Benefits of Additional Real-World CPM Modeling Capabilities with Aurora

Construction CPM Conference 2024

San Antonio, Texas

Robert Richards, PhD

Stottler Henke
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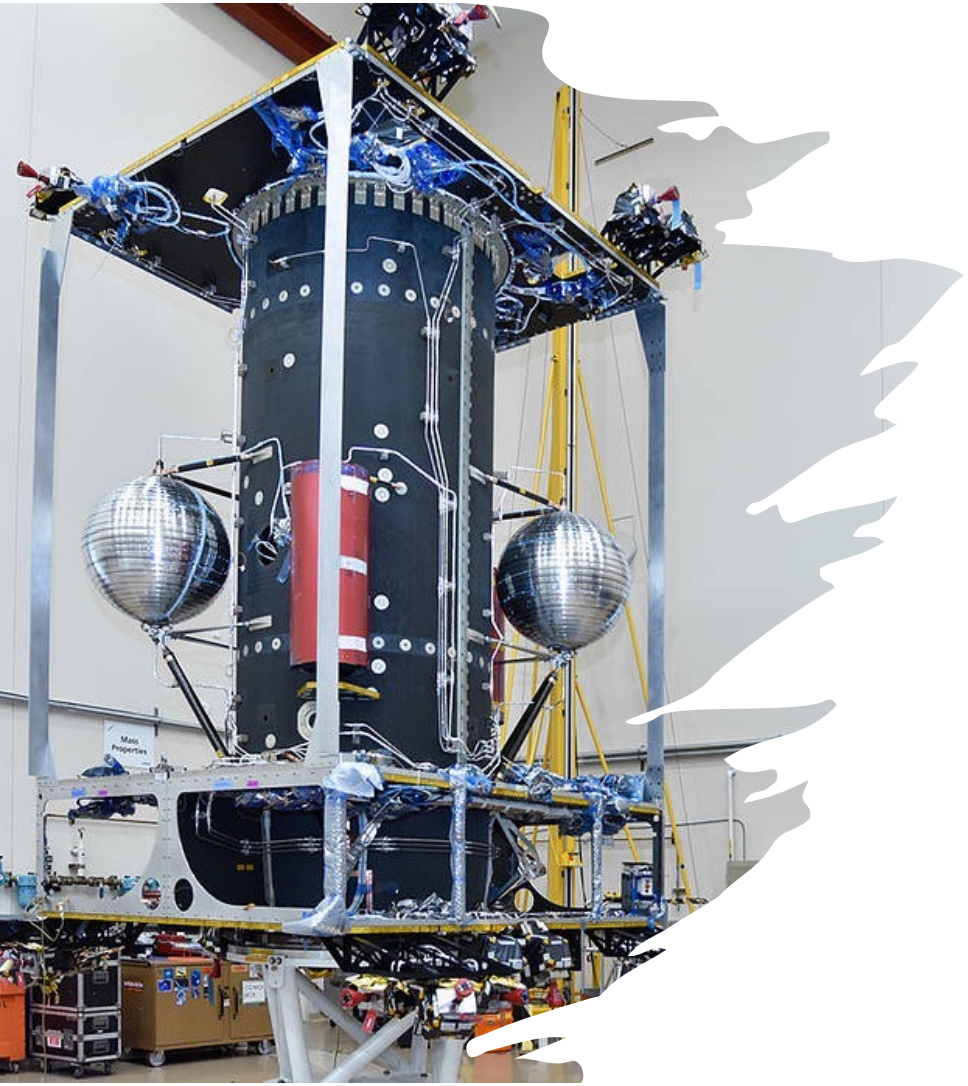
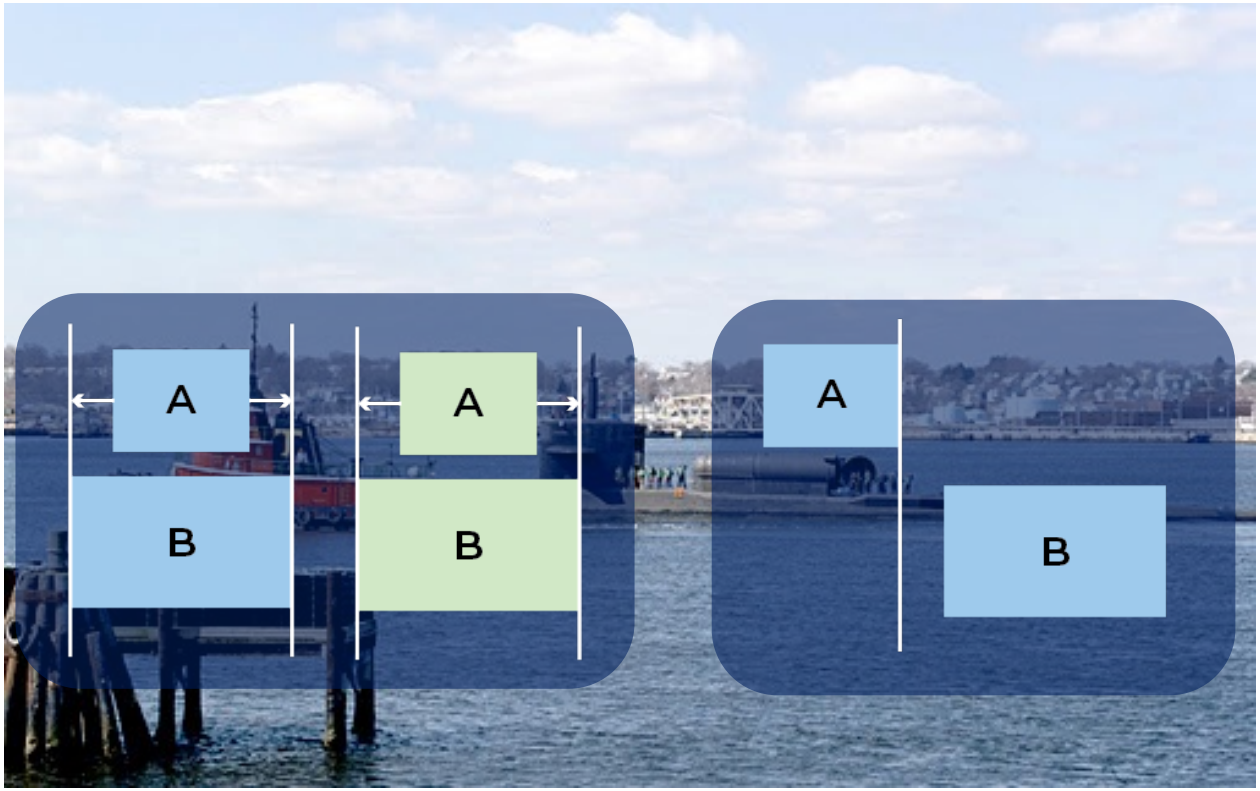


Model to level of detail required

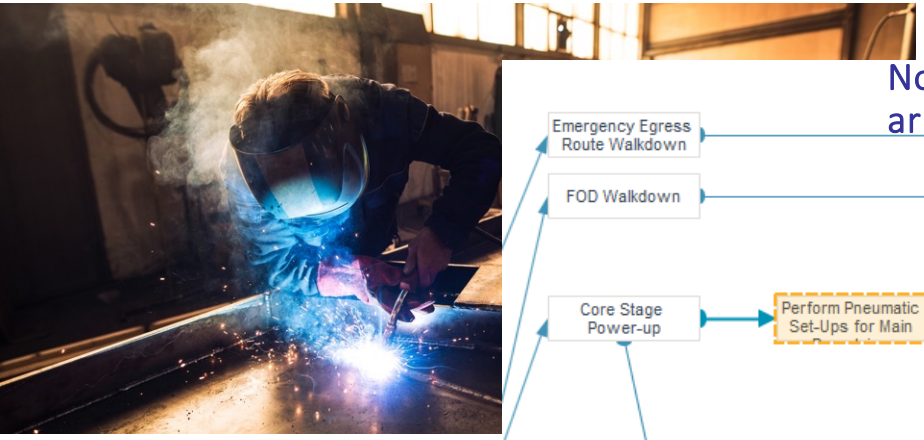
- Technical constraints (E.g., F-S, F-F, S-F, lags)
- Resources
  - Labor: Occupation, skills, certifications
  - Equipment, Tools
- Usage constraints – e.g., tool can only be used for so many hours continuously &/or during a day.
- Spatial / physical space – e.g.,
  - job requires a certain location or type of space
  - two elements should (or should not) be next to each other
- Equipment substitutions – know & use substitutes
- Ergonomic constraints – individual limitations on work conditions

Concurrent & Non-Concurrent Constraints

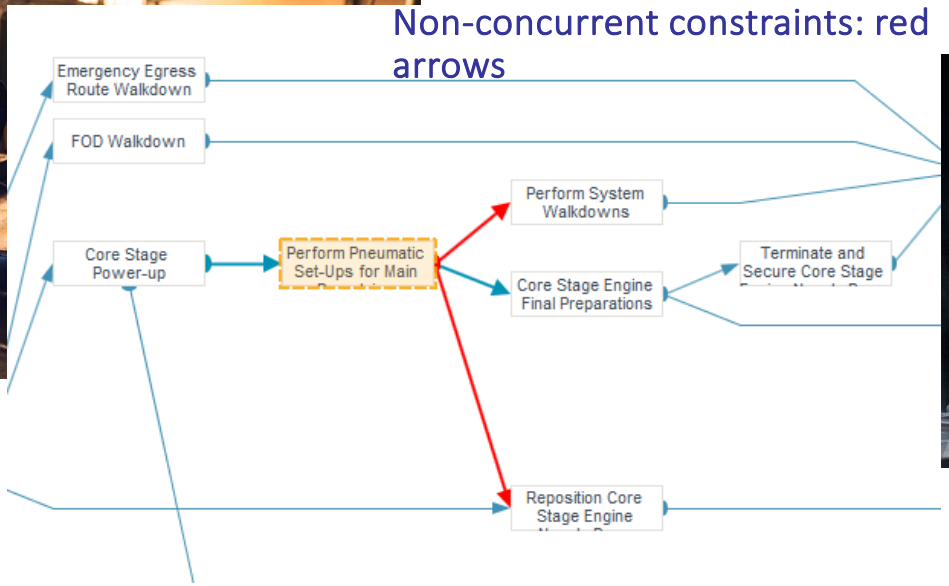


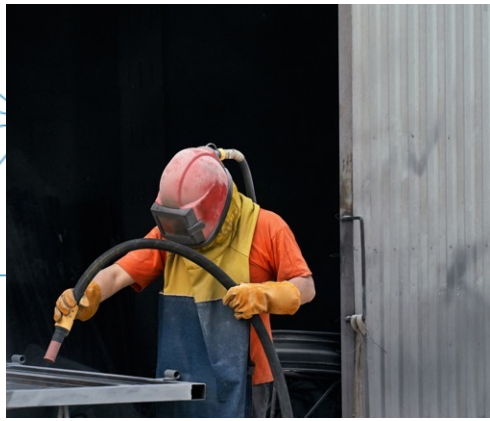
Concurrent & Non-Concurrent Constraints

- Two elements should (or should not) be next to each other



Non-concurrent constraints: red arrows



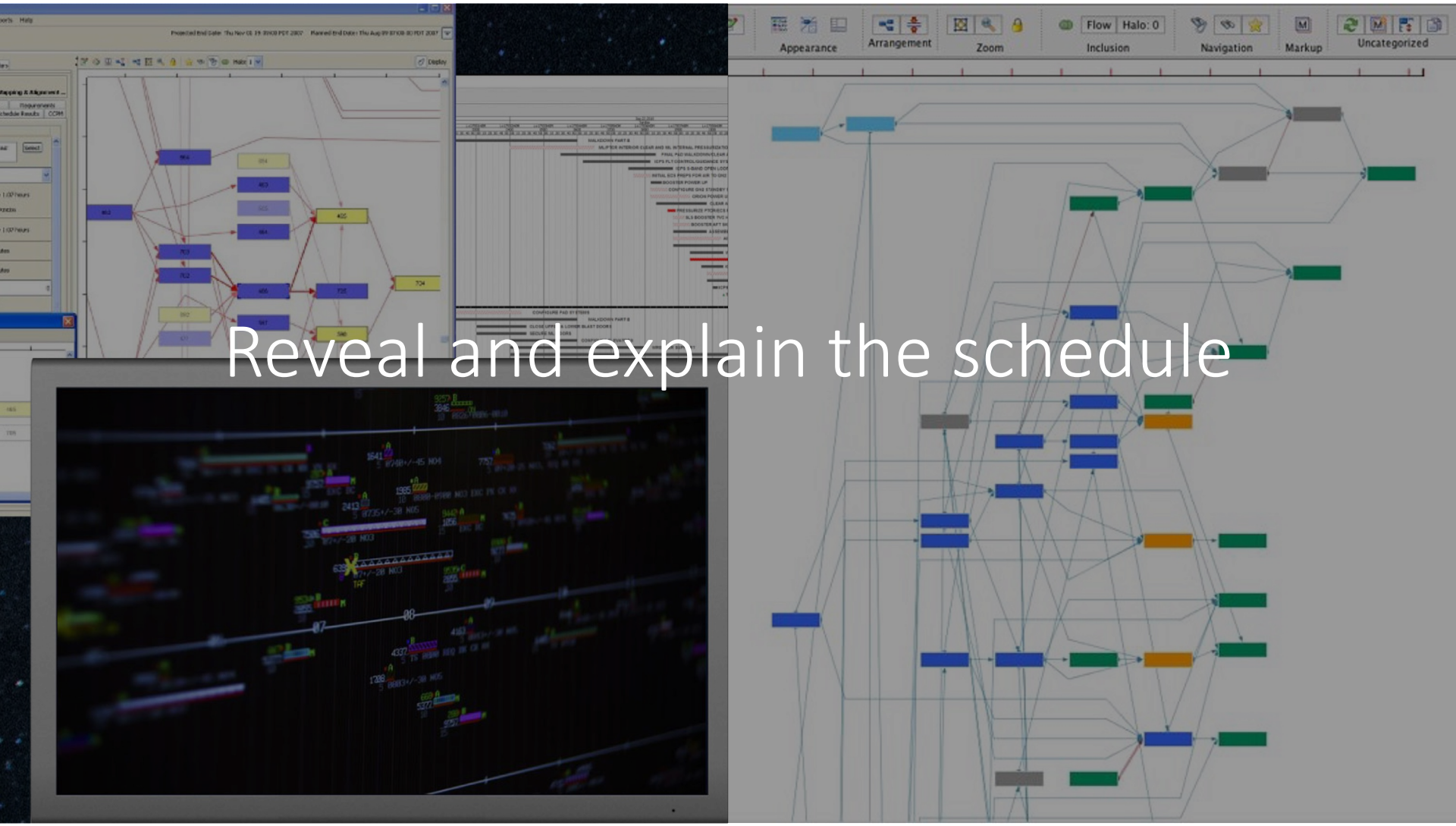


Shift Control Properties

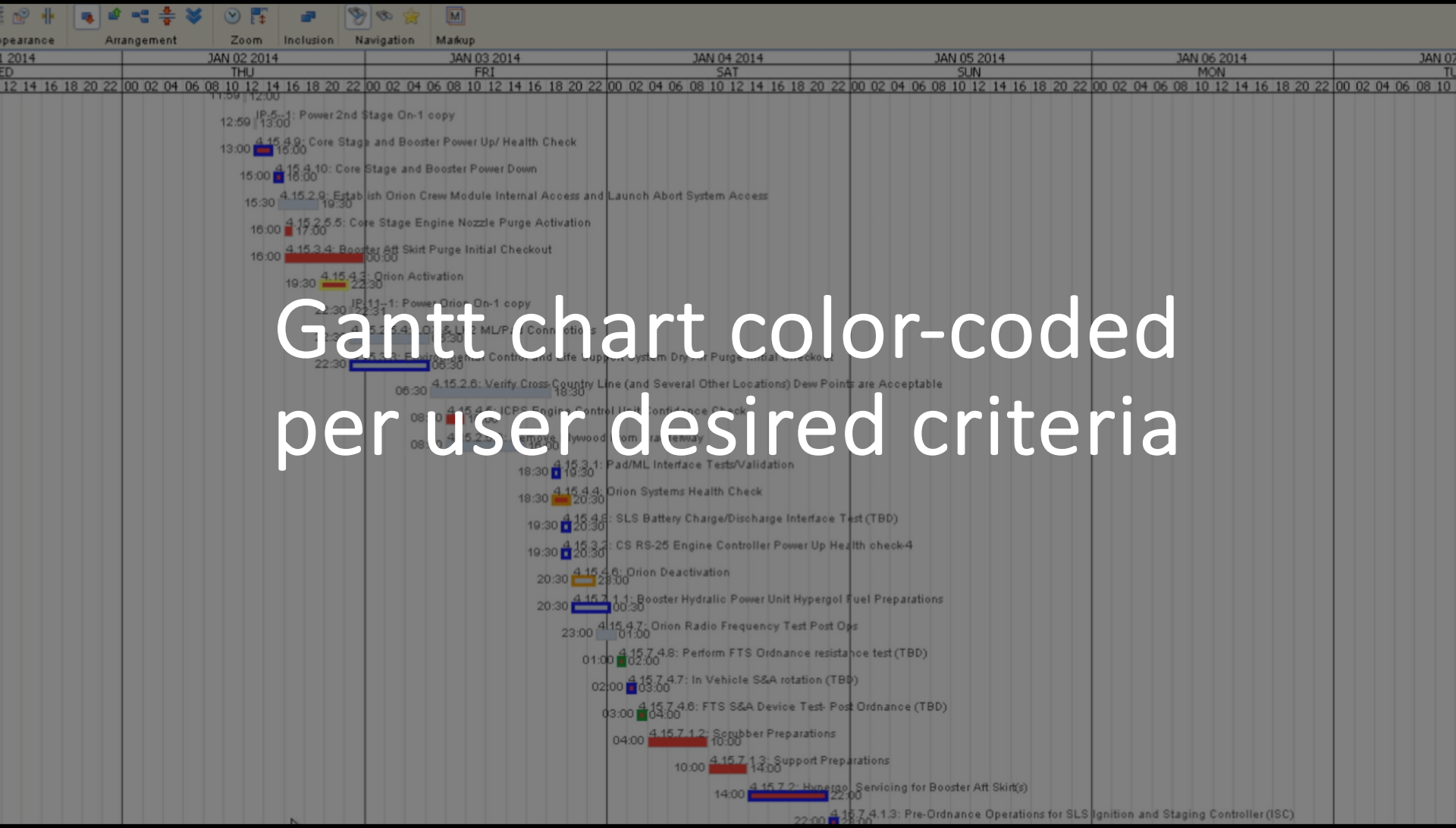
- This is a set of properties that allows the user to control how jobs interact with shift breaks
  - Only start a job if it can finish during the same shift
  - Job can only be performed during the day shift
  - Job can take multiple shifts, but requires same resource constraints

