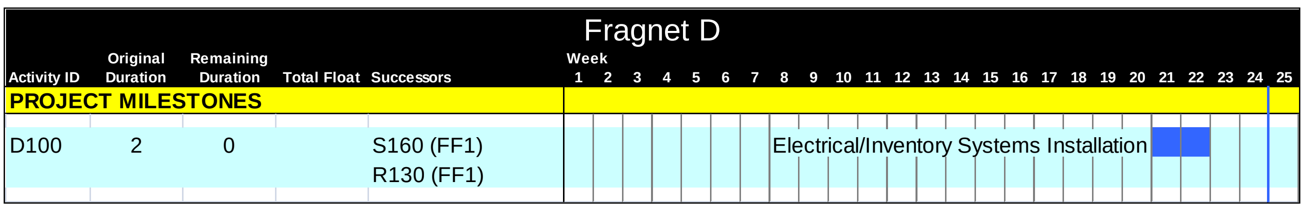


Figure 18 — Fragnet D

Fragnets A through D are added into the as-built schedule, resulting in the model shown in figure 19.

As-Built Schedule Including Fragnets A through D

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Week 1–25
PROJECT MILESTONES					
M100	0	0		S100, S150, R100 A100 (SS0)	Project Start
M990	0	0			Project Finish
STOREHOUSE					
S100	2	0		S110	Excavation
A100	1	0		A110	Test for Contamination
A110	2	0		S100 (FF1)	Remove UST
S110	2	0		S120	Foundation
S120	1	0		R110, S130	Tilt-Up Joining Wall
S130	4	0		S140	Remaining Tilt-Up Walls
C100	3	0		C110, C120	Field Survey Tilt-Up Walls
C110	1	0		S140	Field Cut Structural Steel
C120	4	0		S140 (SS2, FF2)	Modify Roof Panels
S140	3	0		S160	Beams & Roofing
S150	1	0		S160	Select Racking System
D100	2	0		S160 (FF1) R130 (FF1)	Electrical/Inventory Systems Installation
S160	3	0		S170	Install Racking
S170	1	0		M990	Punchlist
RECEPTION					
B100	11	0		R100	Docking Unit Supplier Delay
R100	6	0		R130	Fab/Deliver Docking Unit
R110	3	0		R120	Reception Walls
R120	2	0		R130	Reception Roof
R130	2	0		S170	Install Docking Unit

Figure 19 — As-Built Schedule Including Fragnets A through D

Once the fragnets are added to the as-built schedule, the next step is to "de-status" the schedule so that CPM calculations can be performed. This step is necessary when using many commercial CPM packages because much of the software overwrites or deletes data produced in the network calculation once actual dates have been reported for the activities. While some packages maintain this data, most accounts of MIP 3.8—often referred to as a collapsed-as-built analysis—employ some method of de-statusing the schedule.

To de-status the schedule, several steps are taken. The remaining duration of each activity is set to the actual duration, and the data date is moved back to the beginning of Week 1. In most cases, the logic of the schedule, including the fragnets, keeps each activity scheduled on the actual dates on which it occurred. However, in a few cases, there is no logical tie that drives an activity to be performed on the dates that it actually occurred. In order to match the as-built dates, some analysts insert lags. In this case, early start constraints were used to match dates.

In addition, a suspension period was introduced into the Excavation activity to show that it could not proceed during the testing and removal of the UST. This was done because the testing began as a successor to the start of Excavation, but was concluded as a predecessor to the finish of Excavation. Many software packages cannot calculate a network with this type of relationship, as it will be considered a loop. Instead, the Excavation activity was shown as suspended. When the delay associated with the testing and UST is removed from the schedule (collapsed), the suspension of the Excavation activity will be removed. Suspension periods were also introduced into the Install Racking and Install Docking Unit activities to better depict the fact that those activities did not proceed during the owner's electrical work.

