4-6 October, Nationals Park, Washington DC

(RISK-3847)
The Development of Corrected and Summarized Schedules to Support Monte Carlo Simulation

Project Controls EXPO
Washington, DC - USA

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Speaker Bio – Waylon Whitehead

- Waylon formed sCurve Solutions in 2019. He has 20 years of experience in LNG megaproject execution. He has participated in LNG projects in Australia, the Middle East, and Africa. He has other megaproject execution experience in SE Asia, South America, and the U.S.
- He has authored or co-authored 2 articles in the Cost Engineering Journal and one Recommended Practice - 57R-09 covering integrated cost-schedule risk analysis. He co-presented at the AACE conferences in Toronto in 2016 and New Orleans in 2019.
- He has degrees in Economics, and Political Science, and completed the Global Energy Leadership program at Rice University.
- He lives in Houston, Texas. He loves to fish and has Rhodesian Ridgebacks.

Speaker Bio – David Hulett

- David Hulett founded Hulett & Associates, LLC, a consulting firm focused on project cost and schedule risk analysis and scheduling. For 30 years he has consulted with commercial and US Government agency clients in the US, Canada, South America, Europe, SE Asia and the Middle East.
- He has authored or co-authored 8 articles in the Cost Engineering Journal and two Recommended practices including 57R-09 about integrated cost-schedule risk analysis.
- He has a Ph.D. in economics and is a Fellow, AACE
- He lives in Los Angeles, CA. He has sung in glee club, barbershop chorus and church choirs.

Introduction

- Detailed schedules are often developed after a risk informed schedule could have contributed to optimal project decision making
- Proposed execution schedules are often commercial tools with challenging schedule quality issues
- Detailed contractor schedule for all project work scopes are often available at different times and at different Levels
- Detail in schedules is often accepted as a proxy for schedule quality and suitability for schedule risk modeling
- Considerable time and effort is often spent to render these schedules suitable for modeling and they are still left with residual issues
- Contractor's schedules may not contain the full scope of the project, or other projects which risk impacting Contractor's schedule
- Developing summary schedules for risk modeling or scenario analysis can leave a project with a more reliable tool that is easier to work with

Industry Best Practice for CPM Schedules

Best Practices for CPM Schedules

- Reliance on schedule logic over constraints or imposed dates
- No logical open ends
- Minimal and defendable use of constraints - no mandatory constraints
- Minimization of large lags
- No negative lags
- Reasonable total float values (a commercial and contractual issue for delay)
- Optimize logic - no extraneous or superfluous logic
- No start-to-finish relationships on tasks
- No "broken" or "out-of-sequence" logic or progress
- Identified use of discontinuous logic ("suspend" and "resume" features)
- Consistency between RD (remaining duration) and OD (original duration), with percent complete, actual starts, and finishes

Examples of Issues with Execution Schedules of Actual Projects

Schedule Issues

Oracle Primavera Risk Analysis Schedule Check Report				
Plan Summary				
	Project A	**Project B**	**Project C**	**Project D**
Finish Date	--	--	--	--
Remaining duration	1,895	3,789	1,210	1,381
Normal tasks	4,965	5,088	12,406	7,764
Summary tasks	1,012	1,985	984	5
Milestone tasks	213	1,975	2,192	462
Hammock tasks	17	309	1,180	201
Total Tasks	6,207	9,357	16,762	8,432
Calendars	10	36	64	14
Links	14,324	15,302	45,976	24,043
Tasks no progress	5,088	9,359	8,560	5,211
in-progress tasks	501	-	2,037	695
Completed tasks	618	-	6,065	2,528
Schedule Check Report Summary				
	Project A	**Project B**	**Project C**	**Project D**
Constraints	33	105	464	232
Open-ended tasks	344	76	1,438	526
Out of sequence tasks	8	-	98	262
Lags longer than 0 units	2,432	1,903	8,334	6,368
Negative lags (leads)	0	44	34	-
Positive lags on finish-to-start tasks	298	546	1,291	659
Start-to-finish links	0	25	17	11
Lags between tasks with different calendars	2	428	3,189	1,817
Links to / from summary tasks	0	0	136	-
Total Number of Items found	3,117	3,127	15,001	9,875

- All “Tier 1” Contractor Schedules on projects which were greater than $10 Billion USD in total cost
- Avg # of activities = 7,555
- Avg # of constraints = 208
- Avg # of FS relationships with positive lag to successors = 699
- Avg # of open ends = 596
- Avg # of relationships with lags > 100 days = 635
- Avg # of relationships with negative lags = 20
- Avg # of activities with Total Float > 100 days = 3,143
- Average of 7,780 issues flagged

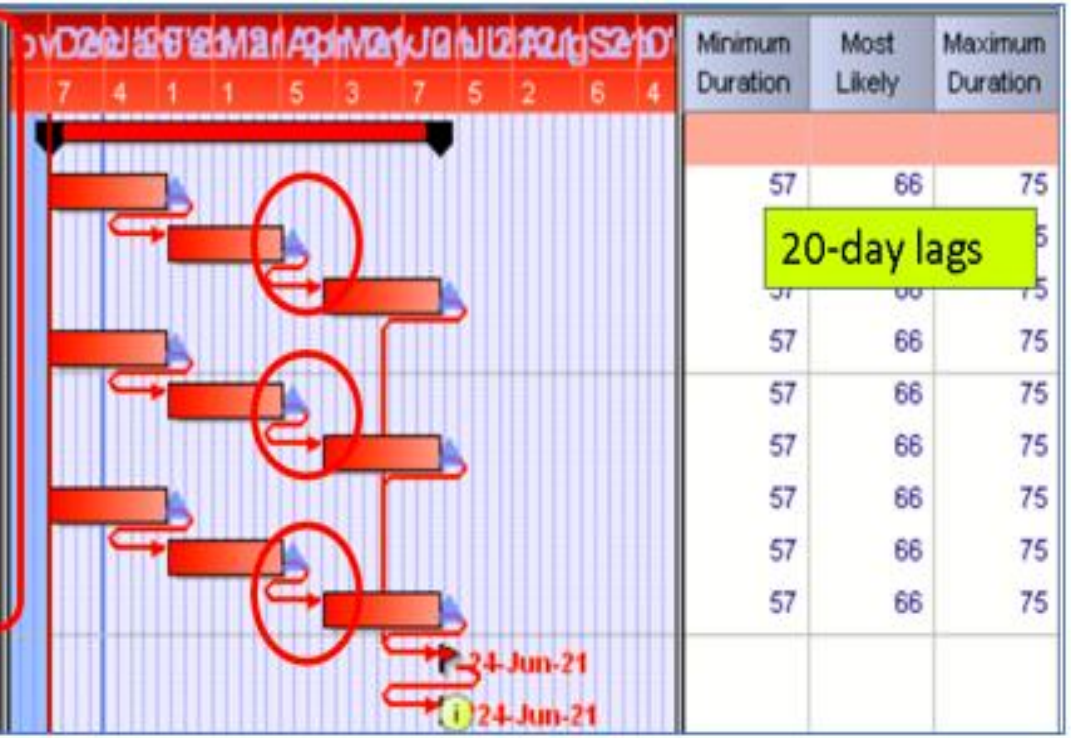
Schedule Issues – Monte Carlo Simulation