Alternative Resource Combinations

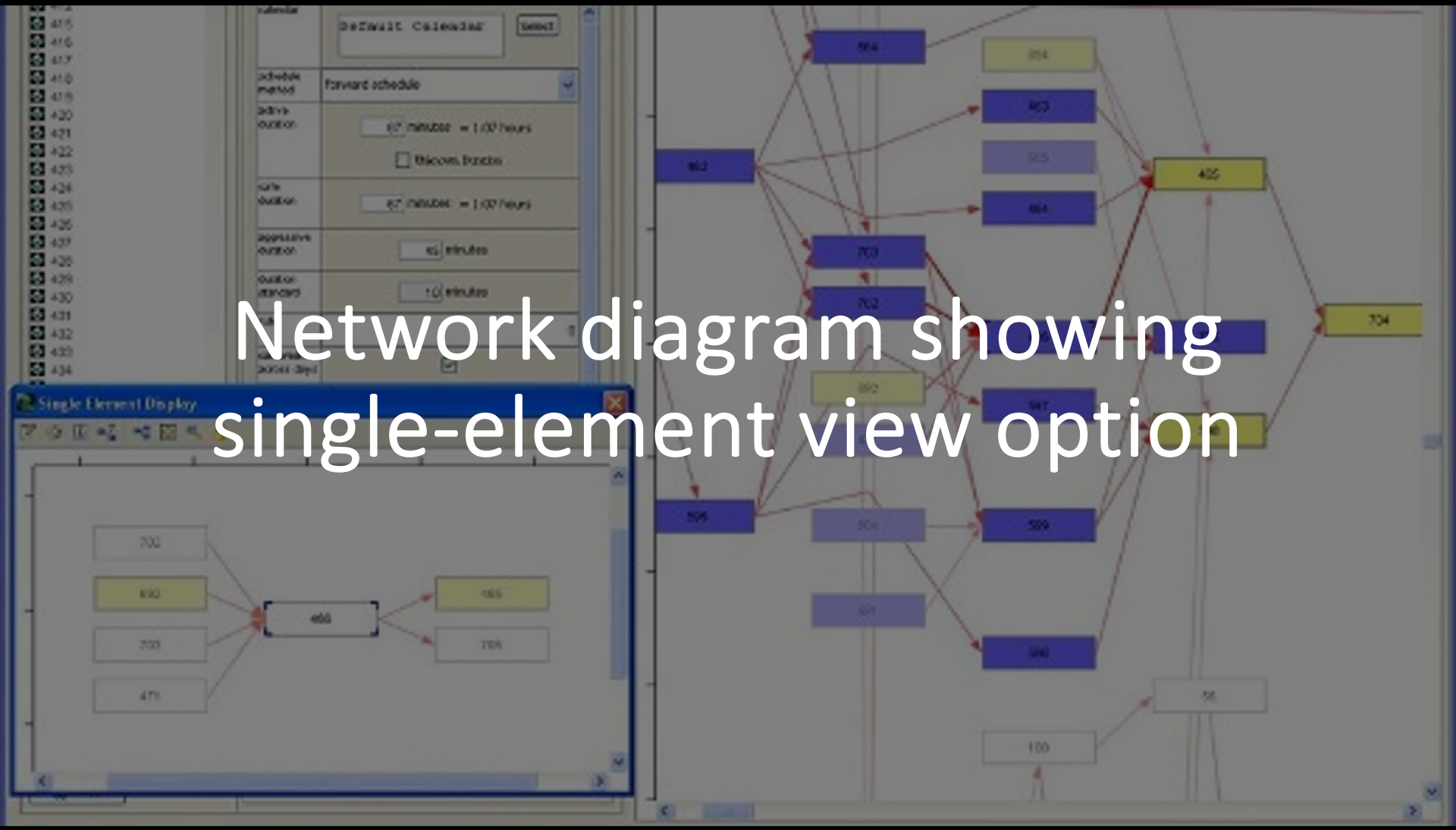
- Plumber & Mechanic
  - a task may require a Plumber and a Mechanic; however, there may also be Cross-trained person that can perform Plumber and Mechanic operations. So, the resource requirements for a task could be
  - (Plumb & Mech) OR (Cross-trained).
  - For cases where the same number of people are always needed, the resource requirement could be
  - ((Plumb & Mech) OR (Cross-trained & Mech) OR (Plumb & Cross-trained) OR (2 Cross-trained)).
- Aurora's intelligent scheduling assigns the Cross-trained individuals to maximize throughput



Reveal and explain the schedule



Gantt chart color-coded per user desired criteria



Network diagram showing single-element view option

Explain the schedule

Name: Post-Operations for Hyper Servicing

Property Search:

Properties | Details | Geometry | Duration Info | Schedule Attributes | Schedule Results | CCPM | Analysis | Actuals | Integrations | Flags | Constraints | Requirements

scheduled order	42
explanation	The end date was affected by the maximum flow time of 7300.00 days, which set it to 12/27/2033 00:00 The start date was affected by Hypergol Servicing for Booster Aft Skirt(s), which set it to 01/03/2014 00:00 The end date was affected by Establish Hazardous Control Area for Ordnance Ops, which set it to 12/25/2033 10:49 The start date was affected by Hypergol Servicing for Booster Aft Skirt(s), which set it to 01/04/2014 22:00 The start date was affected by ForwardSchedule, restricted by availability of Hazardous Pad-1; waiting for Pre-Ordnance Operations for Orion Pyro Safe and Test Panels, which set it to 01/05/2014 The end date was affected by ForwardSchedule, based on duration and start time, which set it to 01/05/2014 15:00

The start date was affected by the flow start time, which set it to 12/01/2017 00:00
The end date was affected by the maximum flow time of 7300.00 days, which set it to 11/26/2037 00:00
The start date was affected by null--66, which set it to 12/27/2017 11:00
The end date was affected by null--108, which set it to 10/29/2037 12:00
The start date was affected by null--66, which set it to 01/06/2018 11:00
The start date was affected by ForwardSchedule, restricted by availability of LWUA; waiting for null--72, which set it to 01/16/2018 11:00
The end date was affected by ForwardSchedule, based on duration and start time, which set it to 01/17/2018 17:00

Beneficial Analytics

- **Monte Carlo Simulation**
  - **Simulate multiple executions of the schedule to show how things are likely to play out. This provides insight into how brittle the schedule is, how likely it will be to run late, etc.**
  - **Only software that can run risk analyses with all the details discussed, taking advantage of the intelligent resource scheduling for each run.**

Equipment resources

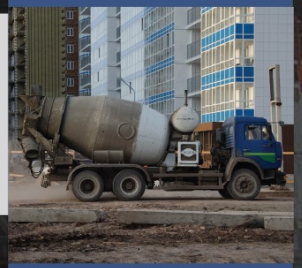
Resources

- **LABOR**
- **EQUIPMENT/TOOLS**
  - CNC milling machine

  - Crane

  - Forklift

  - Cement mixer



Hierarchy of Resources

Resources

- **LABOR**
  - **Occupation:** e.g., Welding
  - **Skills/Certifications**

Submerged Arc Welding

(Canadian Fabricating & Welding, 2019)

Flux Cored Arc Welding

(Venus Wires, 2018)

Gas Tungsten Arc Welding

Gas Tungsten Arc Welding 6" Pipe

Gas Metal Arc Welding

(TEK, 2020)

Preferred Resources

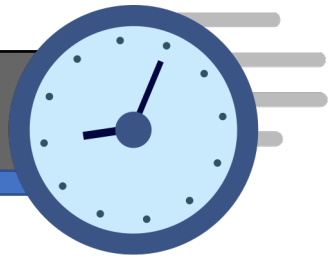
Specify a preference order when defining a set of resources that are mostly interchangeable.

- Prefer work in default shop
- Prefer work by tech, but supervisor can substitute
- Prefer certain equipment
- Prefer certain lab space
- Use consistent auditors for a client

Preferred Resources: Equipment substitutions

- Equipment down, know & use substitutes

Equipment: Usage constraints



E.g., tool can only be used for so many hours continuously &/or during a day.

Spatial / physical space constraints

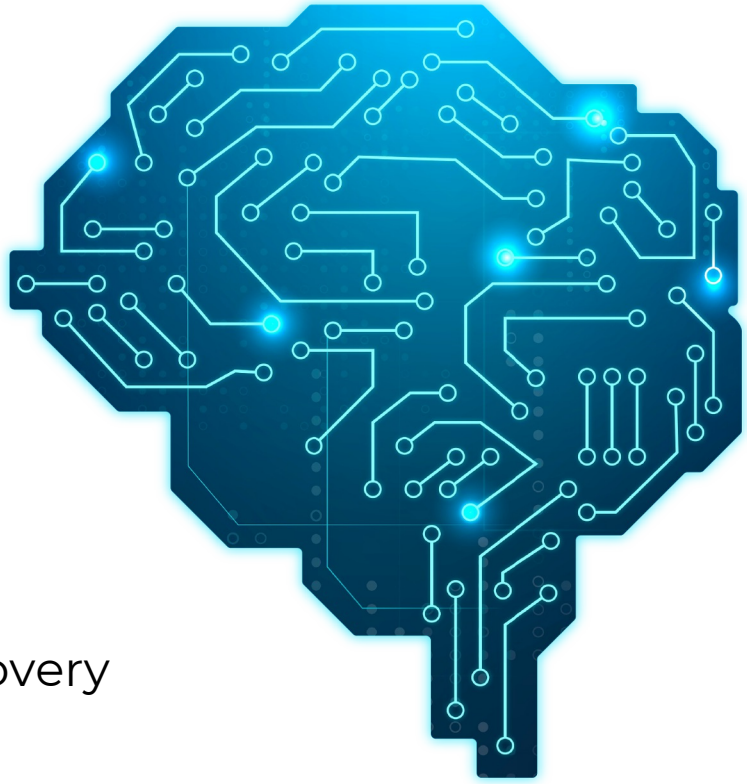
- Job requires a certain location or type of space
- Including the creation and elimination of the space during the project.

Ergonomic constraints – individual limitations on work conditions

E.g., only work so long:
continuously requiring kneeling, and/or
so much kneeling during a shift

About Stottler Henke

Applies artificial intelligence and other advanced software technologies to solve problems that defy solution using traditional approaches.



- Planning & Scheduling
- Education & Training
- Decision Support
- Knowledge Management & Discovery

Founded in 1988

www.StottlerHenke.com

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Background & Perspective

- Artificial Intelligence Research & Development
  - **Software Company**
- Scheduling / Project Management Experience
  - **Learn from schedulers**
  - **Encode that knowledge in software**

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Aurora Overview

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Aurora Approach

Allow the project to be modeled to the level of detail required so that it adapts during execution to the fidelity required to maximize benefit

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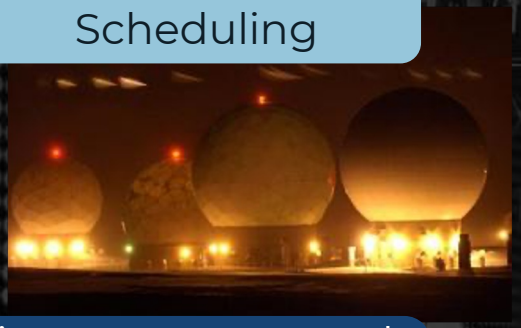
Our clients include…

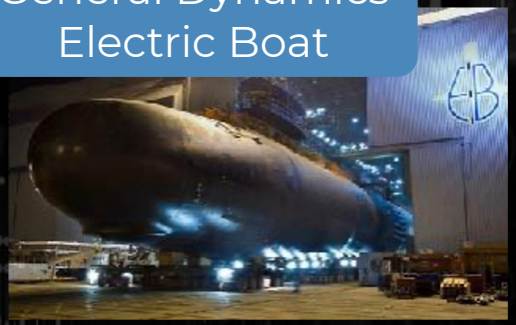
The Boeing Company

Air Force Satellite Scheduling

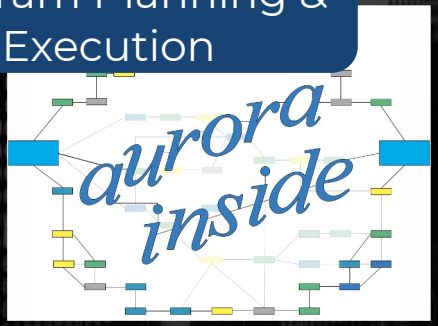


Mitsubishi Heavy Industries

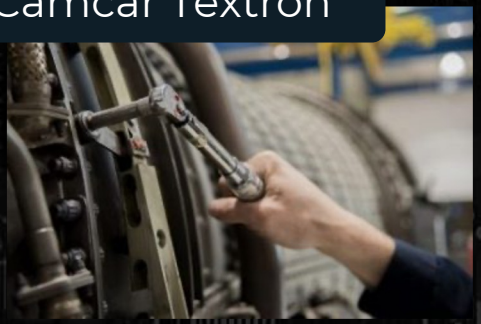
General Dynamics Electric Boat



Siemens Integrated Program Planning & Execution

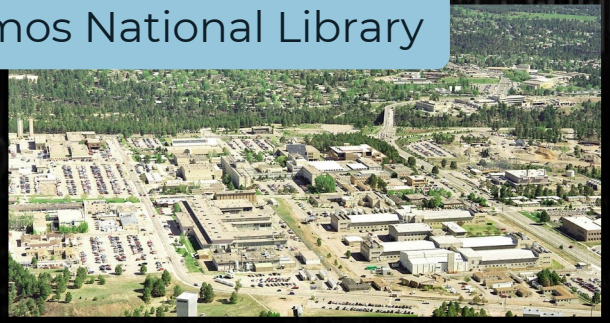


Camcar Textron



Spirit AeroSystems

Los Alamos National Library



Planning and Scheduling

- Given a list of tasks (jobs / activities) each with a set of required resources and constraints, assign resources to tasks (for specific time windows)
- While optimizing:
  - Time to complete
  - Cost
  - Resource utilization
- **NP-Complete, takes exponential time for optimal solution**
- Typical applications (almost every industry):
  - Construction, Manufacturing/Assembly (Aircraft, job shops, semiconductors, textiles, printers, etc.), Training, Airlines, Maintenance, Services, Government, etc.

Projects Completed by

- **Synchronized** effort of multiple **resources**
  - **Scheduling's goal is to optimize the synchronization of resources and other constraints to minimize the duration of the project**
  - **Only resources complete work & thus projects!**

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Critical Path (infinite resources)

- **The duration guaranteed to be the shortest the project will ever be!**
- **Best case scenario**
- **What else in life is approached this way?**

Scheduling Background / Comparisons

- Resource-Constrained Scheduling is NP-Complete, takes exponential time for optimal solution
  - I.e., it is a hard problem
  - Approximate methods are needed
- Most automatic scheduling systems use simple one-pass algorithms
- Standard constraint-based approaches are far less computationally efficient (Aurora takes advantage of structure of scheduling problems and heuristics)

Expert Knowledge & Experience Needed

- Mathematics is not enough (again because problem is NP-Complete, takes exponential time for optimal solution)

- Encoding expert knowledge & experience in software can make this knowledge available to others
  - Learned domain specific heuristics many times beneficial in other domains.

Value Proposition: Aurora

The EXACT same project can be completed significantly faster by using the intelligent scheduling engine in Aurora, versus ANY other software available.

- That is, once the resource-loaded project model is developed, using Aurora will determine a shorter initial schedule, and then by using Aurora during the execution of the project Aurora will make more efficient decisions based on the reality on the ground so the execution results in a shorter project duration versus any other software available.

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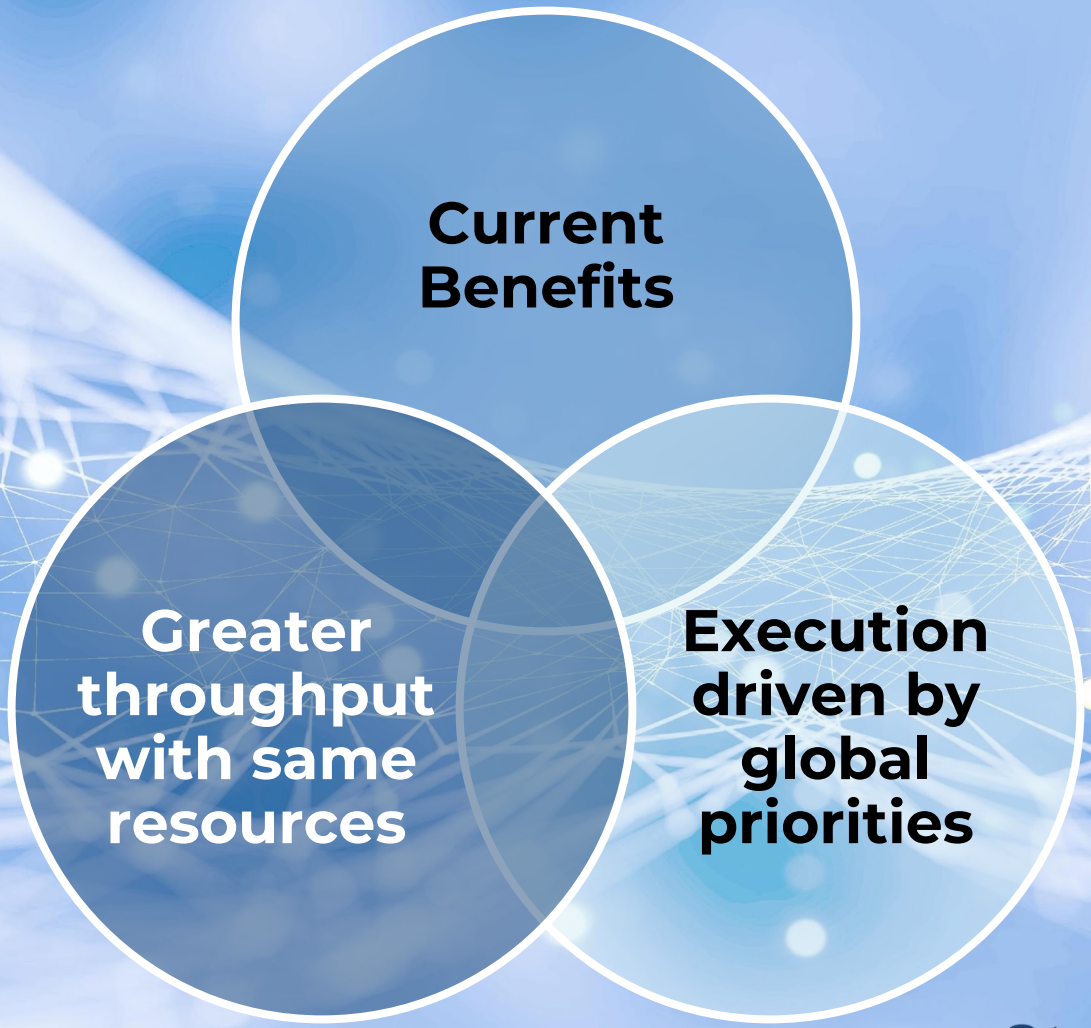
Benefits



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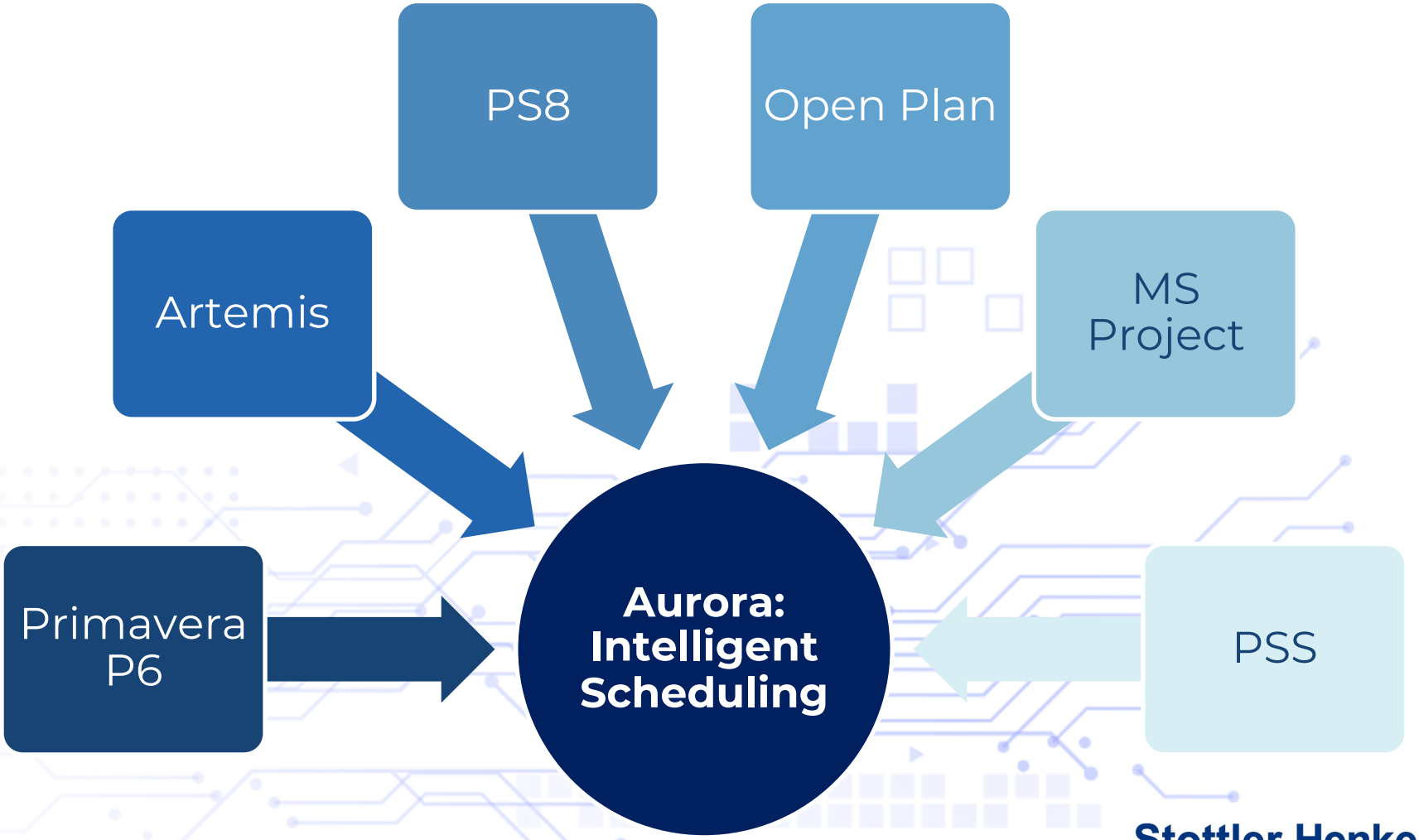
Build in current tool: Benefit from Intelligent Scheduling