De-Statused As-Built Schedule

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Constraints	Week 1–25
PROJECT MILESTONES						
M100	0	0	0	S100, S150, R100 A100 (SS0)		Project Start
M990	0	0	0			Project Finish
STOREHOUSE						
S100	2	2	0	S110	Suspended 2-4	Excavation
A100	1	1	0	A110	Early Start @ 2	Test for Contamination
A110	2	2	0	S100 (FF1)		Remove UST
S110	2	2	0	S120		Foundation
S120	1	1	0	R110, S130		Tilt-Up Joining Wall
S130	4	1	0	S140		Remaining Tilt-Up Walls
C100	3	3	0	C110, C120		Field Survey Tilt-Up Walls
C110	1	1	0	S140		Field Cut Structural Steel
C120	4	4	0	S140 (SS2, FF2)		Modify Roof Panels
S140	3	3	0	S160		Beams & Roofing
S150	1	1	0	S160	Early Start @ 18	Select Racking System
D100	2	2	0	S160 (FF1) R130 (FF1)	Early Start @ 21	Electrical/Inventory Systems Installation
S160	3	3	0	S170	Suspended 21-22	Install Racking
S170	1	1	0	M990		Punchlist
RECEPTION						
B100	11	11	0	R100		Docking Unit Supplier Delay
R100	6	6	0	R130		Fab/Deliver Docking Unit
R110	3	7	0	R120		Reception Walls
R120	2	2	0	R130		Reception Roof
R130	2	4	0	S170	Suspended 21-22	Install Docking Unit

Figure 20 — De-Statused As-Built Schedule

It is notable that every activity in the de-statused as-built is critical. It is not uncommon to have many critical activities prior to collapsing an as-built schedule. This is because every gap in the schedule could potentially be filled with some delaying event, even if the event is simply waiting for one party to begin work. The more gaps in the schedule are filled, the more critical activities there will be in the schedule. The schedule for the example project is relatively simple, with only two logic paths. In the as-built schedule, both of those logic paths are on the as-built critical path.

Once the schedule has been de-statused, the collapse can proceed. The first delay removed from the schedule is the delay associated with the owner's electrical work during Weeks 21 and 22. The delay is removed by removing Fragnet D and the suspensions on Install Racking and Install Docking Unit. The result is shown in figure 21.

Collapsed As-Built with First Delay Removed

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Constraints	Week
PROJECT MILESTONES						
M100	0	0	0	S100, S150, R100 A100 (SS0)		Project Start
M990	0	0	0			Project Finish
STOREHOUSE						
S100	2	2	0	S110	Suspended 2-4	Excavation
A100	1	1	0	A110	Early Start @ 2	Test for Contamination
A110	2	2	0	S100 (FF1)		Remove UST
S110	2	2	0	S120		Foundation
S120	1	1	0	R110, S130		Tilt-Up Joining Wall
S130	4	1	0	S140		Remaining Tilt-Up Walls
C100	3	3	0	C110, C120		Field Survey Tilt-Up Walls
C110	1	1	0	S140		Field Cut Structural Steel
C120	4	4	0	S140 (SS2, FF2)		Modify Roof Panels
S140	3	3	0	S160		Beams & Roofing
S150	1	1	0	S160	Early Start @ 18	Select Racking System
S160	3	3	0	S170		Install Racking
S170	1	1	0	M990		Punchlist
RECEPTION						
B100	11	11	0	R100		Docking Unit Supplier Delay
R100	6	6	0	R130		Fab/Deliver Docking Unit
R110	3	7	0	R120		Reception Walls
R120	2	2	0	R130		Reception Roof
R130	2	4	0	S170		Install Docking Unit

Figure 21 — Collapsed As-Built with First Delay Removed

After the removal of the delays associated with the electrical contractor, the completion date of the project changes from Week 24 to Week 22. This implies that the project would have been completed in Week 22, but for that delay.