- MCS exercises the schedule logic vigorously under different input durations
- Some of the iterations will be quite different from the baseline schedule. The critical path may not be the “risk critical path,” identified by “risk criticality” to be the path most likely to delay the project.
- Issues on other paths that do not matter if the main critical path looks good may become important in simulation.
- Logic has to be strong, reliable and correct even more so than in a CPM setting

Impacts of Schedule Issues and Correction

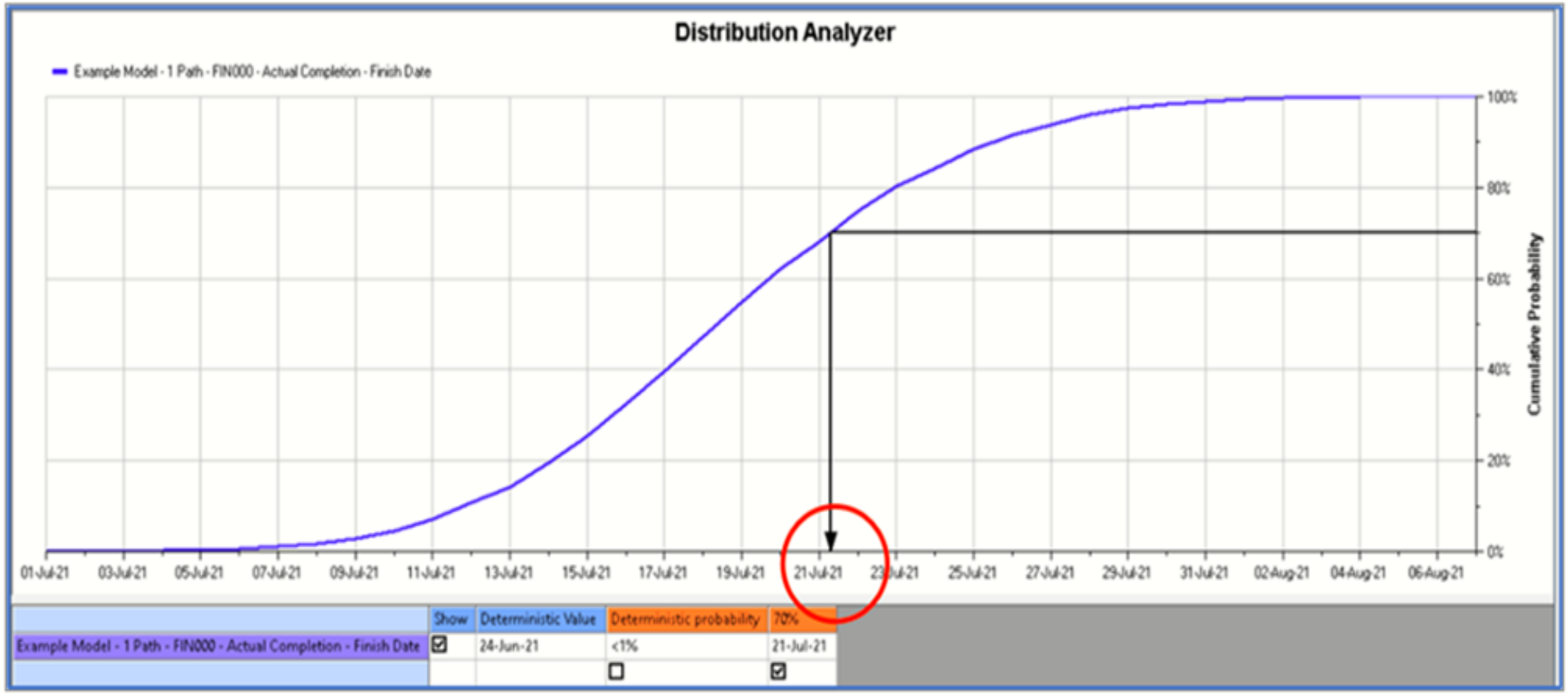
Impact of FS + Positive Lags

ID	Description	emainin Duratior	Start	Finish	Total Finish Floa	Minimum Duration	Most Likely	Maximum Duration
EXAMPI	Example Model - 1 Path	200	07-Dec-20	24-Jun-21	0			
A1000	Activity 1 - Path 1	60	07-Dec-20	04-Feb-21	0	57	66	75
A1020	Activity 2 - Path 1	60	05-Feb-21	05-Apr-21	0			
A1040	Activity 3 - Path 1	60	26-Apr-21	24-Jun-21	0			
B1000	Activity 1 - Path 2	60	07-Dec-20	04-Feb-21	0	57	66	75
B1020	Activity 2 - Path 2	60	05-Feb-21	05-Apr-21	0	57	66	75
B1040	Activity 3 - Path 2	60	26-Apr-21	24-Jun-21	0	57	66	75
C1000	Activity 1 - Path 3	60	07-Dec-20	04-Feb-21	0	57	66	75
C1020	Activity 2 - Path 3	60	05-Feb-21	05-Apr-21	0	57	66	75
C1040	Activity 3 - Path 3	60	26-Apr-21	24-Jun-21	0	57	66	75
FIN000	Actual Completion	0		24-Jun-21	0			
FIN010	Contractual Completion	0		'24-Jun-21	0			



- Initial Schedule has 3 parallel critical paths, each with 3 tasks, each with a FS + 20 day lag to from the 2nd task to the 3rd task
- The deterministic finish is 24 Jun 21

Impact of FS + Positive Lags



- Monte Carlo Simulation using simple uncertainty ranges of 95%, 110%, and 125%
- The P-70 completion is 21 Jul 21