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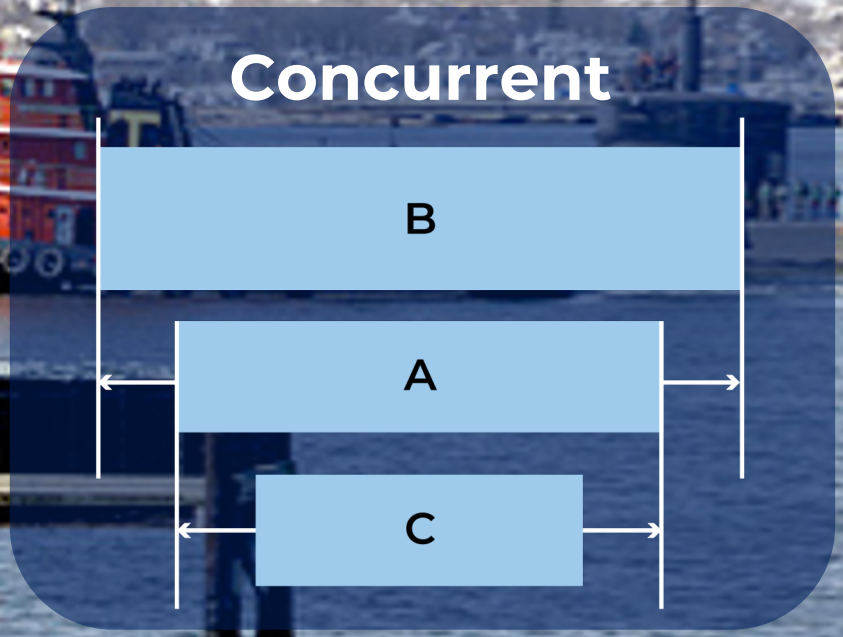
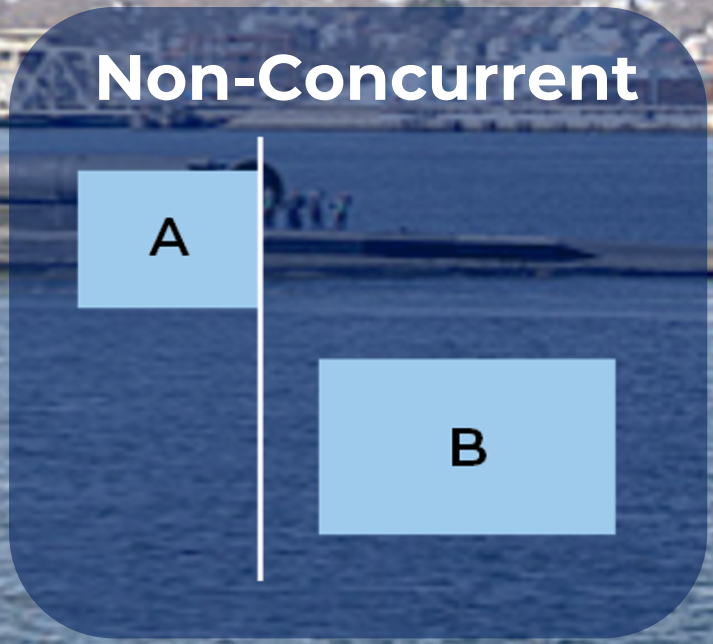
Example Constraint Types

- Temporal constraints
- Resource constraints
- Labor constraints
- Resource Sets – job can be performed by 2 different specialists or (1 generalist and 1 specialist) or 2 generalists.
- Spatial constraints – e.g.,
  - job requires a certain location or type of space;
  - two elements should (or should not) be next to each other
- Ergonomic constraints – individual limitations on work conditions
- Preference constraints – soft constraints that can be ignored under specified situations

Concurrent & Non-Concurrent

- Complex operations requires concept of concurrent & non-concurrent tasks
- Adds another layer of complexity





Tracking Resources

- Set due dates for milestones & deadlines
- Define resource requirements for tasks
- Let Aurora’s intelligent scheduling find the minimum number of resources to meet the milestones / deadlines.

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Capacity Change Constraints

- This allows the user to specify a relationship between a task and a resource.
- Some tasks may make a resource available (e.g., adding a space zone that can subsequently be used for work),
- Others may make a resource unavailable (e.g., installing panels that block access to a space zone).

Upstream/Downstream Task Analysis

- These analyses start with a given job or jobs and walk up/down the network to find the jobs it is dependent on, or the jobs that are dependent on it.
- The upstream analysis can help in understanding a key task and what it is dependent on.
- The downstream analysis can help in understanding a key task and what is impacted by it.

Point-to-Point Analysis

- This finds the path through the network from the first task to the second task (if there is such a path).
- It can be valuable for analyzing a subset of the network that is connected (e.g., all the work linking Milestone 1 and Milestone 2).

Error Analysis

Error Checks

Dependency Loops

This checks for loops in the network.
One column for each job in the loop.

Self-Referential Constraint

This is a special-case loop check that checks whether a job has a constraint to itself.
Columns: “IP Number”, “Job Name”

Flow Date/Job Date Inconsistency Error

This checks user-supplied dates and makes sure that they are compatible.
Columns: “Name", “Project", “Problem"

Early Start/Late End Blank

This makes sure that all early start and late end dates are set.
Columns: "Job Name", "Early Start Date", "Late End Date”

Early Start Before Late End Check

Make sure that the early start is before the late end.
Columns: "Job Name", "Early Start Date", "Late End Date”

Capacity Violation Error

Lists resource requirements for which there are never sufficient resources.
Columns: “Name”, “Requirement”, "Required Quantity", "Available Quantity”

Concurrency Overlap Error

This checks for situations where concurrent jobs in combination will not be satisfiable.
Columns: "Job Names”, “Requirement”, "Required Quantity", "Available Quantity”

Infeasible Exact Constraints

This detects that there is an exact constraint that cannot be satisfied because of another job in between of duration > 0.
Columns: "Exact Start", "Exact End", "Non-Trivial Path”

Infeasible Unbreakable Jobs

This checks for jobs that are not breakable across shifts or days, but are too long for that to be honored.
Columns: "Job Name", "Duration", "Conflict"

Unfenced Use of Unknown Duration

This checks that all jobs with unknown duration have some sort of date limits.
Columns: “Name", “Project”

Monte Carlo Analysis

- Monte Carlo Simulation – This takes advantage of duration distribution information to simulate multiple executions of the schedule to show how things are likely to play out.
- Works with infinite resource schedules
- Works with fully resource-loaded schedules

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One-Pass vs Aurora Scheduling

- Most automatic scheduling systems use simple one-pass algorithms (e.g. process in due-date/priority order, greedy assignment)
  - Most large system vendors and ERP systems
  - Produce schedules far less optimal than Aurora
  - While being far more expensive, waste user $s

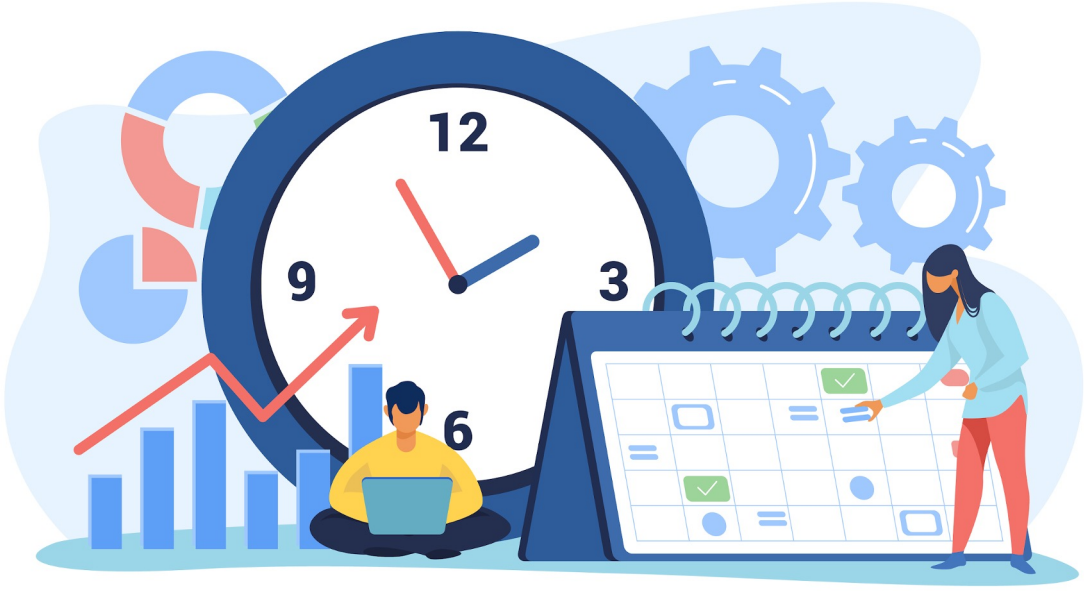
- Standard constraint-based approaches are far less computationally efficient (Aurora takes advantage of structure of scheduling problems and heuristics)

Mixed-mode Scheduling

- Forward schedule
- Backward schedule
- Mixed-mode scheduling
  - Forward and backward scheduling is set on a task-by-task basis.

Schedule Rationale

Aurora includes the rationale for each task on why it was scheduled where it was scheduled, so it is easy to determine what changes could be made for a task to occur earlier.



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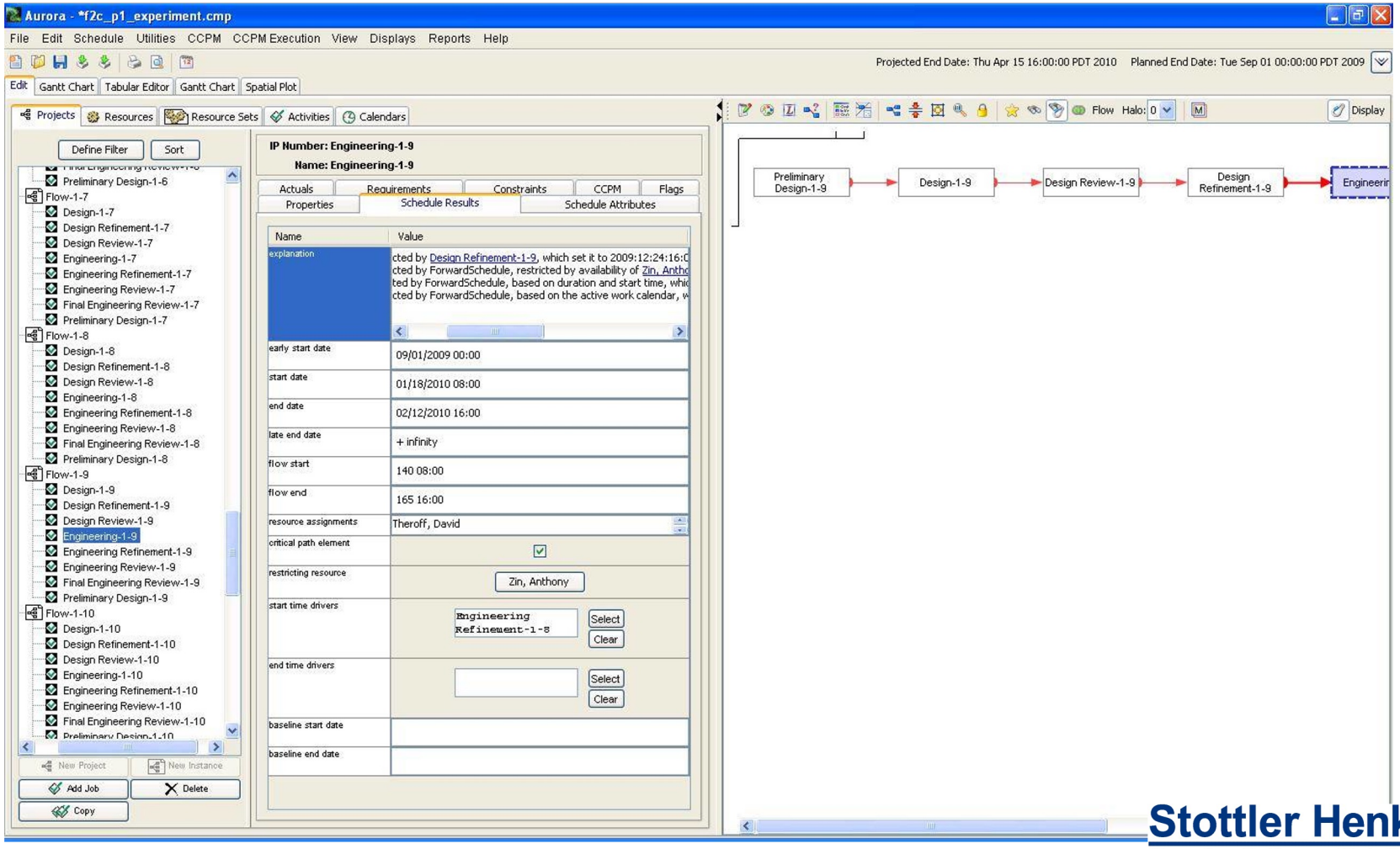
Explanation of Why each Task was Scheduled Where it was



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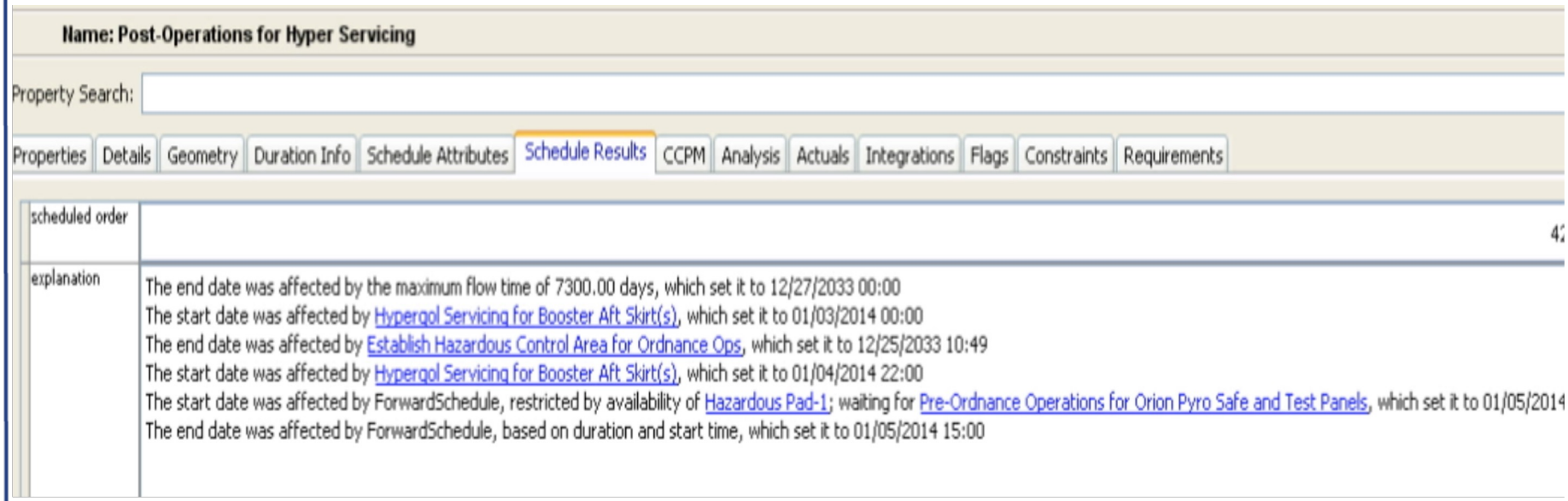
Schedule Results: Explanation



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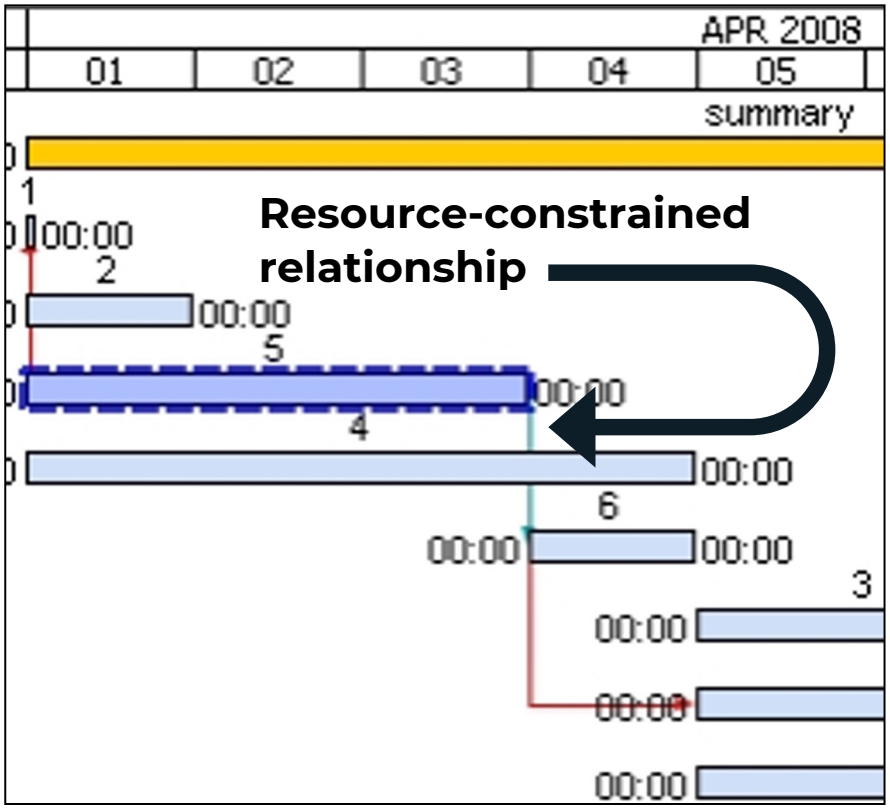
Resource Contention: Visual

Viewing resource contentions in Aurora

In this sample schedule, each task has a resource requirement attached as follows

Task #	Resources Needed
2	1
3	2
4	2
5	2

Note that there is a total amount of only 5 resources. Tasks 2, 4, and 5 are started at the same time (5 resources used). Task 2 completes, but there are not enough resources left to start Task 6, so Task 6 must wait until Task 5 is complete.



Aurora shows you this resource-constrained relationship with a blue-grey line between the two Tasks.