Collapsed As-Built with Second Delay Removed

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Constraints	
PROJECT MILESTONES						
M100	0	0	0	S100, S150, R100 A100 (SS0)		Project Start
M990	0	0	0			Project Finish
STOREHOUSE						
S100	2	2	0	S110	Suspended 2-4	Excavation
A100	1	1	0	A110	Early Start @ 2	Test for Contamination
A110	2	2	0	S100 (FF1)		Remove UST
S110	2	2	0	S120		Foundation
S120	1	1	0	R110, S130		Tilt-Up Joining Wall
S130	4	1	0	S140		Remaining Tilt-Up Walls
C100	3	3	0	C110, C120		Field Survey Tilt-Up Walls
C110	1	1	0	S140		Field Cut Structural Steel
C120	4	4	0	S140 (SS2, FF2)		Modify Roof Panels
S140	3	3	0	S160		Beams & Roofing
S150	1	1	17	S160		Select Racking System
S160	3	3	0	S170		Install Racking
S170	1	1	0	M990		Punchlist
RECEPTION						
B100	11	11	0	R100		Docking Unit Supplier Delay
R100	6	6	0	R130		Fab/Deliver Docking Unit
R110	3	7	0	R120		Reception Walls
R120	2	2	0	R130		Reception Roof
R130	2	4	0	S170		Install Docking Unit

Figure 22 — Collapsed As-Built with Second Delay Removed

Figure 22 shows the second change in collapsing the as-built schedule. The early-start constraint that maintained the Select Racking System to be scheduled in Week 18 is removed. Select Racking System falls back to Week 1, where it was in the original as-planned schedule. Its float value (highlighted in yellow) has also changed. However, there is no savings to the project finish date. This implies that no time would have been saved by selecting the racking system sooner, and that the later-than-planned selection did not cause a project delay.

Collapsed As-Built with Third Delay Removed

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Constraints
PROJECT MILESTONES					
M100	0	0	0	S100, S150, R100 A100 (SS0)	
M990	0	0	0		
STOREHOUSE					
S100	2	2	0	S110	Suspended 2-4
A100	1	1	0	A110	Early Start @ 2
A110	2	2	0	S100 (FF1)	
S110	2	2	0	S120	
S120	1	1	0	R110, S130	
S130	4	1	6	S140	
S140	3	3	6	S160	
S150	1	1	17	S160	
S160	3	3	6	S170	
S170	1	1	0	M990	
RECEPTION					
B100	11	11	0	R100	
R100	6	6	0	R130	
R110	3	7	0	R120	
R120	2	2	0	R130	
R130	2	4	0	S170	

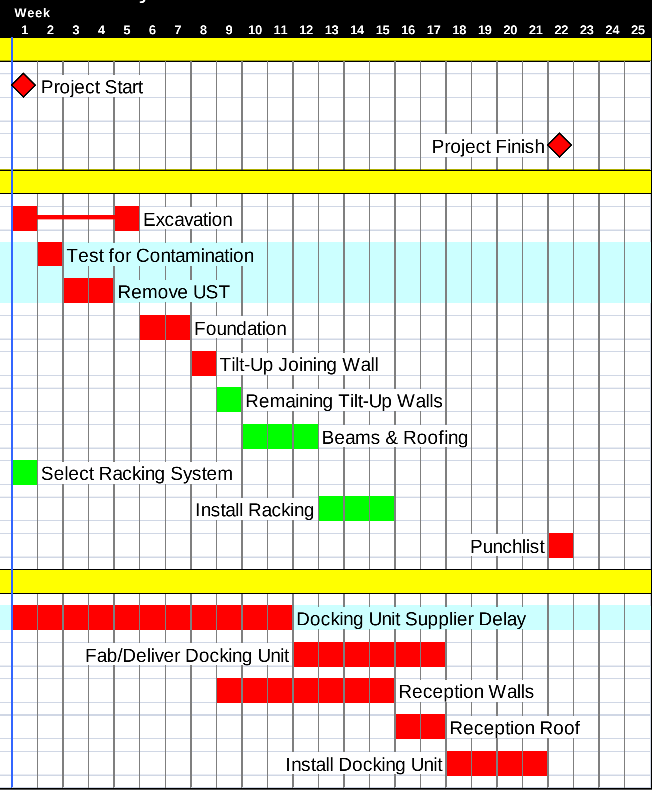


Figure 23 — Collapsed As-Built with Third Delay Removed

Continuing to work back through the project schedule, the third delay removed is the delay associated with Beams and Roofing. Removal of the activities for Field Survey Tilt-Up Walls, Field Cut Structural Steel, and Modify Roof Panels allows Beams and Roofing to be scheduled immediately after the Remaining Tilt-Up Walls. In fact, if not for the dimensional issues, the Beams and Roofing activity was planned to proceed after the tilt-up walls.