Impact of FS + Positive Lags

ID	Description	Remaining Duration	Start	Finish	Total Finish Float	Minimum Duration	Most Likely	Maximum Duration
EXAMPL	Example Model - 1 Path	200	07-Dec-20	24-Jun-21	0			
A1000	Activity 1 - Path 1	60	07-Dec-20	04-Feb-21	20	57	66	75
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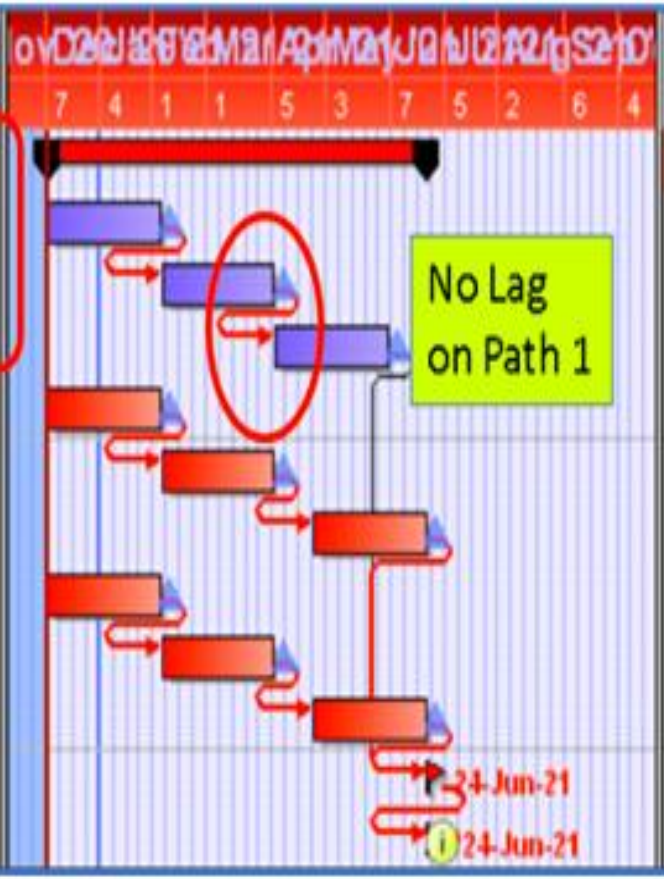
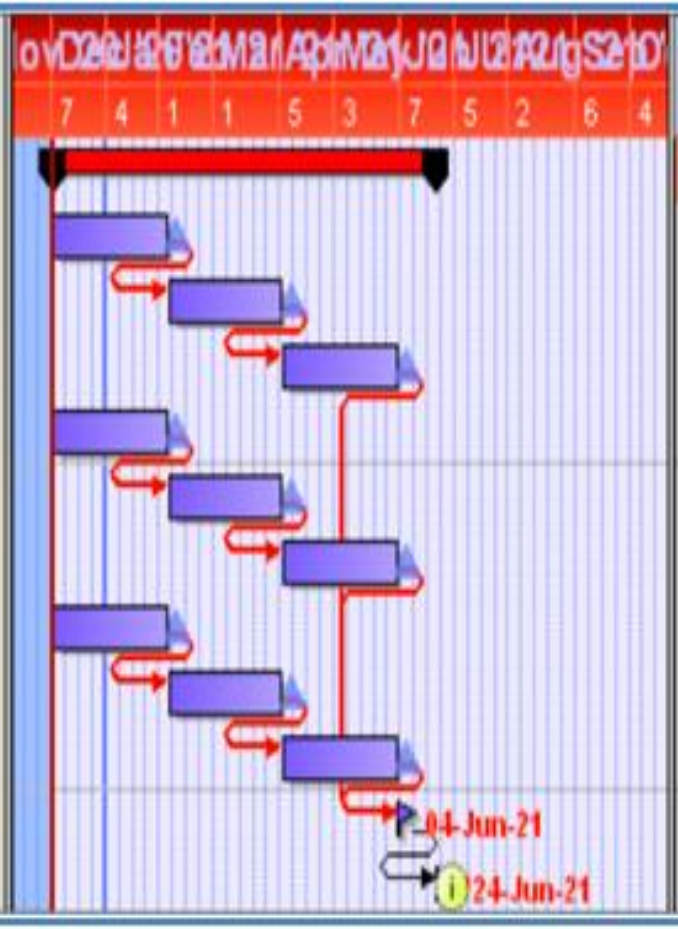
FIN000	Actual Completion	0		24-Jun-21	0			
FIN010	Contractual Completion	0		'24-Jun-21	0			



- Removing the lag from one path (partial correction to schedule)
- Monte Carlo Simulation using same uncertainty ranges of 95%, 110%, and 125%