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Resource Contention: Task

The Single Element Display in Aurora helps the user visualize the relationships between tasks:

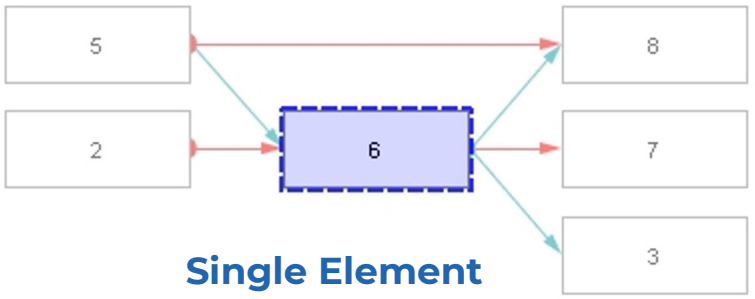
- Blue-grey lines denote a resource-constrained work flow
- Red lines denote temporally-constrained work flow

Referring to the three diagrams to the right:

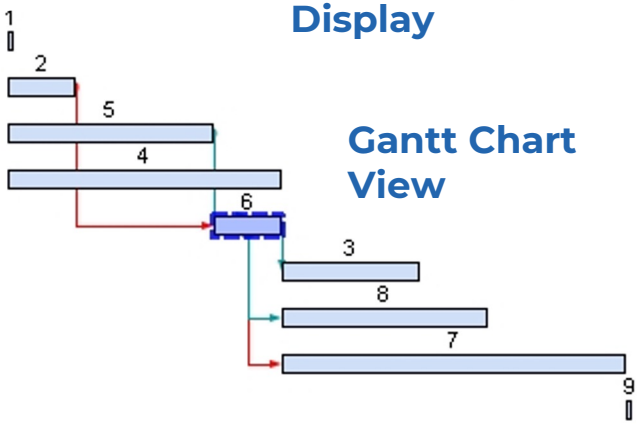
- Task 6 can start any time after Task 2 is completed (red line in Single Element Display), but must wait for Task 5 to release resources (blue-grey line).

- Tasks 3 and 8 must wait for 6 to release resources before they can start, as shown in the Gantt Chart View

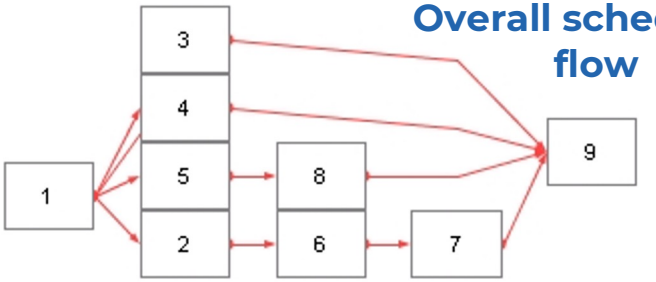
- Task 7 starts after Task 6 completes (red line in Single Element Display)



Single Element Display



Gantt Chart View



Overall schedule flow

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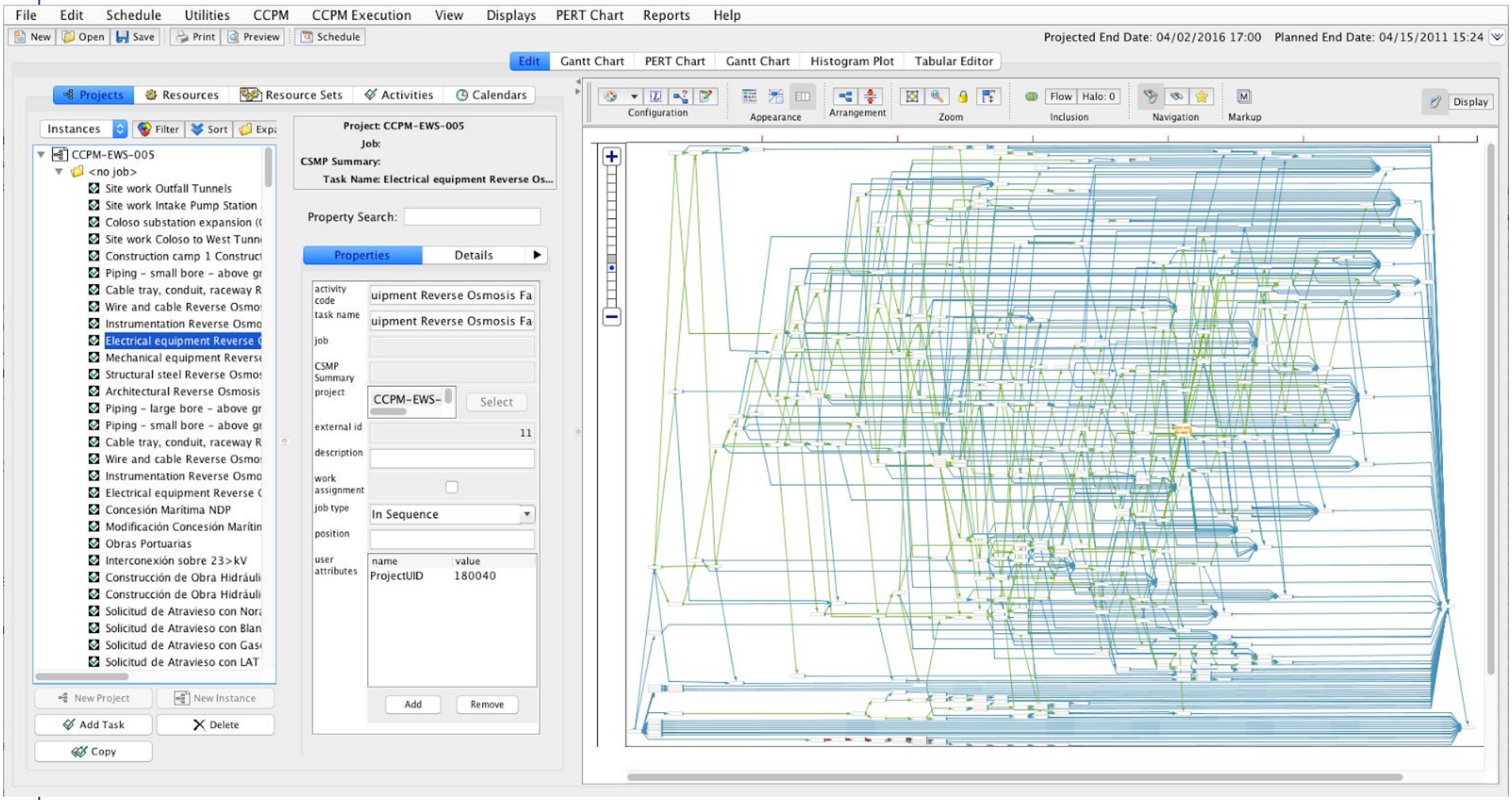
Aurora: Beneficial Graphics



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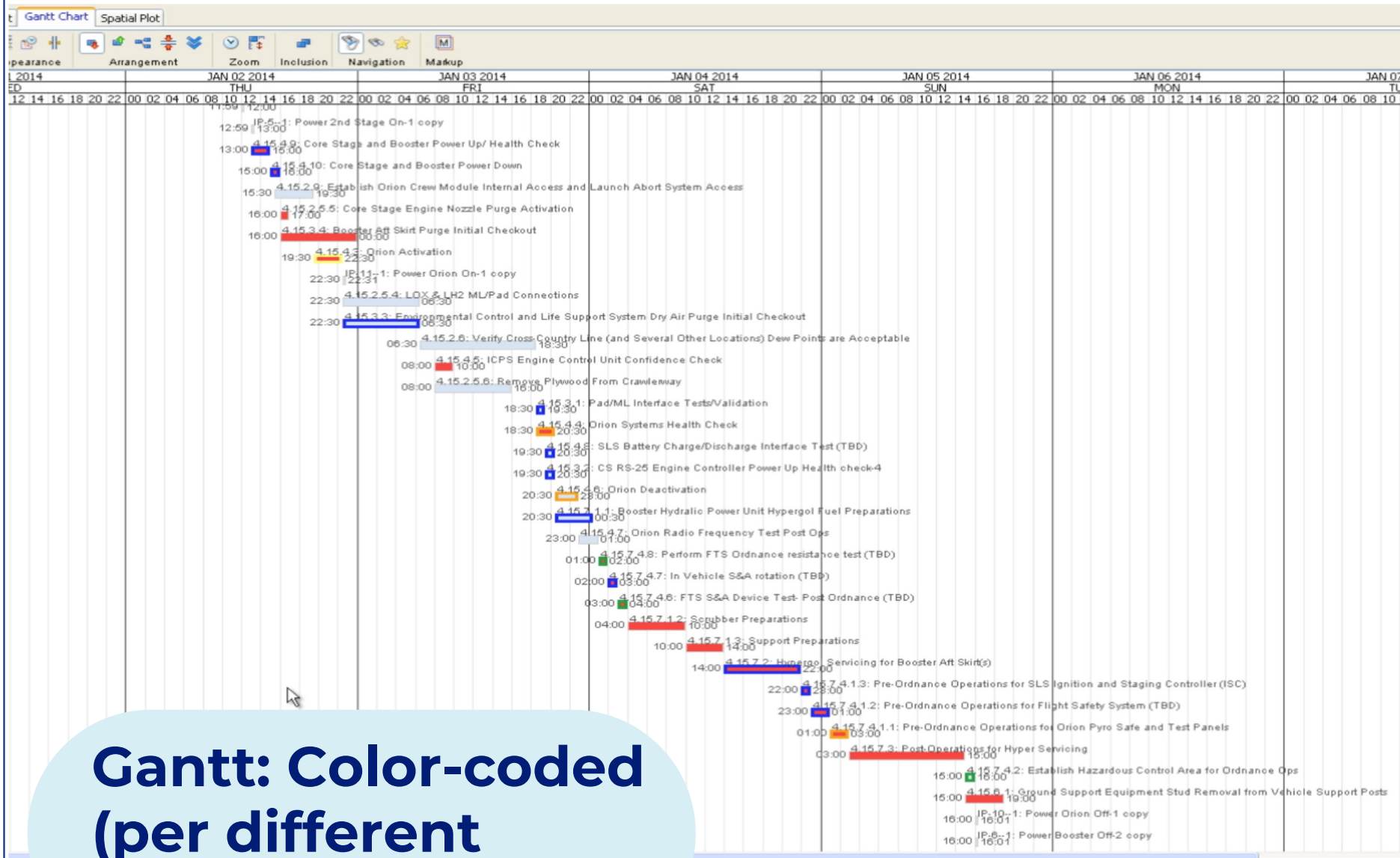

Gantt: Color-coded (per different requirements)

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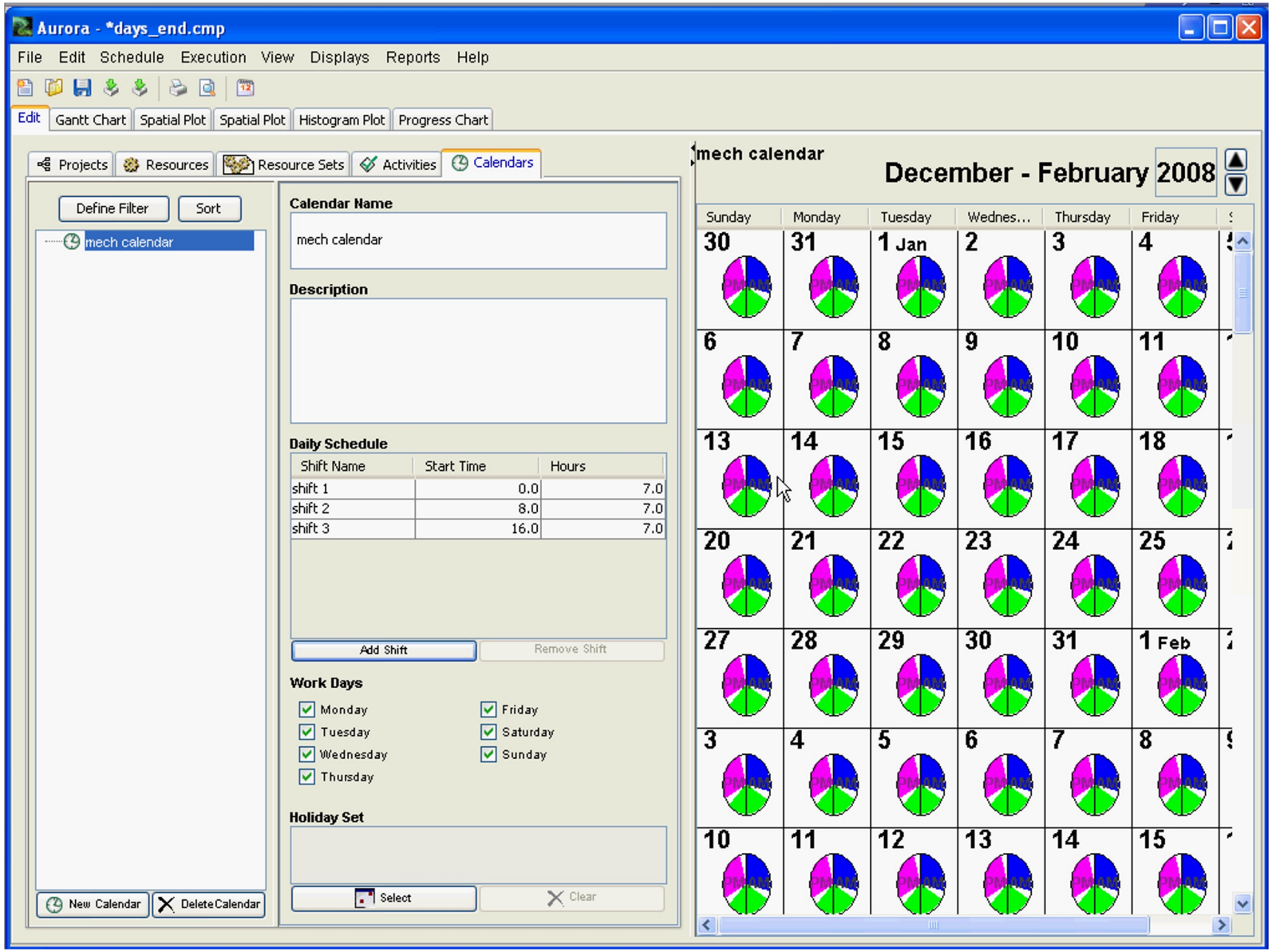

Calendars

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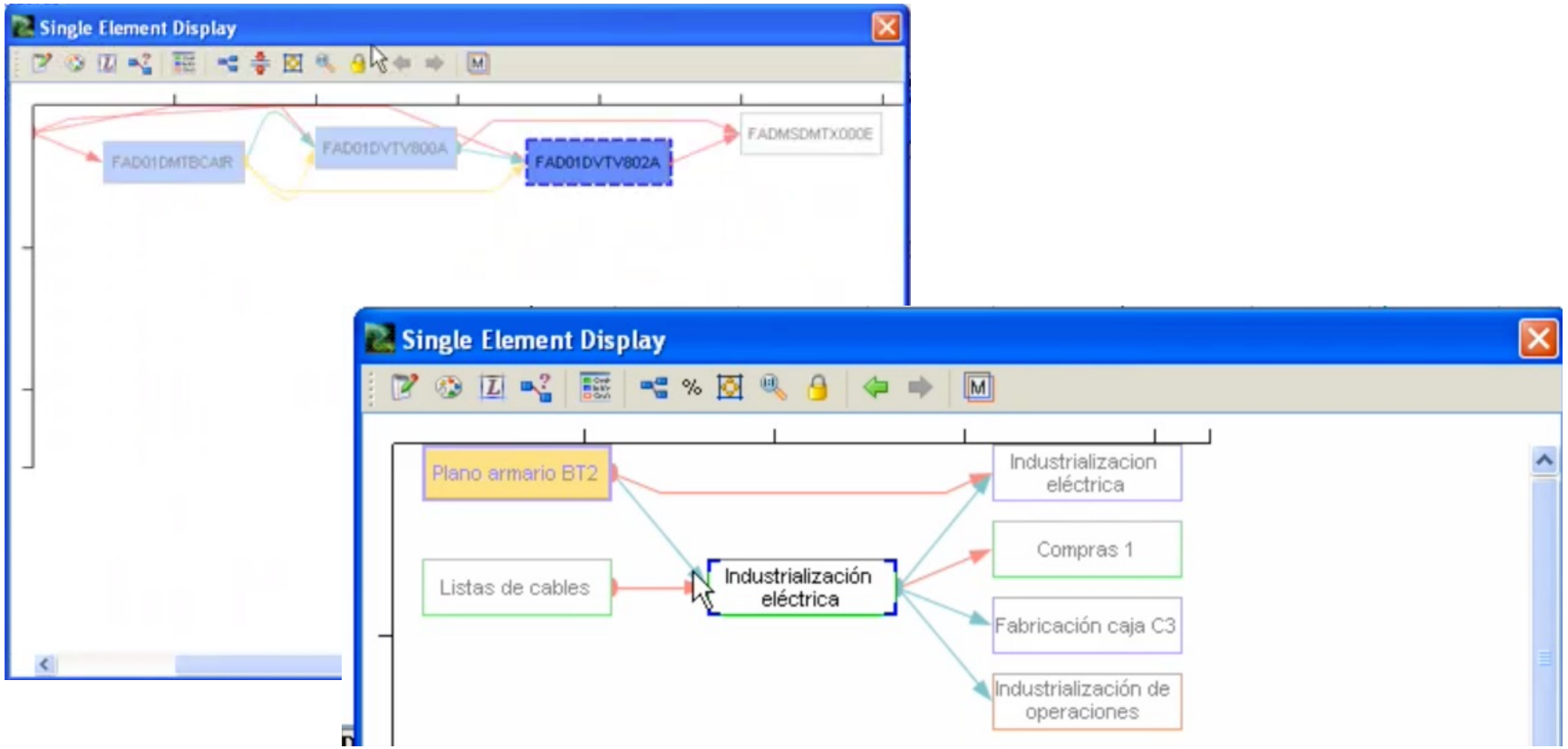
Single Element Display