Although removing the field survey and modification activities results in a six-week savings to the Beams and Roofing activity and its successor, Install Racking, there is no overall project savings. Removing the delay does nothing more than create six weeks of float for that group of activities. This is because the Excavation and Docking Unit Supplier Delay are both driving paths of activities that will still take 22 weeks to complete.

Collapsed As-Built with Fourth Delay Removed

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Constraints	Week
PROJECT MILESTONES						
M100	0	0	0	S100, S150, R100 A100 (SS0)		Project Start
M990	0	0	0			Project Finish
STOREHOUSE						
S100	2	2	0	S110	Suspended 2-4	Excavation
A100	1	1	0	A110	Early Start @ 2	Test for Contamination
A110	2	2	0	S100 (FF1)		Remove UST
S110	2	2	0	S120		Foundation
S120	1	1	0	R110, S130		Tilt-Up Joining Wall
S130	4	1	6	S140		Remaining Tilt-Up Walls
S140	3	3	6	S160		Beams & Roofing
S150	1	1	17	S160		Select Racking System
S160	3	3	6	S170		Install Racking
S170	1	1	0	M990		Punchlist
RECEPTION						
R100	6	6	11	R130		Fab/Deliver Docking Unit
R110	3	7	0	R120		Reception Walls
R120	2	2	0	R130		Reception Roof
R130	2	4	0	S170		Install Docking Unit

Figure 24 — Collapsed As-Built with Fourth Delay Removed

The fourth delay removed from the project schedule is the Docking Unit Supplier Delay. Removing that delay results in the schedule shown in figure 24. Again, there is no overall project savings as there is still a path of activities that will take 22 weeks to complete.

Collapsed As-Built with Fifth Delay Removed

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Constraints	Week
PROJECT MILESTONES						
M100	0	0	0	S100, S150, R100		Project Start
M990	0	0	0			Project Finish
STOREHOUSE						
S100	2	2	0	S110		Excavation
S110	2	2	0	S120		Foundation
S120	1	1	0	R110, S130		Tilt-Up Joining Wall
S130	4	1	6	S140		Remaining Tilt-Up Walls
S140	3	3	6	S160		Beams & Roofing
S150	1	1	14	S160		Select Racking System
S160	3	3	6	S170		Install Racking
S170	1	1	0	M990		Punchlist
RECEPTION						
R100	6	6	8	R130		Fab/Deliver Docking Unit
R110	3	7	0	R120		Reception Walls
R120	2	2	0	R130		Reception Roof
R130	2	4	0	S170		Install Docking Unit

Figure 25 — Collapsed As-Built with Fifth Delay Removed

The fifth delay removed from the project schedule is the delay to Excavation because of UST removal. The delay activities are removed, along with the suspension period on the Excavation Activity that was in the model. Removing the UST delay results in a savings of three weeks, and the project completion date moves back to Week 19.

All delay activities have now been removed from the model, but the schedule still shows a three-week delay, when compared to the original as-planned schedule. As shown in figure 25, the remaining delay appears to be because of the extended duration of the Install Docking Unit and Reception Walls activities. Install Docking Unit overran its duration by two weeks, even once the delay associated with the electrical work was removed. The preceding Reception Walls activity overran its duration by four weeks.

Collapsed As-Built with Extended Durations Removed

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Constraints
PROJECT MILESTONES					
M100	0	0	0	S100, S150, R100	
M990	0	0	0		
STOREHOUSE					
S100	2	2	0	S110	
S110	2	2	0	S120	
S120	1	1	0	R110, S130	
S130	4	1	0	S140	
S140	3	3	0	S160	
S150	1	1	8	S160	
S160	3	3	0	S170	
S170	1	1	0	M990	
RECEPTION					
R100	6	6	4	R130	
R110	3	3	0	R120	
R120	2	2	0	R130	
R130	2	2	0	S170	