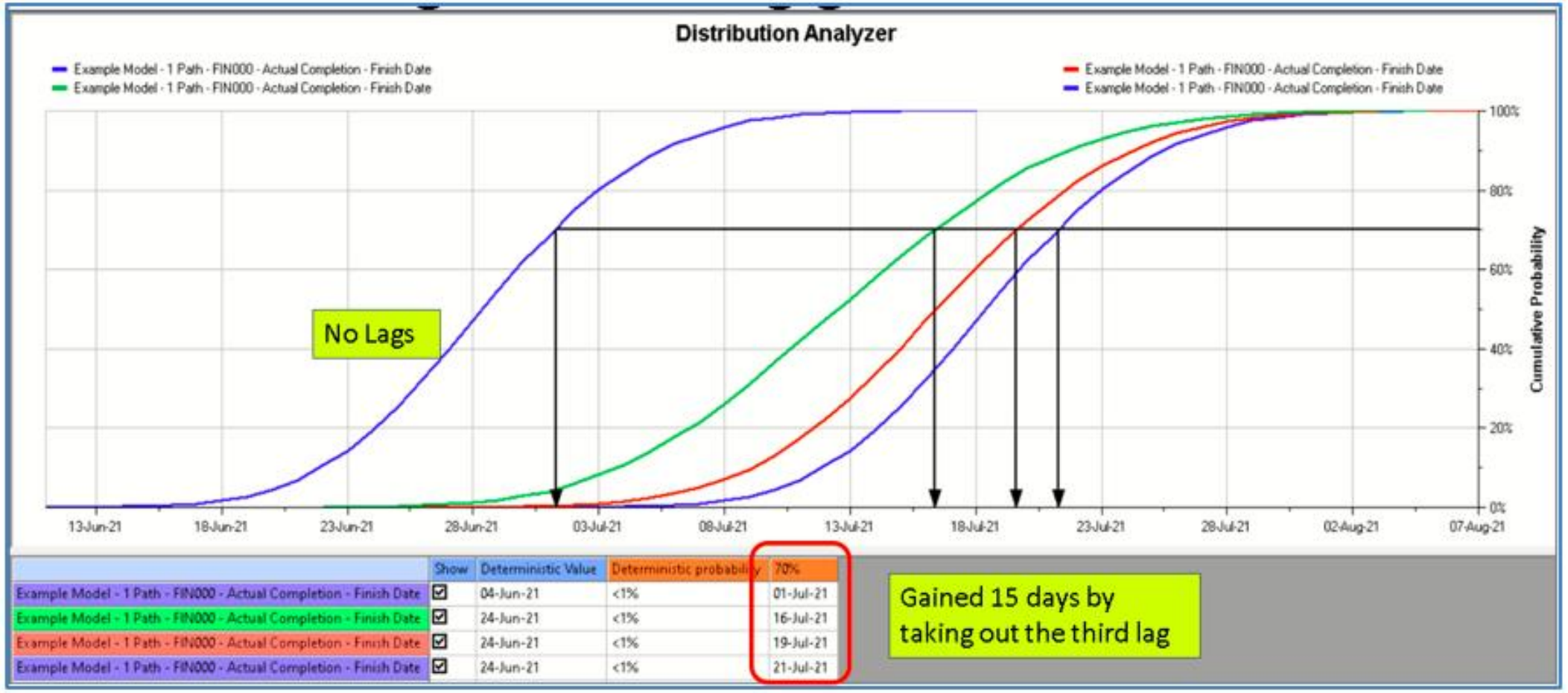
Impact of FS + Positive Lags

Description	Remaining Duration	Start	Finish	Total Finish Float	Minimum Duration	Most Likely	Maximum Duration
Example Model - 1 Path	**200**	**07-Dec-20**	**24-Jun-21**	**0**			
Activity 1 - Path 1	60	07-Dec-20	04-Feb-21	20	57	66	75
Activity 2 - Path 1	60	05-Feb-21	05-Apr-21	20	57	66	75
Activity 3 - Path 1	60	06-Apr-21	04-Jun-21	20	57	66	75
Activity 1 - Path 2	60	07-Dec-20	04-Feb-21	20	57	66	75
Activity 2 - Path 2	60	05-Feb-21	05-Apr-21	20	57	66	75
Activity 3 - Path 2	60	06-Apr-21	04-Jun-21	20	57	66	75
Activity 1 - Path 3	60	07-Dec-20	04-Feb-21	20	57	66	75
Activity 2 - Path 3	60	05-Feb-21	05-Apr-21	20	57	66	75
Activity 3 - Path 3	60	06-Apr-21	04-Jun-21	20	57	66	75
Actual Completion	**0**		**04-Jun-21**	**20**			
Contractual Completion	**0**		**'24-Jun-21**	**0**			



- Removing all lags (complete correction to schedule)
- Total Float goes from 0 to 20 days on all paths in deterministic schedule

Impact of FS + Positive Lags



- Monte Carlo Simulation using simple uncertainty ranges of 95%, 110%, and 125%
- The P-70 completion is 1 Jul 21

Methods of Examination and Correction

Schedule Issues and Correction

- Latent float, FS + positive lags, constraints, excessive use of large lags, and open-ended activities can lead to unreliable model results and make optimizing decisions difficult. These issues are often found in the contractor's detailed schedule.
- Working to improve only one or only a few paths in a large, complex schedule may not yield the improvements in accuracy we hope for
- At a minimum, correction must be thorough on all critical and near-critical paths (with an expansive definition of near when schedules are years long)
- Without a thorough and time-consuming examination of schedule flaws, it is possible that needed corrections will not be made (a single missed open-ended activity could change the critical or a near-critical path)

Schedule Issues and Correction

- Monte Carlo simulation software packages typically have built-in functionality to run quality checks on the schedule to flag issues which potentially undermine or negatively influence the results of the risk modeling
- One typical technique to correct these issues is to take the list that the simulation software generates, and for either the Risk Practitioner or the project Planning team to correct the issues shown :
- The large number of errors makes this challenging to do in a reasonable amount of time
- The Planning teams do not typically agree that all of the issues need to be addressed and that many of them are “normal” CPM practice (especially the lags!)
- The corrections made may not be ideal to differentiate between using the schedule for a purely project purpose v. using the schedule for the purpose of risk modeling or what-if analysis

Schedule Issues and Correction

- Another typical technique is to extract only the critical and near-critical paths from the schedule, correct those, and then use those in simulation

  - Even then, there may be a sufficiently large number of errors remaining to make this a challenge

  - We may be by definition conducting simulation on less than the full scope of the project. While this may not affect the schedule risk analysis (SRA) results it will surely invalidate the integrated cost-schedule risk analysis (ICSRA)

  - This technique assumes that the critical and near-critical paths would not change if other things not initially shown as influencing them were wrong (open-ended activities at least could change them). Repeating an earlier comment, the “risk-critical path” may not be the path most likely to delay the project, so all candidate paths need to be compliant.

  - We would have created a tool for modeling only, as it does not have the full project scope and as a result may not be suited for scenario or decision analysis