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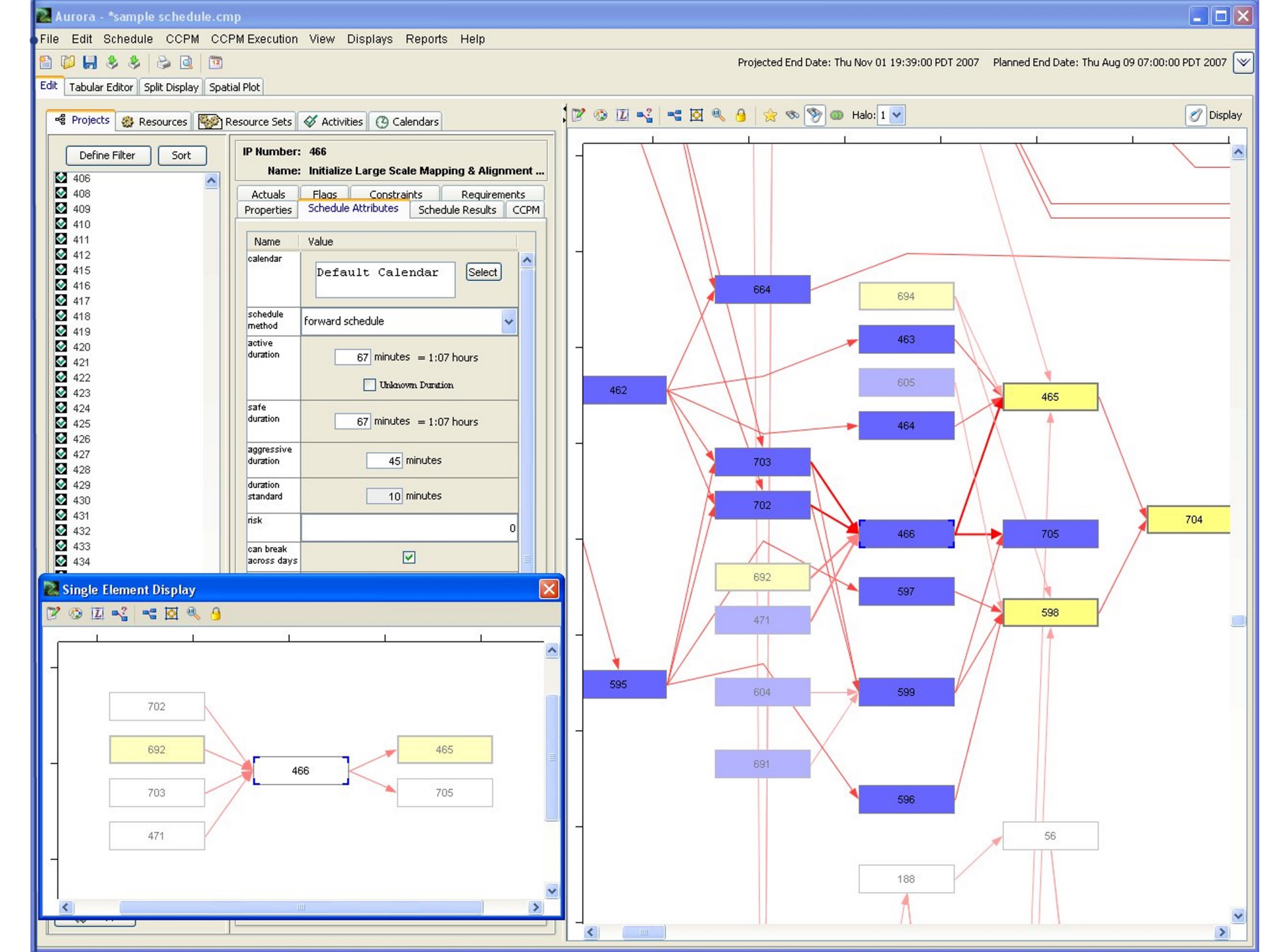
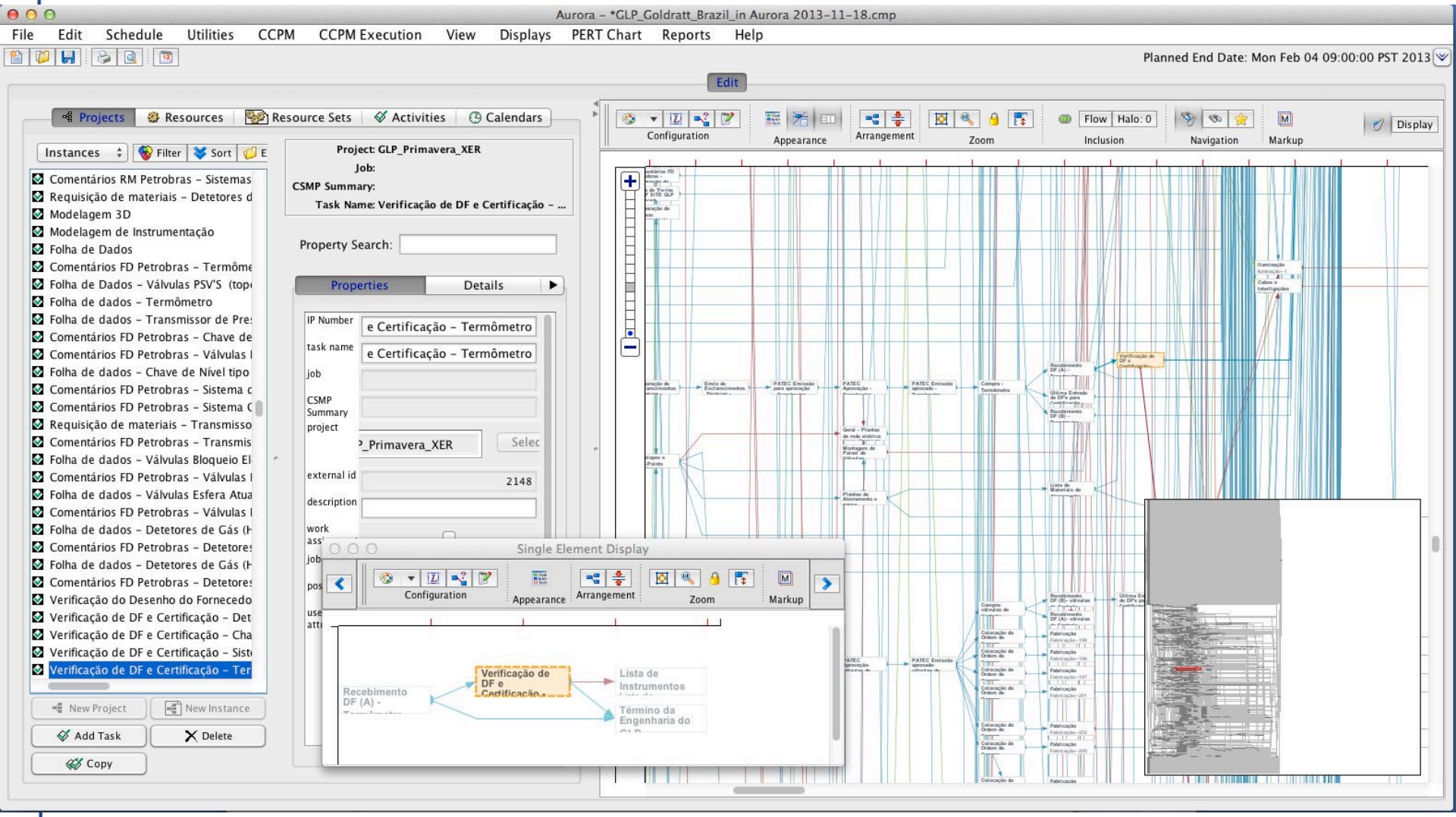

Aurora - *sample schedule.cmp
File Edit Schedule CCPM CCPM Execution View Displays Reports Help
Projected End Date: Thu Nov 01 19:39:00 PDT 2007 Planned End Date: Thu Aug 09 07:00:00 PDT 2007
Edit Tabular Editor Split Display Spatial Plot
Projects Resources Resource Sets Activities Calendars
Define Filter Sort
406 408 409 410 411 412 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434
IP Number: 466
Name: Initialize Large Scale Mapping & Alignment ...
Actuals Flags Constraints Requirements
Properties Schedule Attributes Schedule Results CCPM
Name Value
calendar Default Calendar Select
schedule method forward schedule
active duration 67 minutes = 1:07 hours
Unknown Duration
safe duration 67 minutes = 1:07 hours
aggressive duration 45 minutes
duration standard 10 minutes
risk 0
can break across days
Halo: 1
Display
664 694 463 605 462 465 464 703 702 704 466 705 692 597 598 471 595 604 599 691 596 56 188
Single Element Display
702 692 703 471 466 465 705



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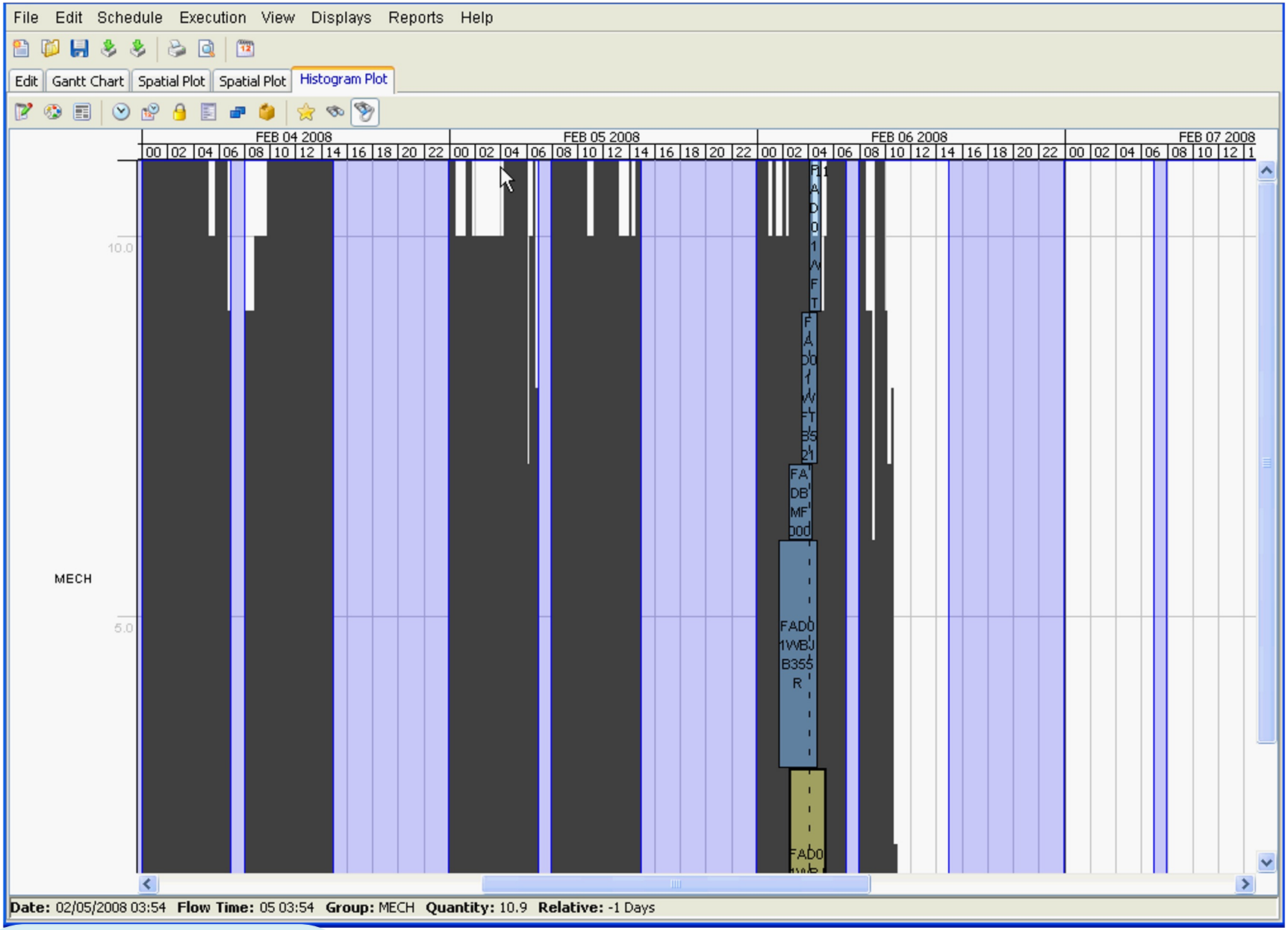

Histogram

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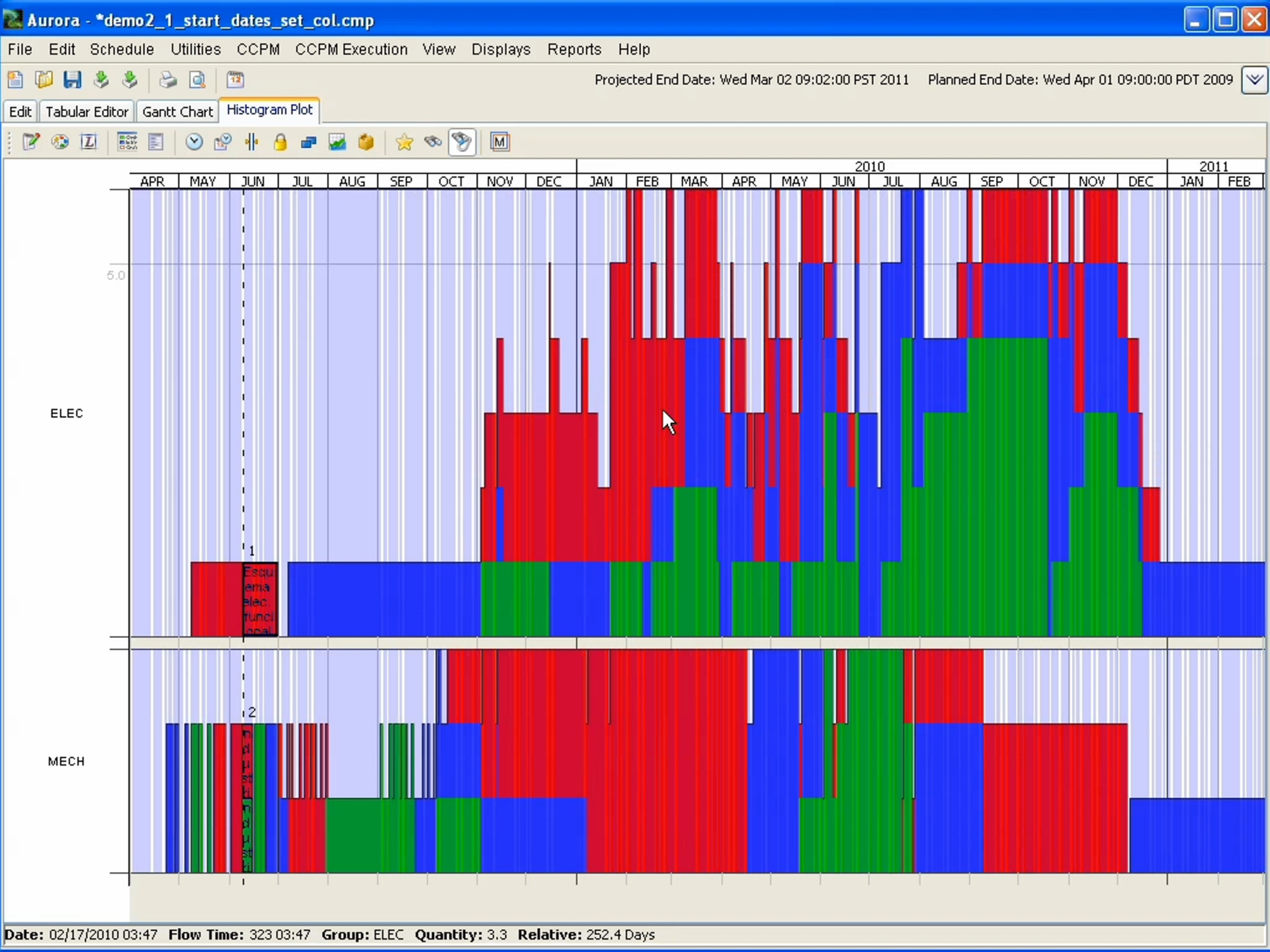
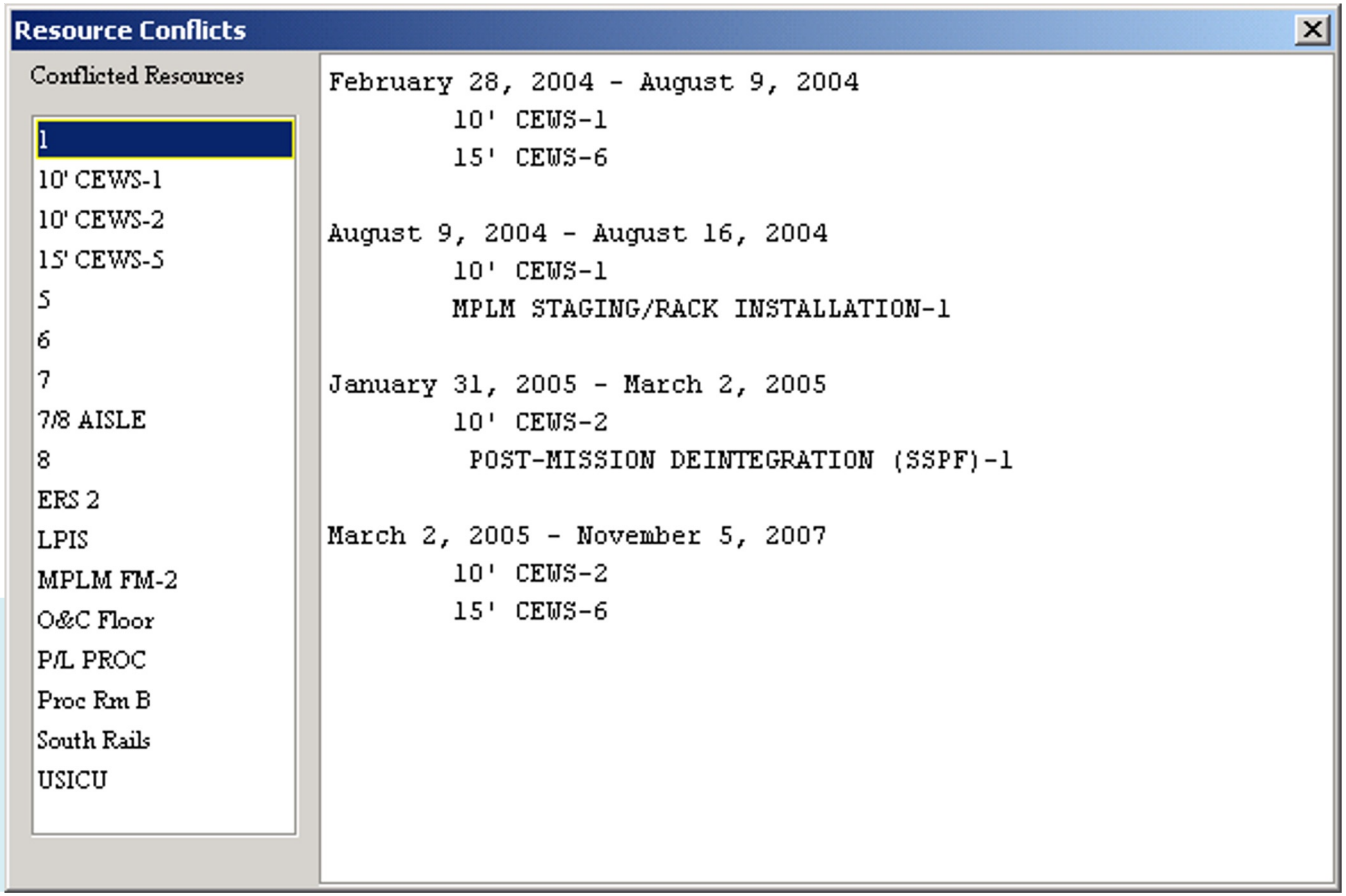

Aurora - *demo2_1_start_dates_set_col.cmp
File Edit Schedule Utilities CCPM CCPM Execution View Displays Reports Help
Projected End Date: Wed Mar 02 09:02:00 PST 2011
Planned End Date: Wed Apr 01 09:00:00 PDT 2009
Edit
Tabular Editor
Gantt Chart
Histogram Plot
2010
2011
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB
5.0
ELEC
MECH
1
2
Date: 02/17/2010 03:47 Flow Time: 323 03:47 Group: ELEC Quantity: 3.3 Relative: 252.4 Days

Aurora: Conflict Viewing



- Aurora can usually resolve all conflicts.
- If a schedule is over-constrained, resulting in one or more conflicts, those elements are displayed in red.
- Users can see a global view of all conflicts in the schedule by using a conflict display window.