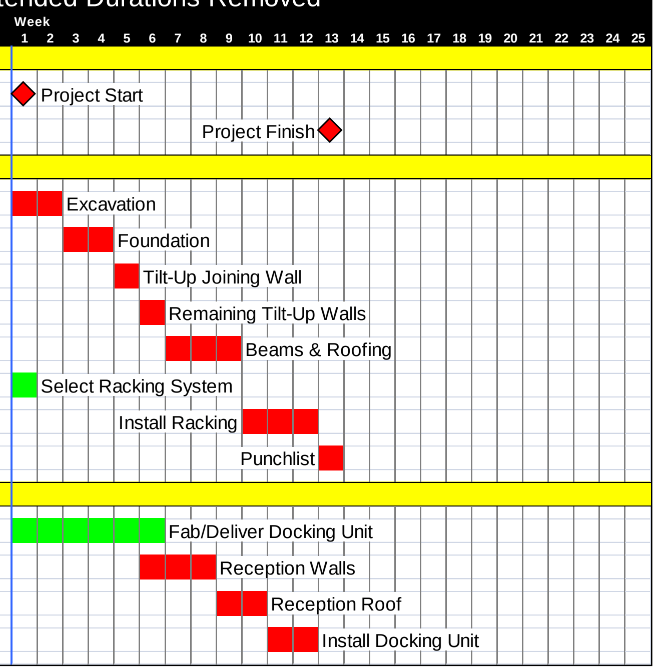


Figure 26 — Collapsed As-Built with Extended Durations Removed

Removing the extended durations results in a schedule that would have completed in 13 weeks, as opposed to the 19 weeks shown in figure 25. That would imply that the extended durations caused six weeks of delay, but the project was scheduled to take 16 weeks in the as-planned schedule. Recalling that the Remaining Tilt-Up Walls activity was completed three weeks faster than planned, we can understand the discrepancy.

Collapsed As-Built with Remaining Tilt-Up Walls Duration Restored

Activity ID	Original Duration	Remaining Duration	Total Float	Successors	Constraints
PROJECT MILESTONES					
M100	0	0	0	S100, S150, R100	
M990	0	0	0		
STOREHOUSE					
S100	2	2	0	S110	
S110	2	2	0	S120	
S120	1	1	0	R110, S130	
S130	4	4	0	S140	
S140	3	3	0	S160	
S150	1	1	11	S160	
S160	3	3	0	S170	
S170	1	1	0	M990	
RECEPTION					
R100	6	6	7	R130	
R110	3	3	3	R120	
R120	2	2	3	R130	
R130	2	2	3	S170	

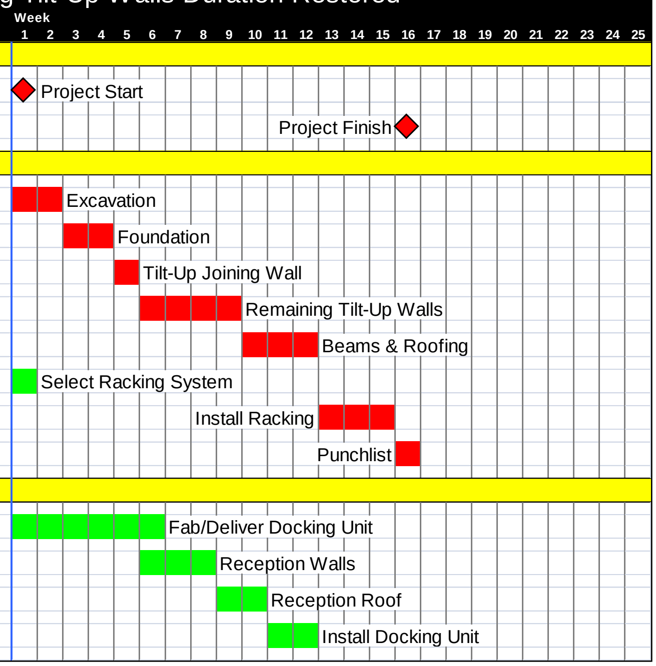


Figure 27 — Collapsed As-Built with Remaining Tilt-Up Walls Duration Restored

Restoring the duration of Remaining Tilt-Up Walls drives the project finish date back to Week 16. Therefore, the better-than-planned progress of Remaining Tilt-Up Walls appears to have resulted in a three-week savings to the project completion date. Once this last change is made to the as-built schedule, it now matches the as-planned schedule. In fact, it is identical to the as-planned schedule. Fully collapsing an as-built schedule does not always result in a schedule that is identical to the as-planned schedule. However, in this simple case, the analysis has had that result, which might provide a check that the analysis has been completed thoroughly.