Building Summary Schedules – 2 Techniques

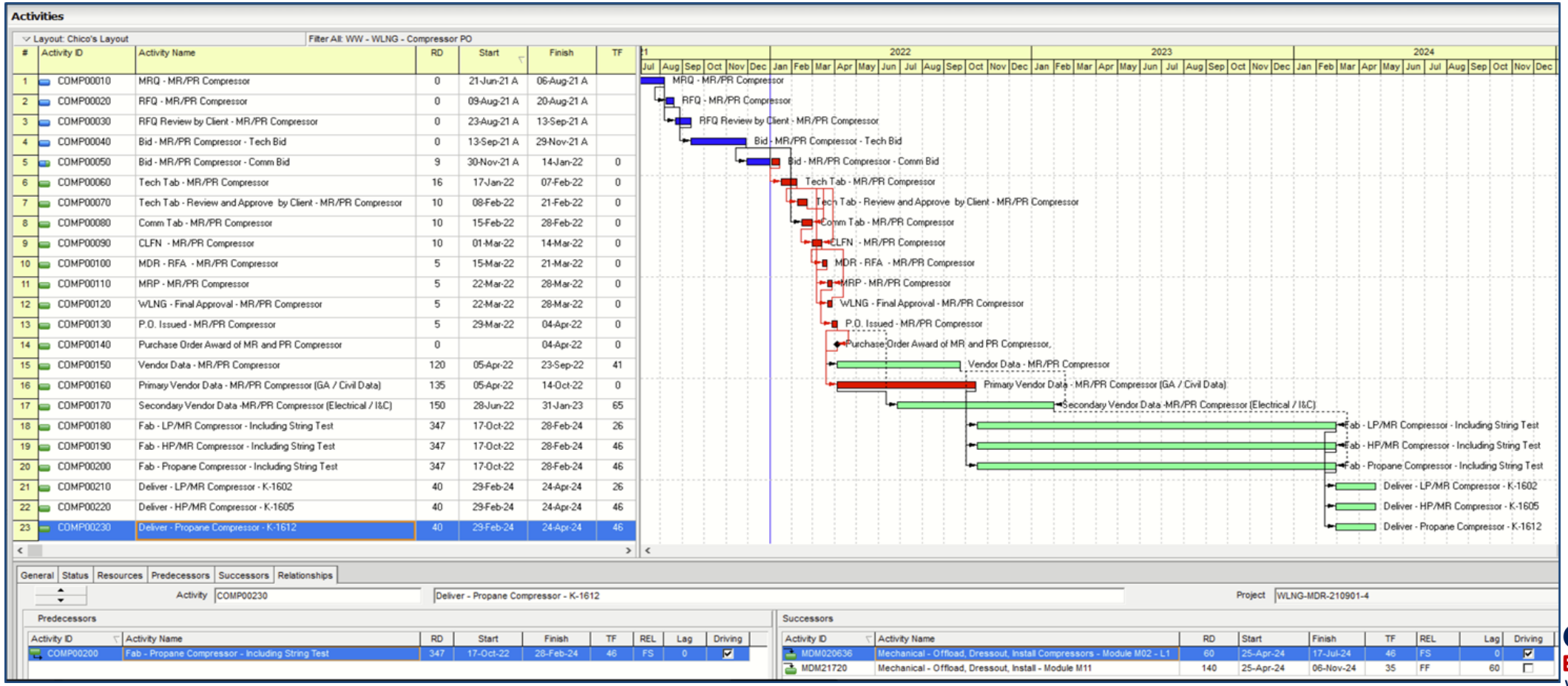
Technique 1 - Building a Summary Schedule from Available Detailed Schedules

Clues to Building a Summary Schedules

- AACE Recommended Practice “78R-13 - Original Baseline Schedule Review - as Applied In EPC” provides some clues for what might be contained in a good summary schedule:
  - Activities accounting for the full scope of the project
  - Activities that account for utility or permit restrictions
  - Critical Engineering
  - Critical Procurement and long lead time activities
  - Construction activities sufficiently detailed to understand potential resource issues
  - Activities to understand coordination with other projects or 3rd parties
  - Project milestones which bookend and describe the contract(s) and performance periods
- A summary schedule which meets these goals is best for risk modelling as it allows all risk to be imparted to the model (if we model only the critical and near critical paths their may be significant risk which has no place to apply structurally as we have dropped scope)
- A summary schedule capturing these requirements can be maintained and updated to remain a valuable tool for scenario or decision analysis for the life of the project as it is inherently more nimble than a detailed schedule

Summarizing Detailed Schedules - Procurement

- The quickest path to a schedule suitable for risk modeling and decision analysis may be to take the detailed schedules and to use them to create a summary schedule
- A typical string of activities for Procurement of major equipment in a detailed schedule might look like this – 23 activities for a single P.O.:



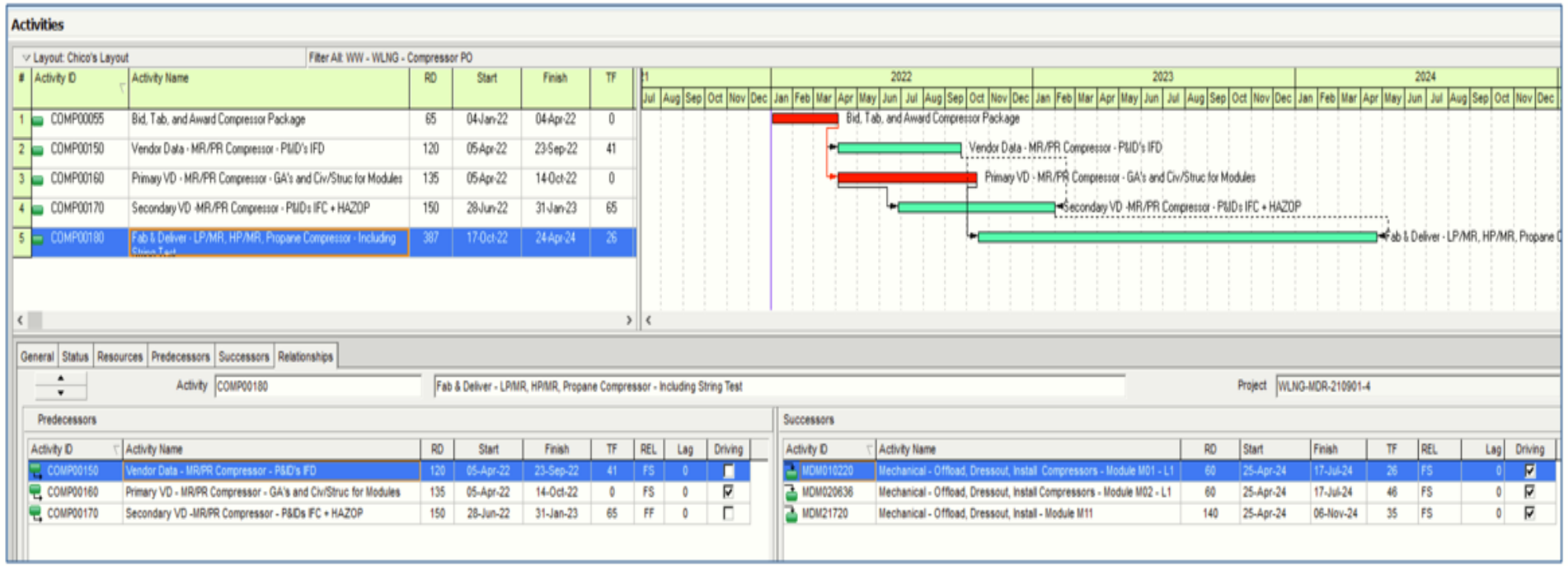
#	Activity ID	Activity Name	RD	Start	Finish	TF
1	COMP00010	MRQ - MR/PR Compressor	0	21-Jun-21 A	06-Aug-21 A	
2	COMP00020	RFQ - MR/PR Compressor	0	09-Aug-21 A	20-Aug-21 A	
3	COMP00030	RFQ Review by Client - MR/PR Compressor	0	23-Aug-21 A	13-Sep-21 A	
4	COMP00040	Bid - MR/PR Compressor - Tech Bid	0	13-Sep-21 A	29-Nov-21 A	
5	COMP00050	Bid - MR/PR Compressor - Comm Bid	9	30-Nov-21 A	14-Jan-22	0
6	COMP00060	Tech Tab - MR/PR Compressor	16	17-Jan-22	07-Feb-22	0
7	COMP00070	Tech Tab - Review and Approve by Client - MR/PR Compressor	10	08-Feb-22	21-Feb-22	0
8	COMP00080	Comm Tab - MR/PR Compressor	10	15-Feb-22	28-Feb-22	0
9	COMP00090	CLFN - MR/PR Compressor	10	01-Mar-22	14-Mar-22	0
10	COMP00100	MDR - RFA - MR/PR Compressor	5	15-Mar-22	21-Mar-22	0
11	COMP00110	MRP - MR/PR Compressor	5	22-Mar-22	28-Mar-22	0
12	COMP00120	WLNG - Final Approval - MR/PR Compressor	5	22-Mar-22	28-Mar-22	0
13	COMP00130	P.O. Issued - MR/PR Compressor	5	29-Mar-22	04-Apr-22	0
14	COMP00140	Purchase Order Award of MR and PR Compressor	0		04-Apr-22	0
15	COMP00150	Vendor Data - MR/PR Compressor	120	05-Apr-22	23-Sep-22	41
16	COMP00160	Primary Vendor Data - MR/PR Compressor (GA / Civil Data)	135	05-Apr-22	14-Oct-22	0
17	COMP00170	Secondary Vendor Data -MR/PR Compressor (Electrical / I&C)	150	28-Jun-22	31-Jan-23	65
18	COMP00180	Fab - LP/MR Compressor - Including String Test	347	17-Oct-22	28-Feb-24	26
19	COMP00190	Fab - HP/MR Compressor - Including String Test	347	17-Oct-22	28-Feb-24	46
20	COMP00200	Fab - Propane Compressor - Including String Test	347	17-Oct-22	28-Feb-24	46
21	COMP00210	Deliver - LP/MR Compressor - K-1602	40	29-Feb-24	24-Apr-24	26
22	COMP00220	Deliver - HP/MR Compressor - K-1605	40	29-Feb-24	24-Apr-24	46
23	COMP00230	Deliver - Propane Compressor - K-1612	40	29-Feb-24	24-Apr-24	46