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Enhancing Resource - Leveling via Intelligent Scheduling

SCHEDULING ISN'T ROCKET SCIENCE

It’s harder

Bottom Line Results

- Productivity Increases &/or Costs Decrease
- Unfair Competitive Advantage

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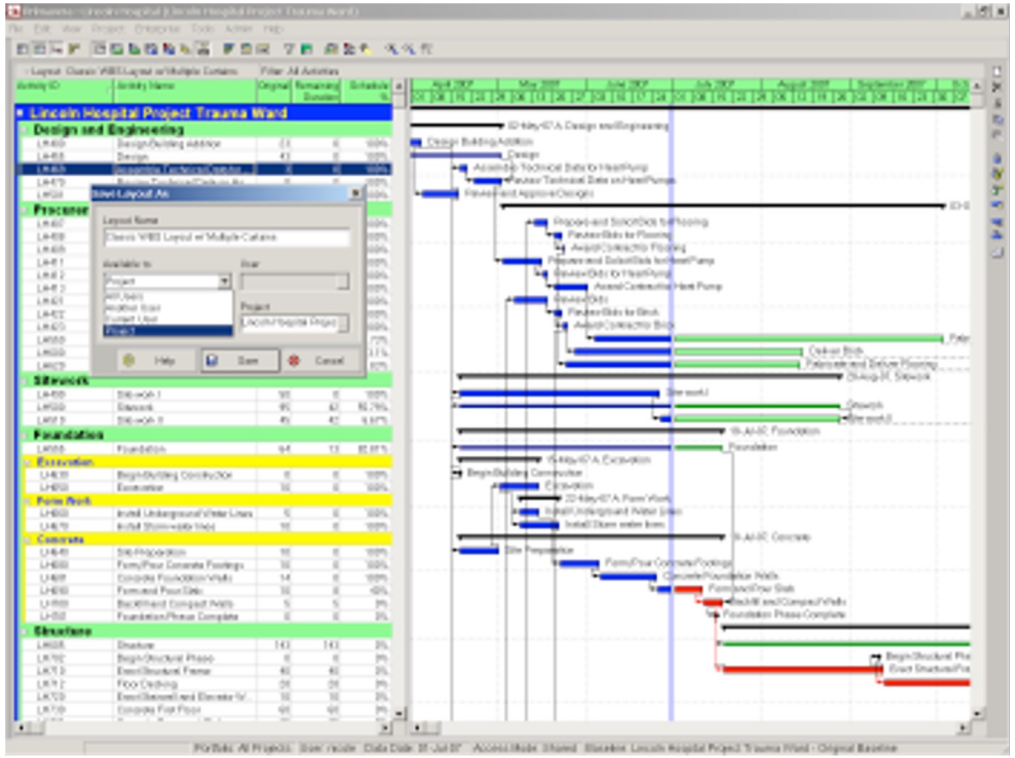
Resources and Resource Loaded Critical Path

- Large organizations developing and building complex systems rely on schedules and project management.
- Many CPM projects are resource constrained (in reality, even if not modeled that way)



- Resource constraints (e.g., labor, space, equipment) greatly complicates the scheduling problem.
  - Hence a '*reason*' to ignore

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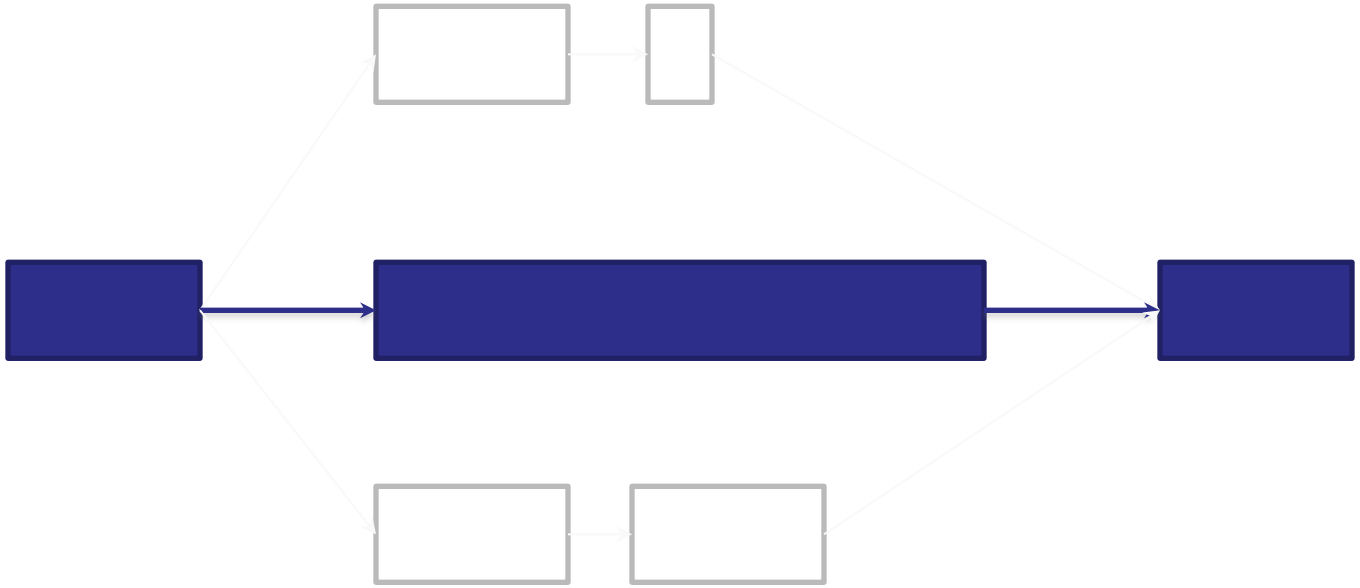
Critical Path

Shortest path through the network, taking duration into account



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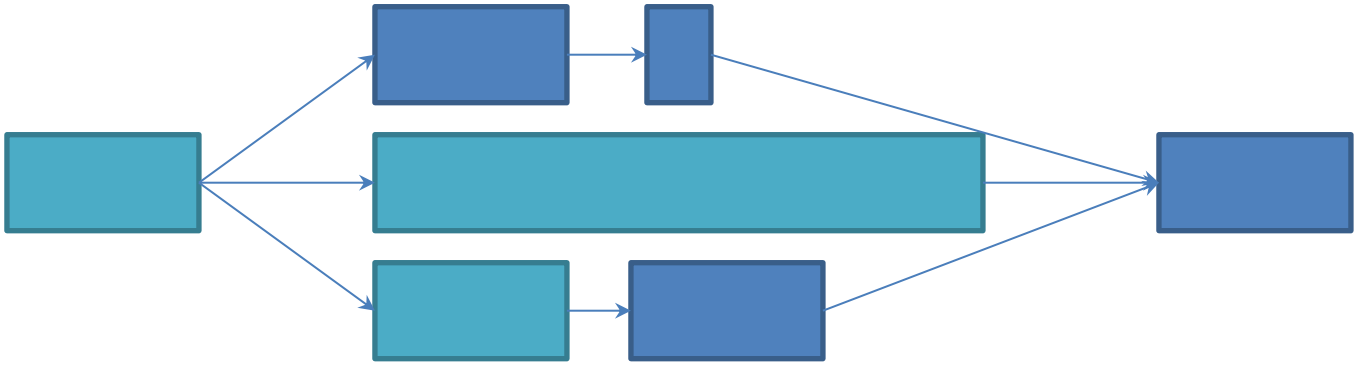
Critical Chain = Resource Constrained Critical Path

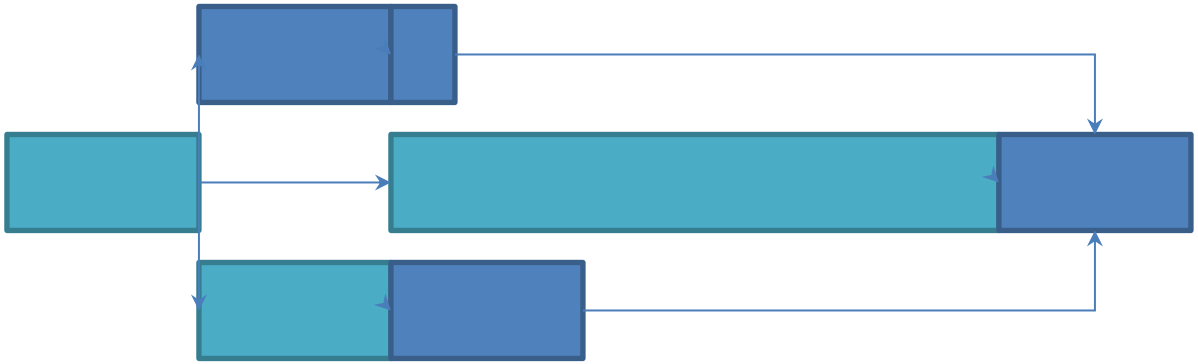
- Shortest path through the resource-loaded schedule, *taking resource contentions into account*
- Multiple possibilities for the same network, based on the resource requirements and schedule results

Critical Chain – Example 1



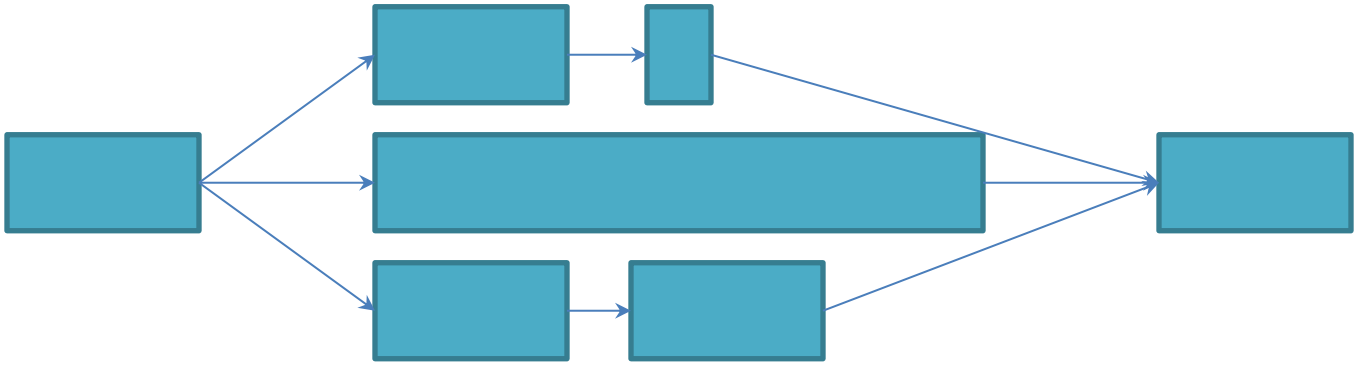
Requires resource 1

As scheduled:



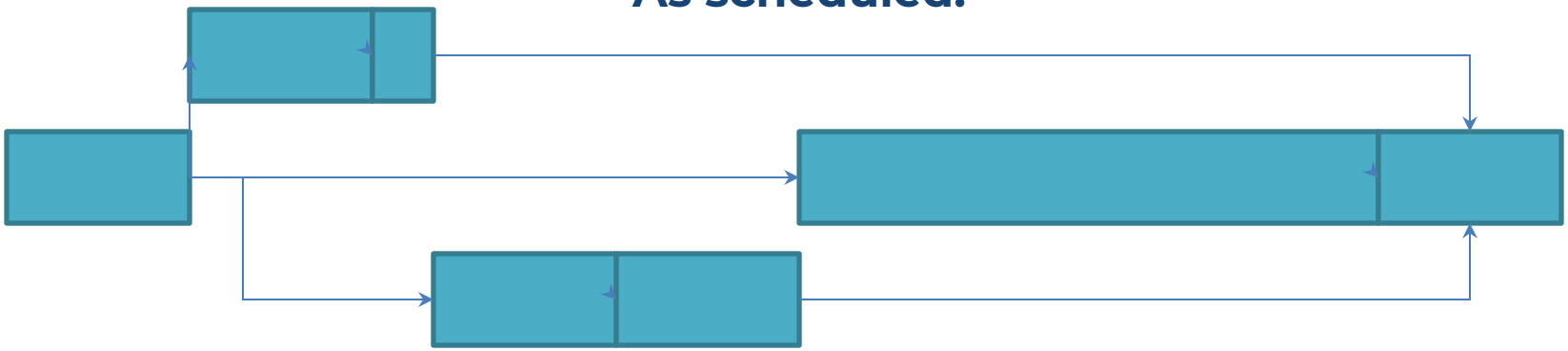
Critical chain:

Critical Chain – Example 2



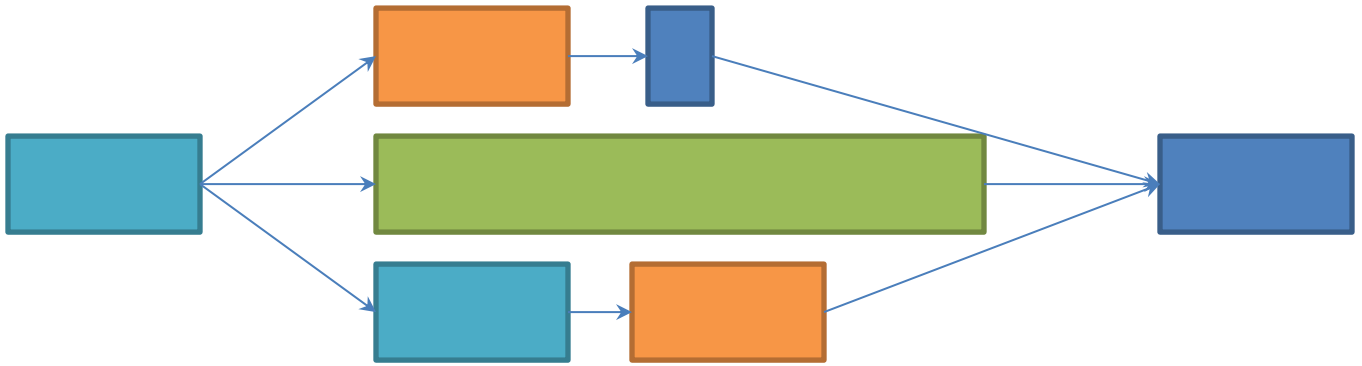
Requires resource 1 (all require same bottlenecking resource)

As scheduled:



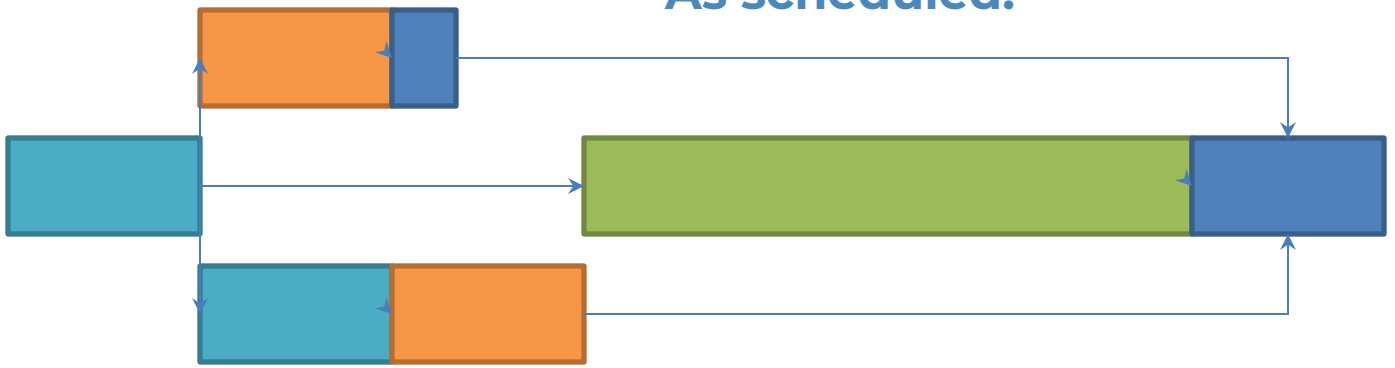
Critical chain:

Critical Chain – Example 3



Requires resource 1 Requires resource 2 Requires resource 1 and 2

As scheduled:



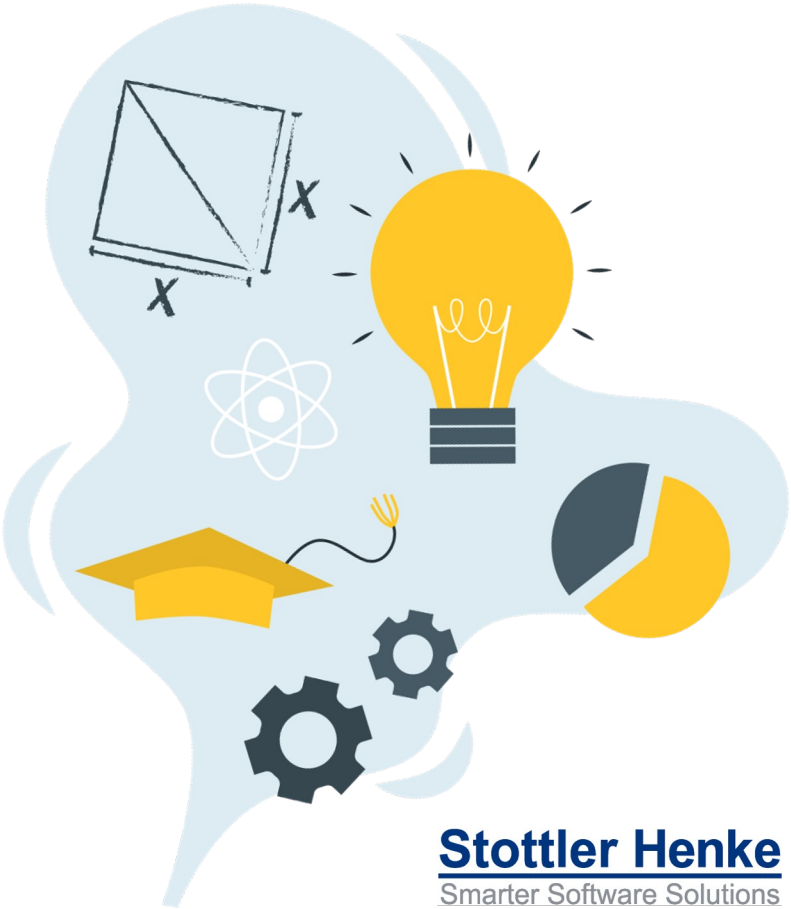
Critical chain:

Scheduling Background / Comparisons

- Resource-Constrained Scheduling is NP-Complete, takes exponential time for optimal solution
  - I.e., it is a hard problem
  - Approximate methods are needed
- Most automatic scheduling systems use simple one-pass algorithms
- Standard constraint-based approaches are far less computationally efficient (Aurora takes advantage of structure of scheduling problems and heuristics)

Expert Knowledge & Experience Needed

- Mathematics is not enough (again because problem is NP-Complete, takes exponential time for optimal solution)
- Encoding expert knowledge & experience in software can make this knowledge available to others
  - Found domain specific heuristics many times beneficial in other domains.



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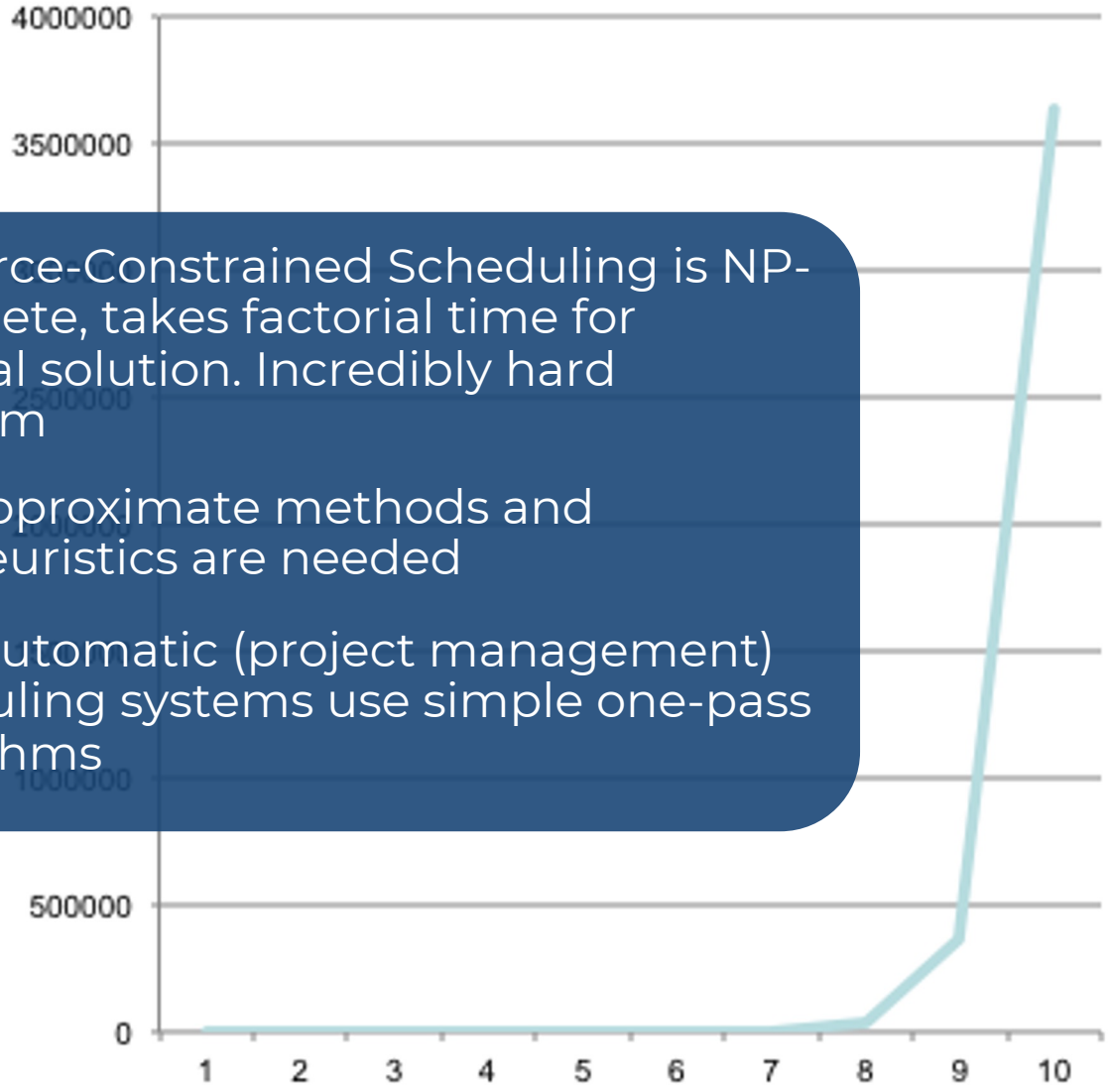
Scheduling is Difficult