MIP 3.8 recommends that a constructability analysis be performed on the collapsed as-built schedule. For the example project, it is noted that the logic of the collapsed as-built is the same as the logic of the as-planned schedule. It is also consistent with the manner in which the project was actually constructed, although the as-built durations were longer or shorter than the as-planned durations in some cases. Based on those facts, the collapsed as-built is deemed to represent a constructable plan. No further constructability analysis is deemed necessary in this instance.

Now that the collapse has been completed, the results of the analysis can be summarized. For example, the following conclusions might outline the cause of the eight-week project delay:

- Two weeks associated with delays to Install Racking and Install Docking Unit (concurrently) because of the owner's electrical contractor
- Three weeks associated with the delay to Excavation due to testing and UST removal
- Two weeks because of slower-than-planned progress of Install Docking Unit (prior to the mobilization of the owner's electrical contractor)
- Four weeks because of the slower-than-planned progress of Reception Walls

- These delays total 11 weeks, but there were three weeks of mitigation due to the better-than-planned progress of Remaining Tilt-Up Walls, resulting in a net total of eight weeks of project delay.

Comparison and Commentary

Three separate analyses have been performed on the example project based on three different Method Implementation Protocols. MIPs 3.1 and 3.2 are similar. They are based on an observational comparison of the as-planned and as-built schedules. MIP 3.8 has a different approach, focusing on modeling delays so that they can be subtracted from the as-built schedule. Table 4 compares the results of the three approaches.

Summary of Delays from Three Analyses			
Activity	**MIP 3.1**	**MIP 3.2**	**MIP 3.8**
Project Start	0	0	0
Excavation	3	3	3
Foundation	0	0	0
Tilt-Up Joining Wall	0	0	0
Remaining Tilt-Up Walls	(3)	(3)	(3)
Beams & Roofing	6	6	0
Select Racking System	0	0	0
Install Racking	2	2 concurrent	2 concurrent
Fab/Del Docking Unit	0	0	0
Reception Walls	0	0	4
Reception Roof	0	0	0
Install Docking Unit	0	2 concurrent	2 + 2 concurrent
Punchlist	0	0	0
Project Finish	0	0	0
Total	**8**	**8**	**8**

Table 4 — Summary of Delays from Three Analyses

Based on MIPs 3.1 and 3.2, the delays surrounding the construction of the storage area structure were found to be the same. Three weeks of delay were associated with Excavation; three weeks of savings with Remaining Tilt-Up Walls; and six weeks of delay with Beams and Roofing. However, the two MIPs found different results for the last two weeks of delay. They were associated with Install Racking, based on MIP 3.1. They were associated concurrently with Install Racking and Install Docking Unit, based on MIP 3.2. This is interesting, considering that the analysis approach in MIP 3.2 is essentially a more granular version of the approach in MIP 3.1. Yet, MIP 3.1 found that all delay to the project was associated with the Storehouse, while MIP 3.2 found that a small portion of the delay was because of work in Reception.

MIP 3.8 produced the same results for the early part of the project. The delays found through erection of the Remaining Tilt-Up Walls were found to be the same as those identified in MIPs 3.1 and 3.2. However, MIP 3.8 produced significantly different results for the later part of the project. No delay was found to be associated with Beams and Roofing in the Storehouse because of the fact that the

Reception Walls and Install Docking Unit activities in Reception took much longer than planned. Four weeks of delay were associated with Reception Walls, and two weeks of delay were associated with Install Docking Unit. The final two weeks of delay were found to be concurrently associated with Install Racking and Install Docking Unit, similar to what was found in MIP 3.2.

Table 5 presents a simplified summary of the results of the three analyses by distributing the concurrent delays equally among the associated activities. In other words, the two-week delay that was concurrently associated with Install Racking and Install Docking Unit was distributed to allocate one week of delay to each activity. This allows for a simpler presentation. However, the summarized values include more than one delay factor in some cases. For example, the summary of MIP 3.8 now shows three weeks of delay associated with Install Docking Unit. However, two of those weeks were associated with the extended duration of the installation before mobilization of the owner's electrical contractor, and one of those weeks was associated with the allocated portion of the two-week delay, during which the electrical contractor was working and concurrently delaying the completion of Install Racking and Install Docking Unit.