Activity ID	Activity Name	RD	Start	Finish	TF	REL	Lag	Driving
COMP00200	Fab - Propane Compressor - Including String Test	347	17-Oct-22	28-Feb-24	46	FS	0	☑

Activity ID	Activity Name	RD	Start	Finish	TF	REL	Lag	Driving
MDM020636	Mechanical - Offload, Dressout, Install Compressors - Module M02 - L1	60	25-Apr-24	17-Jul-24	46	FS	0	☑
MDM21720	Mechanical - Offload, Dressout, Install - Module M11	140	25-Apr-24	06-Nov-24	35	FF	60	☐

Summarizing Detailed Schedules - Procurement

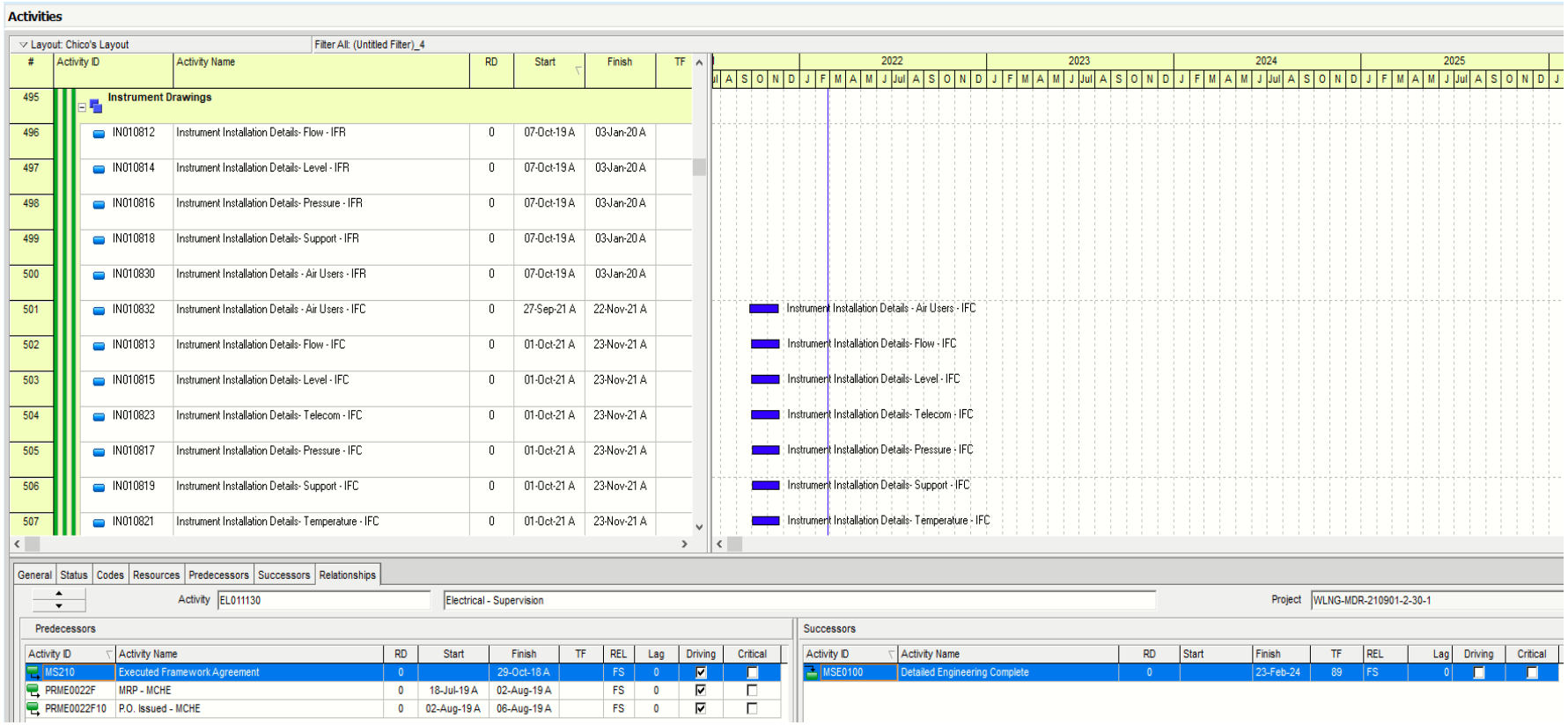
- The same Procurement string can be reduced from 23 activities to 5 activities – nearly a 75% reduction in the number of activities
- This is accomplished by collapsing the FS tasks along the string which do not have ties outsides of the string
- The critical path is maintained
- The interface logic between Engineering and Procurement and between Procurement and Construction are maintained