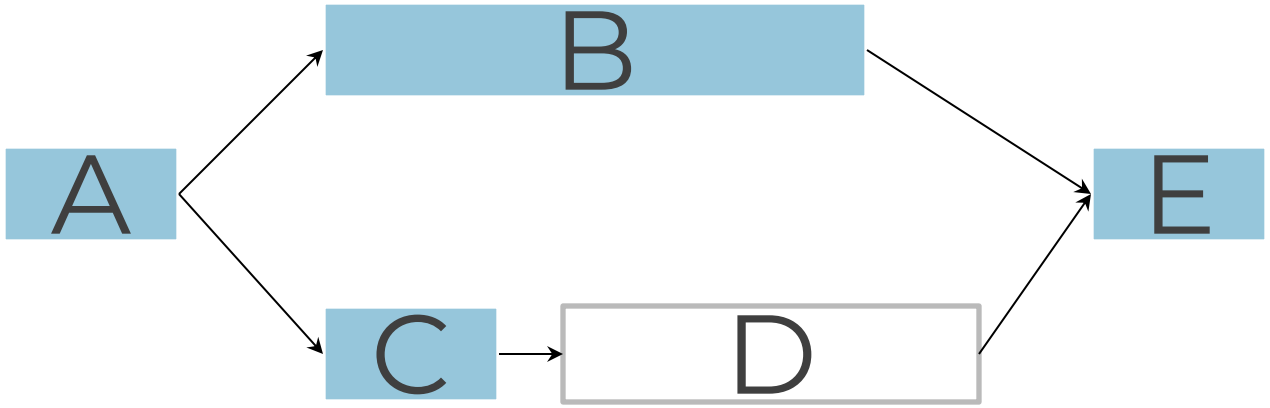
1	1
2	2
3	6
4	24
5	120
6	720
7	5040
8	40320
9	362880
10	3628800



- Resource-Constrained Scheduling is NP-Complete, takes factorial time for optimal solution. Incredibly hard problem
  - Approximate methods and heuristics are needed
- Most automatic (project management) scheduling systems use simple one-pass algorithms

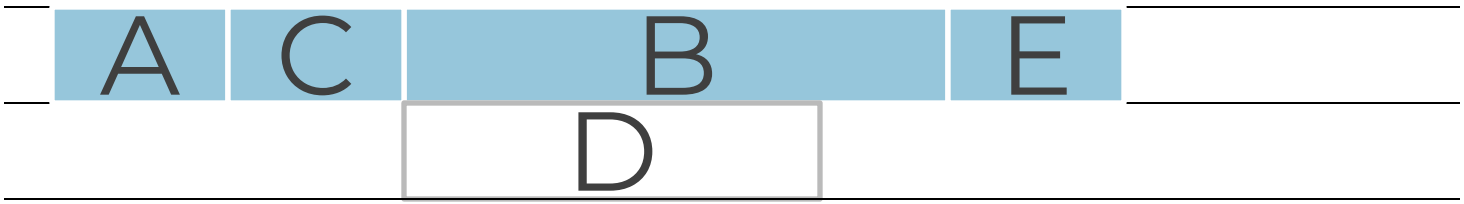
Why order matters?

The example below involves jobs using two resources, light blue and white

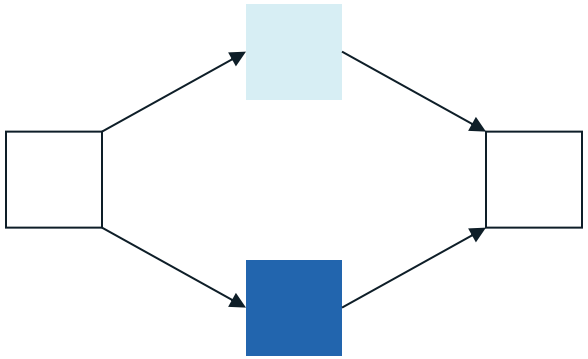


Schedule 1: B before C

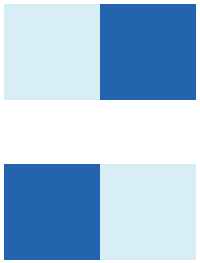
Schedule 2: C before B



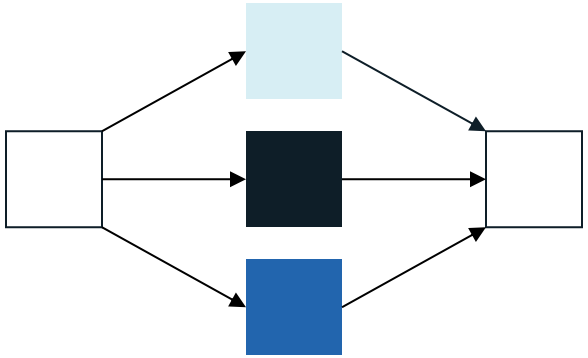
Two tasks that can occur in either order (one at a time)



results in two options

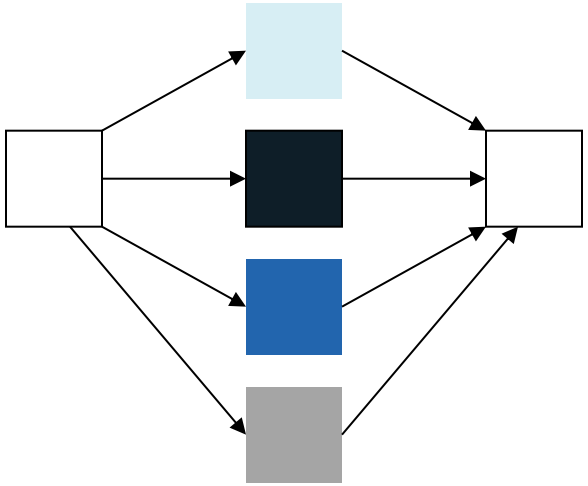


Three tasks that can occur in any order (one at a time)

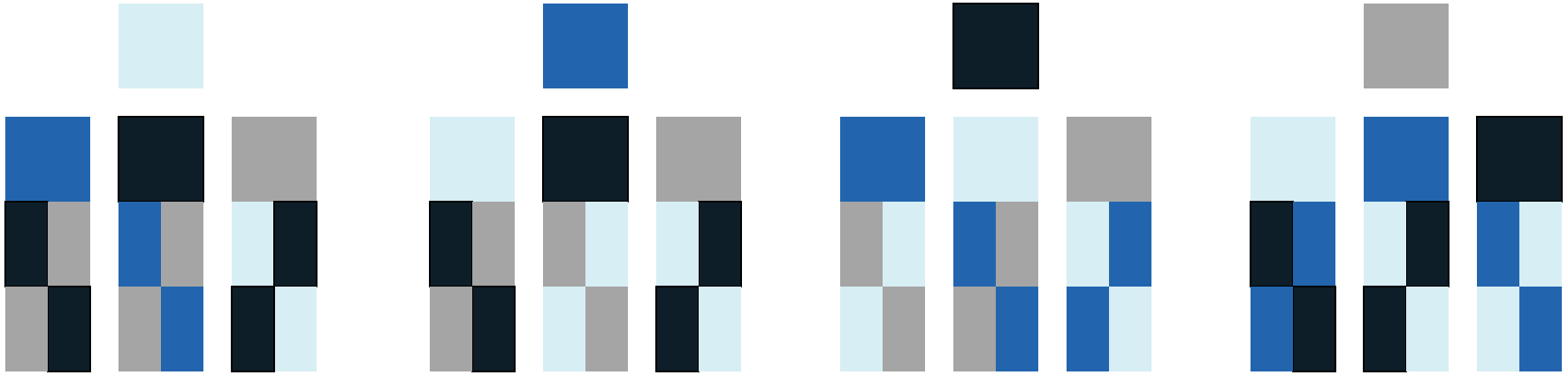


results in six options

Four tasks that can occur in any order (one at a time)



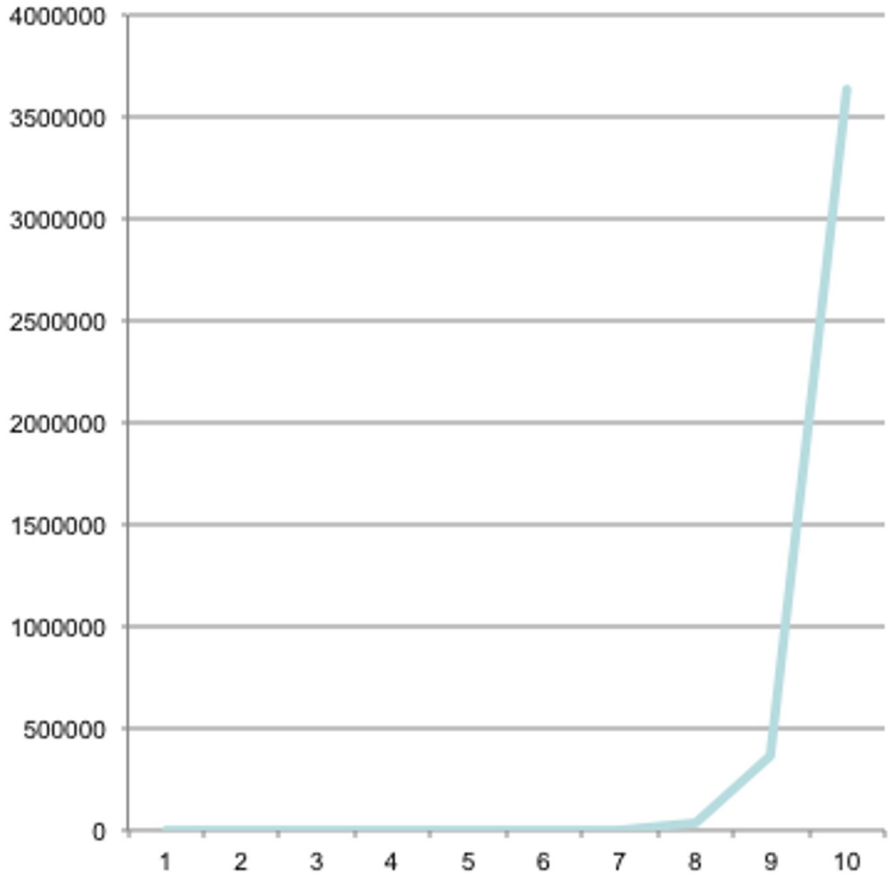
results in twenty-four options



Why can’t you search for the best order?

- Ordering options scale as N!

1	1
2	2
3	6
4	24
5	120
6	720
7	5040
8	40320
9	362880
10	3628800



Why Intelligent Scheduling is Not Used/Available?

- Resource-loaded scheduling is difficult
  - Whole field of Operations Research
- Not leveraged in the Project Management domains that Primavera serves
- Usually, demand is generated from knowledgeable users
- Not promoted by solution providers

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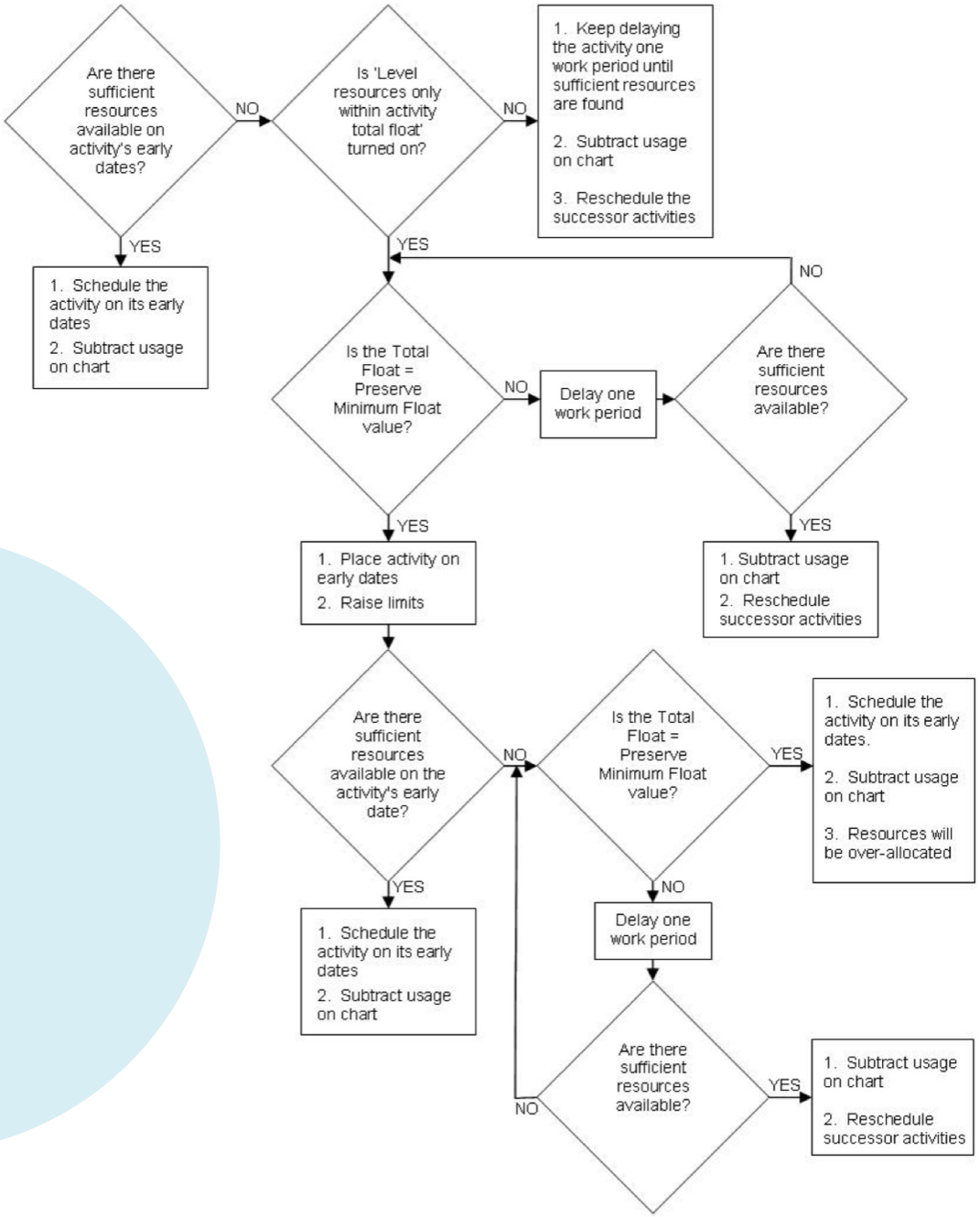
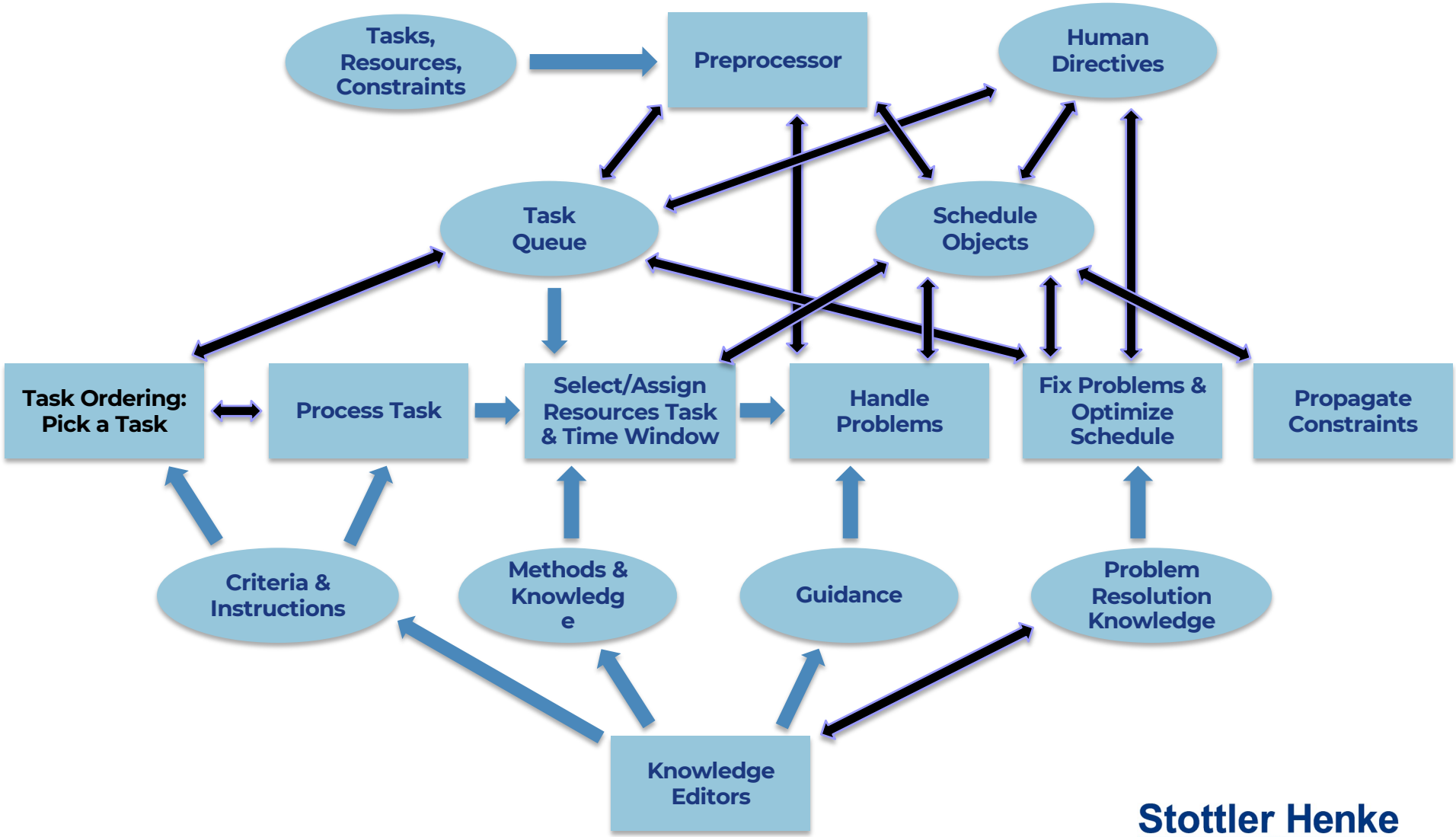
Primavera Resource Leveling flowchart



Aurora Architecture



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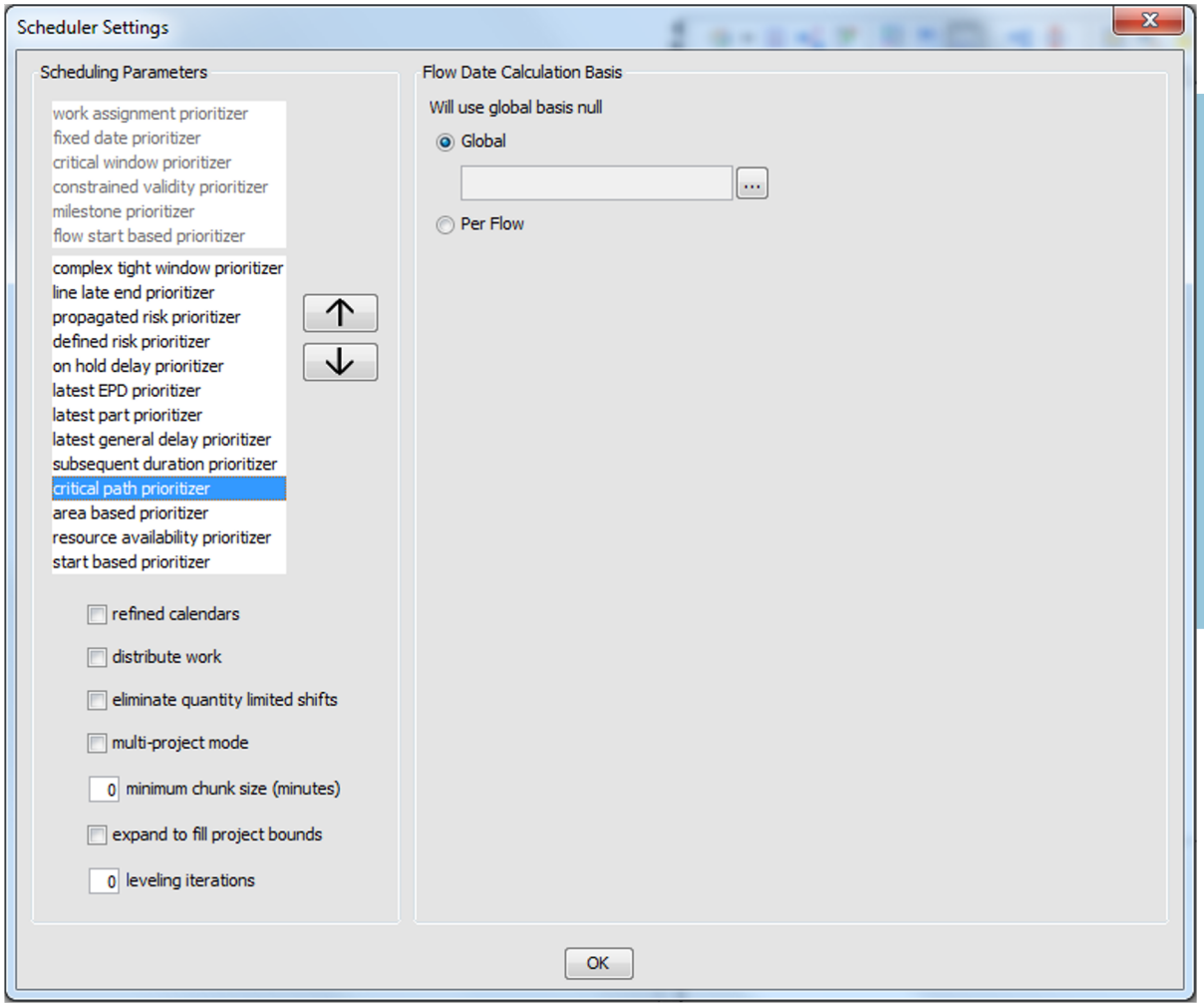
Artificial Intelligence: Capture Human Knowledge – How best to schedule



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Scheduling Comparisons

- Multiple sources reveal the effect of the Scheduling Engine
- For larger projects (>1,000): Aurora has been able to find project durations 50% shorter than other software for the same data set.
- Much of the potential improvement offered by modeling resources is being squandered.
- Resource leveled schedules are sub-optimal

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Why Important?/Motivation

- So much work is put into developing project plan before hitting the **schedule / Level Resources … button**
- Days, Weeks, Months
- What if your resulting schedule is 10% longer than it needs to be because of the scheduling engine?
- Would **you** care?