Simplified Summary of Delays from Three Analyses			
Activity	**MIP 3.1**	**MIP 3.2**	**MIP 3.8**
Project Start	0	0	0
Excavation	3	3	3
Foundation	0	0	0
Tilt-Up Joining Wall	0	0	0
Remaining Tilt-Up Walls	(3)	(3)	(3)
Beams & Roofing	6	6	0
Select Racking System	0	0	0
Install Racking	2	1	1
Fab/Del Docking Unit	0	0	0
Reception Walls	0	0	4
Reception Roof	0	0	0
Install Docking Unit	0	1	3
Punchlist	0	0	0
Project Finish	0	0	0
Total	**8**	**8**	**8**

Table 5 — Simplified Summary of Delays from Three Analyses

The simplified summary in table 5 is not the most convenient way to summarize delays for presentation of a responsibility analysis due to the summarization of independent delays to the same activity. However, it is useful in comparing the results of the multiple analysis techniques in allocating the eight-week project delay to the activities. Table 6 expands on this comparison by including the analyses based on MIPs 3.3 and 3.7, which were presented in 2008 [2].

Summary of Delays from Five Analyses					
Activity	**MIP 3.1**	**MIP 3.2**	**MIP 3.3**	**MIP 3.7**	**MIP 3.8**
Project Start	0	0	0	0	0
Excavation	3	3	3	3	3
Foundation	0	0	0	0	0
Tilt-Up Joining Wall	0	0	0	0	0
Remaining Tilt-Up Walls	(3)	(3)	(1)	0	(3)
Beams & Roofing	6	6	1	1.5	0
Select Racking System	0	0	0	0	0
Install Racking	2	1	1	1	1
Fab/Del Docking Unit	0	0	3	1.5	0
Reception Walls	0	0	0	0	4
Reception Roof	0	0	0	0	0
Install Docking Unit	0	1	1	1	3
Punchlist	0	0	0	0	0
Project Finish	0	0	0	0	0
Total	**8**	**8**	**8**	**8**	**8**

Table 6 — Summary of Delays from Five Analyses

Table 6 shows the differing conclusions that were reached by applying five different analysis techniques to the same project. Although all techniques found delays whose total correlated with the overall eight-week project delay, no two analysis techniques allocated the delays to the activities in the same way. MIPs 3.1 and 3.2 emphasized the significant delay to the roofing in the Storehouse. MIPs 3.3 and 3.7 found that some of the delay during that time was associated with the delayed fabrication of the docking unit. MIP 3.8 found no delay associated with the roofing due to the slower-than-planned progress on the Reception Walls during that time.

Conclusion

The differences in the results of the five analyses highlight the importance affect that the analysis technique can have on the identification of activity delays, especially when delays are occurring on more than one path of activities. As stated in 2008, "When there are multiple impacts to a project and many activities are performed later than their original late dates, the partitioning of project delay into the underlying activity delays can be more easily influenced by the analysis technique chosen. . . . The best analyses are those that take advantage of the best sources of project information available and incorporate that information into an objective analysis of the project schedule. In the end, the results of any analysis must be tied to actual project events to ensure that the model is a fair reflection of reality [2]."

The additional analysis of the example project presented here further highlights the fact that two reasonable analysts are likely to reach somewhat different conclusions if they use different analysis techniques. The debate as to which analysis techniques provide the best answer in the most situations is continuing. It is doubtful that there is any one analysis technique that provides the best answer in every situation. Some of the analysis techniques presented in this paper may be disallowed for use in certain forums because of legal precedent. However, they may still be used in a presentation to negotiate a contract time extension. The presentation of the particular analysis techniques in this paper is not meant as an endorsement. Rather, it is meant to provide practitioners with the ability to compare the merits and failings of each analysis technique presented in RP29R-03, in order to facilitate debate and lead the community of practitioners to consensus regarding best practices in forensic schedule analysis.

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