Summarizing Detailed Schedules - Engineering

- Detailed Engineering schedules often contain many activity strings which are not necessary to show in a summary schedule
  - Lighting Calculations
  - Instrument Installation Detail Drawings
  - Grounding
  - Pipe Support Drawings and Pipe Support Installation Details
  - Standard drawings for these types of drawings

- These can be deleted without removing “scope”



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Summarizing Detailed Schedules - Conclusion

- Use a mechanical analysis tool to remove all redundant logic
- Consider deleting or greatly summarizing any completed tasks
- Delete unnecessary detail (instrument installation detail drawings, pipe supports, non-critical P.O.'s like those for thermowells, small-bore non-alloy pipe and fittings, etc..) can remove thousands of activities
- EPC schedules are designed to link to progress tools, procurement reports, and even construction completion databases – because they serve these purposes in addition to being a planning tool they often contain detail that is not necessary to maintain the integrity of a schedule for risk or decision modeling
- Additional summarization can be approached by looking at strings of activities which are connected with simple FS logic with no additional logic
- Interface logic between Engineering and Procurement and between Procurement and Fabrication or Construction must be maintained
- The critical and near critical paths, assuming they were accurate in the detailed schedules, should be the same in the summarized schedule
- Verify the accuracy of the summary schedule by checking float on summarized strings to make sure it is the same as float and dates on detailed strings which were summarized

Technique 2 - Building a Summary Schedule from a Blank Page

Creating a Summary Schedule from Scratch

- This could be necessary earlier in the project lifecycle (FEL0 – FEL2) before contractors schedules are available
- Creating a summary schedule requires a thorough understanding of the full project scope and other projects or coordination activities which may be necessary to include for risk modeling and decision analysis to be thorough
- It is helpful to have experience with the type of project being executed and have experience with type of project to be able to identify errors in logic that would not work as scheduled

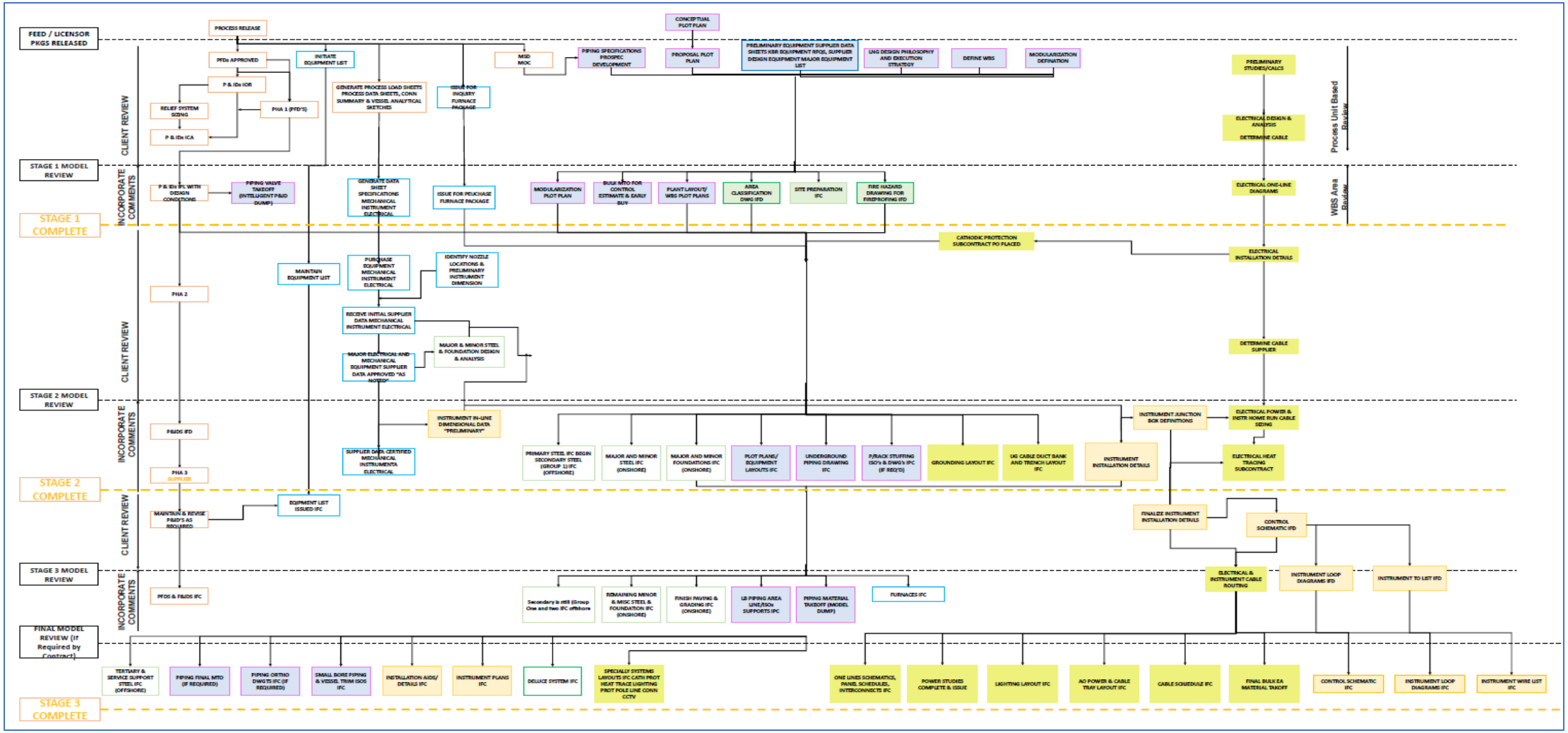
  - Typical engineering workflows so that the development of information which drives procurement of critical equipment as well as bulk procurement + reaching IFC status for fabrication or construction

  - Critical Equipment and sensitivities / risks around those packages (number of suppliers, commodity price influences, etc…)

  - Identify all of the predecessors necessary for a successor such as integration and test, must all be present and hooked up

Creating a Summary Schedule - Engineering

- This example Engineering workflow provides some ideas of how to summarize Engineering



Creating a Summary Schedule - Engineering

- The horizontal yellow lines show 3 stages (Stage 1, Stage 2, Stage 3)
- In Stage 1, the following key information should be included in the summary schedule

  - Feed / Licensor Packages development and inputs
  - Process Flow Diagrams
  - Major Equipment List
  - Preliminary Load List
  - Process Data Sheets
  - Process Load Sheets
  - Heat & Material Balance
  - Material Specifications
  - Process & Instrument Diagrams (for preliminary Process Hazard Analysis)
  - Conceptual Plot Plan / Equipment Layout
  - Preliminary Site Preparation Info
  - Preliminary Design Philosophy and Execution

Creating a Summary Schedule - Engineering

- In Stage 2, the following key information should be included in the summary schedule
  - Process Flow Diagrams finalized
  - Major Equipment List finalized
  - Process Data Sheets finalized
  - Process Load Sheets finalized
  - Process & Instrument Diagrams – Issue for Design
  - Equipment List - IFD
  - Plot Plan & Equipment Layout – IFD to IFC
  - Site Preparation (Rough Grade, Drainage) - IFC
  - HAZOP inputs
  - Dimensional information for inline instruments
  - Major Equipment Vendor Data available
  - Building Designs IFC
  - 80% Bulk Material

Creating a Summary Schedule - Engineering

- In Stage 3, the following key information should be included in the summary schedule
  - Process & Instrument Diagrams – IFC (with HAZOP comments included)
  - Equipment List - IFC
  - Plot Plan & Equipment Layout – IFC
  - Site Preparation (Rough Grade, Drainage) - IFC
  - Detailed Engineering Drawings
    - Civil (grading, roads, foundations) and Structural Steel issued IFC
    - Piping Isometrics IFC
    - Wire & Cable Schedules, One Line Diagrams IFC
    - Loop Diagrams and Complex Loop Diagrams IFC
    - Final Bulk Material Take-Offs

Creating a Summary Schedule - Procurement

- **Stage 1**
  - Licensor Package engineering and development schedule
  - Major Equipment supply - preliminary durations
  - Vendors of benchmarking information used for major module fabrication
  - Benchmarking data used to develop durations (and timing) for balance of equipment and bulks procurement
  - Bid cycles developed for key EPC contracts
- **Stage 2**
  - Cycle times for bids or commercial activities defined
  - All critical equipment durations defined with PO's
  - Durations for any long lead bulk material (9% nickel, titanium, etc.) defined
- **Stage 3**
  - Final delivery durations and date targets for all bulk materials

Creating a Summary Schedule - Construction

- **Stage 1 (FEL0-2)**
  - Preliminary Execution strategy (modularization, key subcontracts, site access / availability)
  - Benchmark durations used for high-level construction activities – typically disciplined based
    - Site Preparation
    - Rough Grade Drainage
    - U/G Pipe & Electrical
    - Foundations
    - Mechanical
    - Piping
    - Electrical
    - Instrumentation
    - Pre-Commissioning / Commissioning / Start-Up

Creating a Summary Schedule – Use of Benchmarks

Start of Detailed Engineering	1st A/G Isos	Set LNG Compressors
Start of Field Construction	90% Model Review	AG Piping started
Final Investment Decision / NTP	Last Piping MTO	Storage Tanks Completed
Start of Detailed Eng	ICSS - FAT - 1st Batch	Jetty Complete (except for loops)
Plot Plans - 100% IFC	Refrig Compressor Manu Duration	1st Loop Checks
Equipment List - 100% IFC	Cold Box Manufacting Duration	Control Building 100% Complete
First P&ID - IFD	MCHE Manufacturing Duration	First Fire GTGs
First P&ID - IFC	First Electrical One Lines - IFC	Fuel Gas into Facility at Full Volume
1st Piping MTO	Instrument Index - IFC	Perm Power Generation energized
Last P&ID - IFC	Last Isos IFC	Initial Flare light off
HAZOP - ISBL - start	Beach Landing / Initial Site Access	Gas for initial runs of turbine
HAZOP - OSBL - start	1st Strutural, Permanent Concrete	N2 Leak Checks on Compressors
30% Model Review	MOF Available	Defrost refrigeration and feed gas circuits
50% Model Review	Set Methane Cold Box or MCHE	1st Cargo

Creating a Summary Schedule - Construction

- **Stage 2 (FEL2-3)**
  - Schedule developed based on construction WBS areas with discipline durations within those areas
  - Schedule durations adjusted considering estimated hours
- **Stage 3 (Execution)**
  - Durations adjusted to reflect final design quantities and live forecast
  - Schedule converted from Area based to System based construction

Conclusion

Conclusion

- Detailed schedules often have many issues which jeopardize their reliability for use in risk modeling or scenario analysis

- A typical workaround to correcting all issues is to extract the critical and near-critical paths for use as the risk model
  - Uncorrected errors in the total file may impact what critical and near-critical paths are
  - Project work may be de-scoped in the process, invalidating any ICSRA

- Correcting the detailed schedules to make them reliable can take longer than building a stand-alone, logically linked, integrated schedule

Conclusion

- The question may be whether to fix the detailed schedule or to build a new schedule

- In part this may be determined by whether the person responsible for the detailed schedule is cooperative

- The detailed schedule is not fixable because of the way it was built. For instance, it may not use the Work Breakdown Structure consistently

- In these situations building a summary schedule becomes essential – the detailed schedule is not a reliable tool for Monte Carlo simulation

- One benefit is that the builder of the summary schedule can
  - Start with a good WBS
  - Know and follow scheduling best practices
  - Understand how the project phases must work, activities must interact, to get the right output

- A good-quality summary schedule can be updated if the risk analysis is to be repeated

Conclusion

- Can get a schedule earlier at a sufficient level of detail to use throughout the project lifecycle

- Summarized schedule can be used by entire team and is suited for other purposes
  - Full team can review and understand complete schedule instead of looking at only portions
  - Schedule can be developed to use for risk modeling much earlier
  - Schedule can be used for scenario analysis
  - Summary schedule is easily understood and can be briefed to management, whereas the detailed schedule is not easily presented, couched in too much unimportant detail

- A summary schedule is easier to maintain to a higher mechanical standard
  - Schedule does not have to be built to integrate with other tools (progressing systems, etc…)

(RISK-3847)
The Development of Corrected and Summarized Schedules to Support Monte Carlo Simulation

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THANK YOU

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