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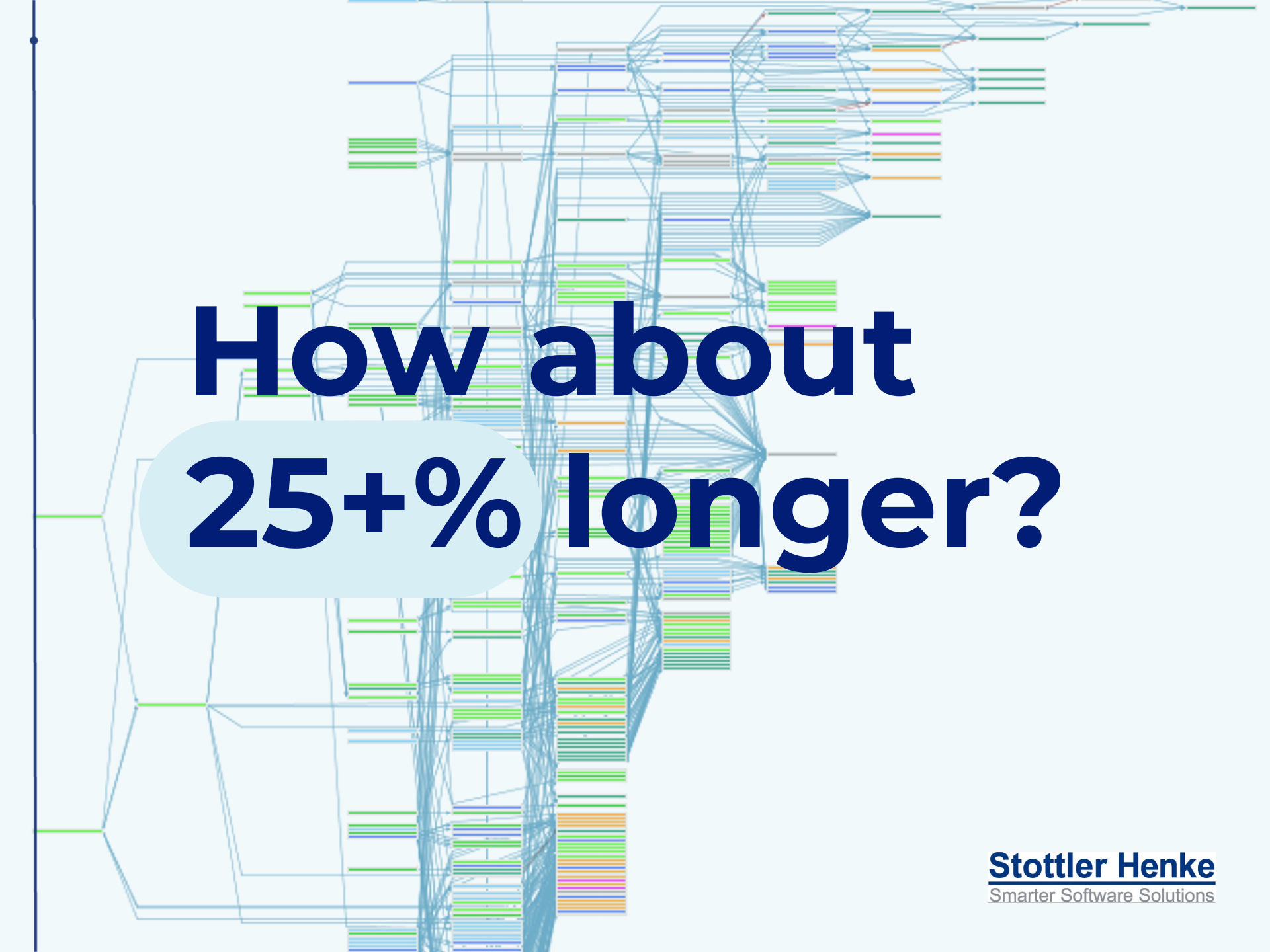

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Motivation: Visual

- Following figure shows.
  - **Critical Path (unfilled boxes)**
  - **Resource Constrained Critical Paths (Both "correct," only difference was scheduling technique applied)**
- The goal is the shortest correct schedule

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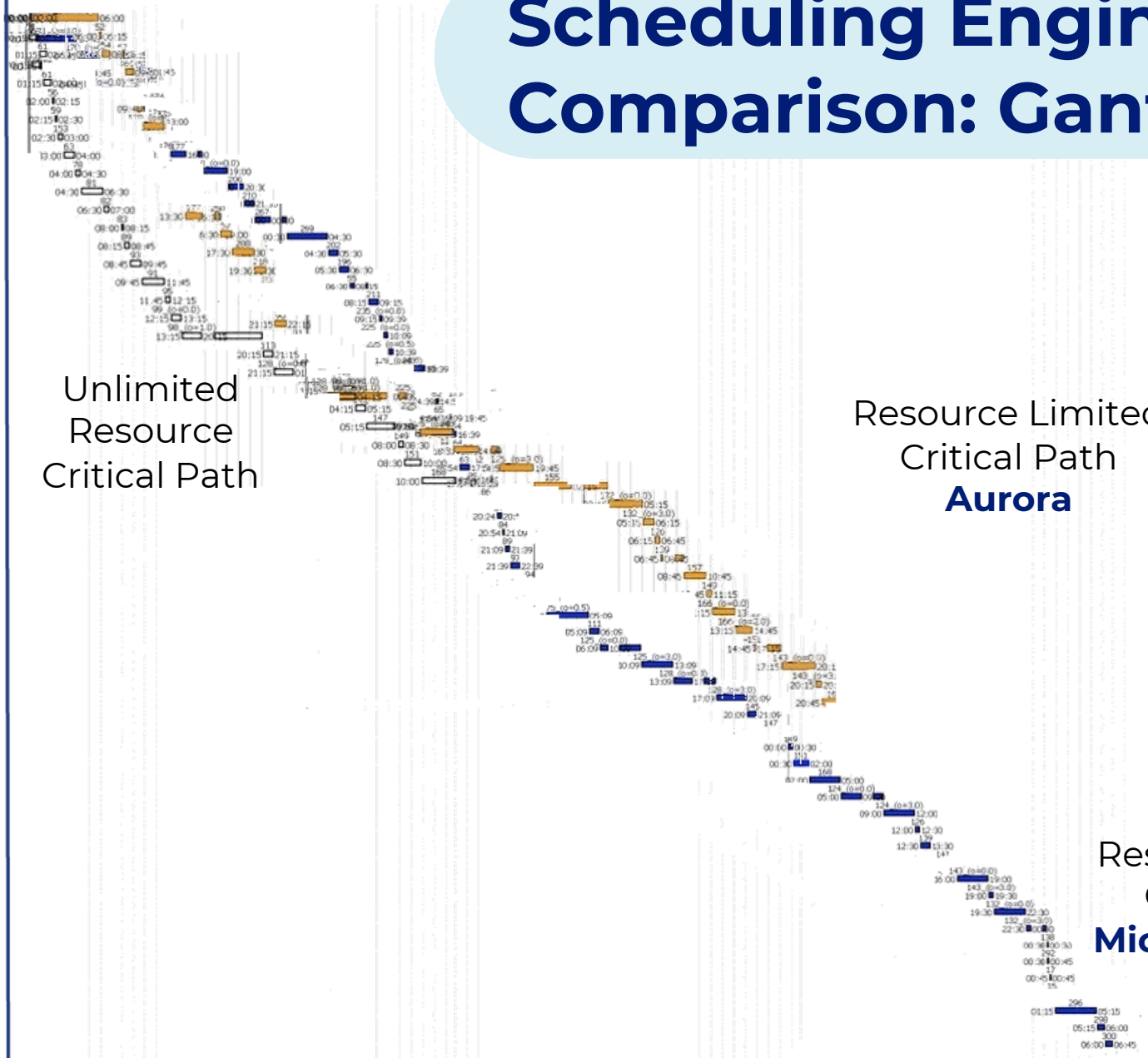
Scheduling Engine Comparison: Gantt Chart

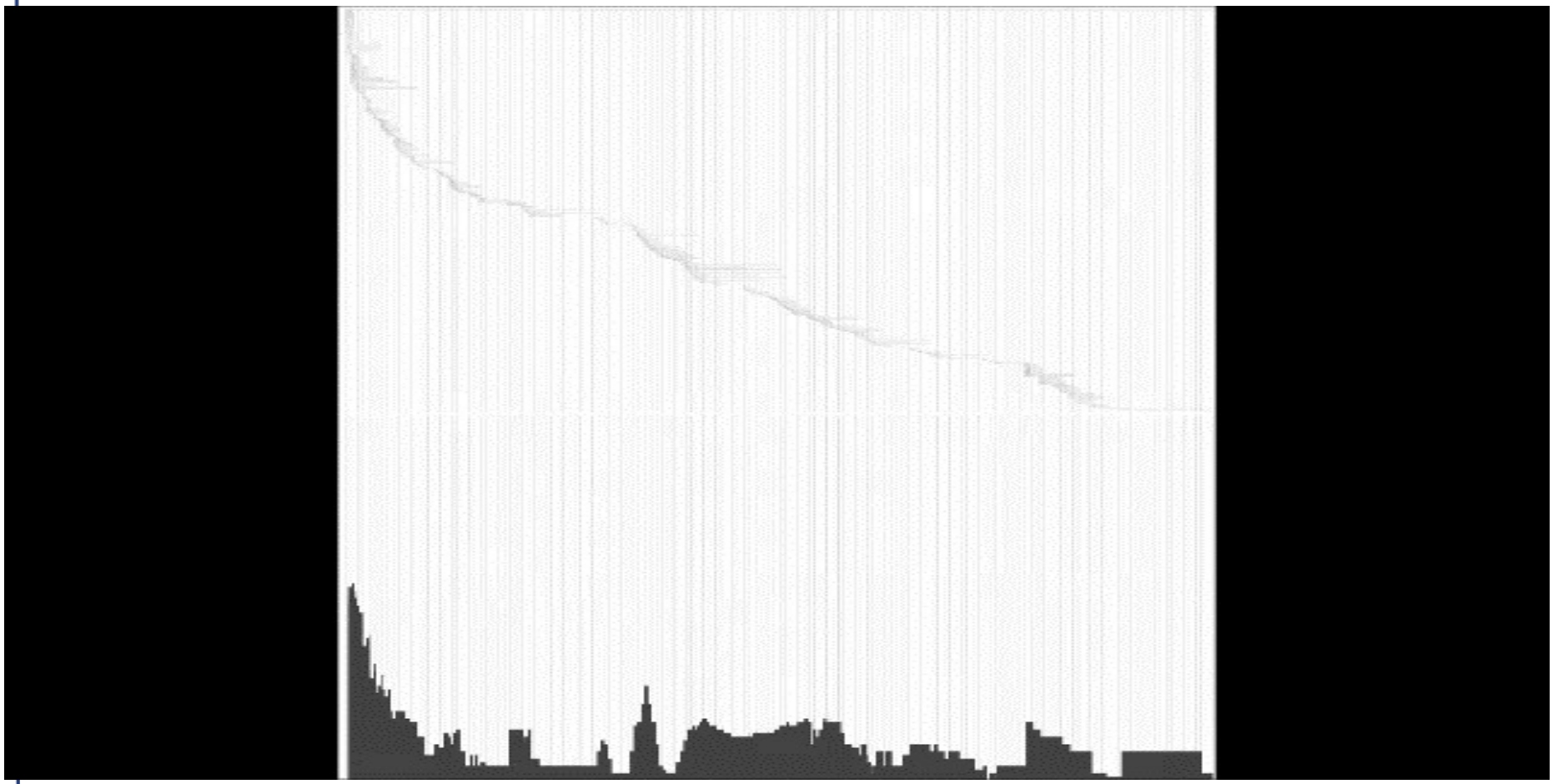


Unlimited Resource Critical Path

Resource Limited Critical Path **Aurora**

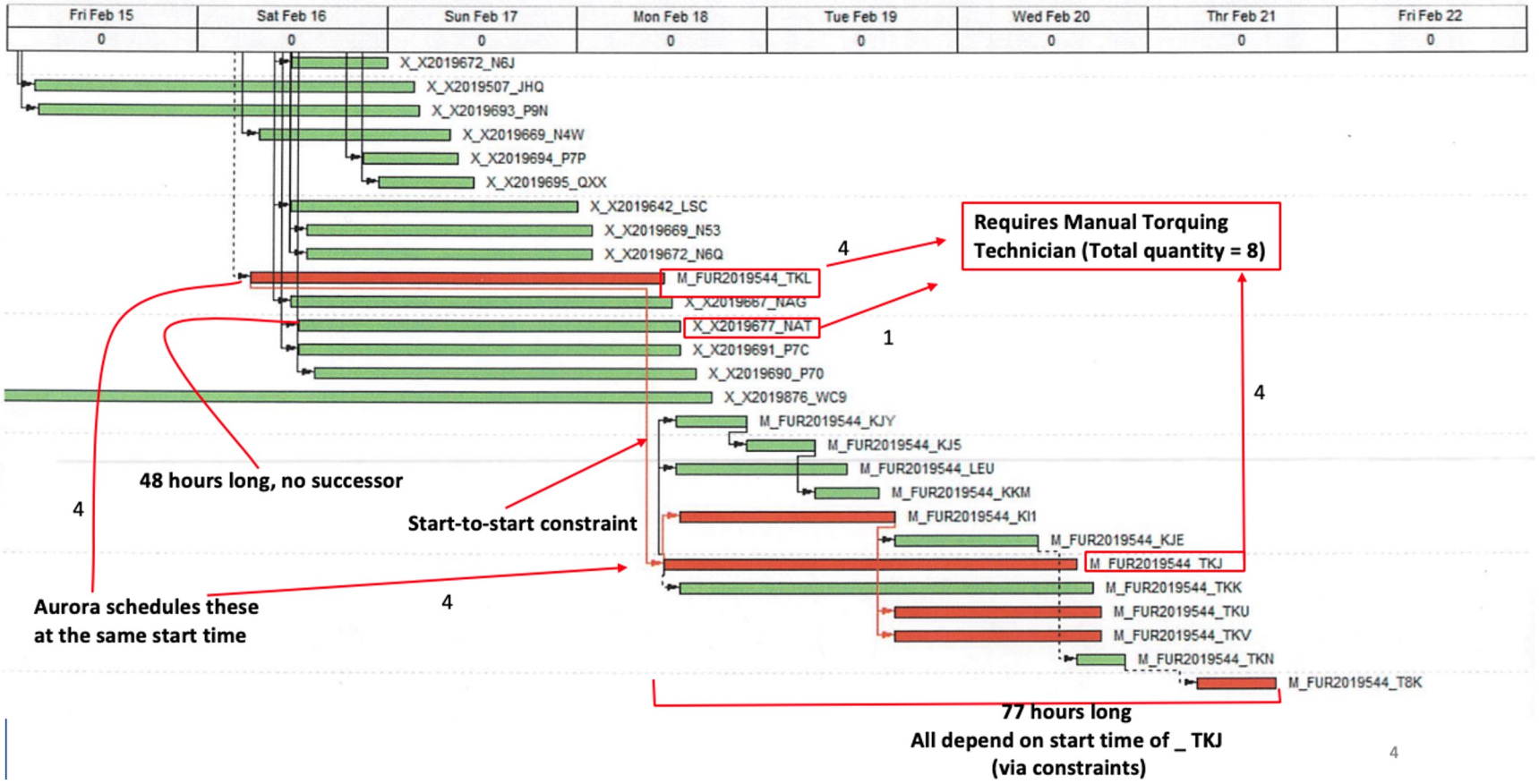
Resource Limited Critical Path **Microsoft Project**

MS Project results (START) vs Aurora results (END): Animation



Animation: P6 at start vs Aurora at the end

Example: P6 vs Aurora (End of Schedule)



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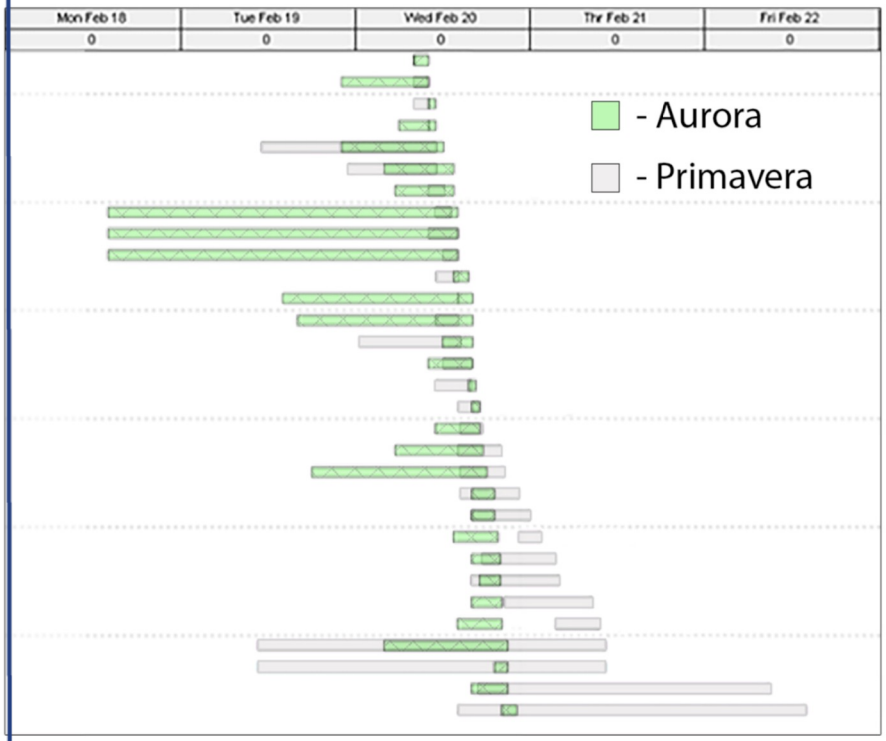
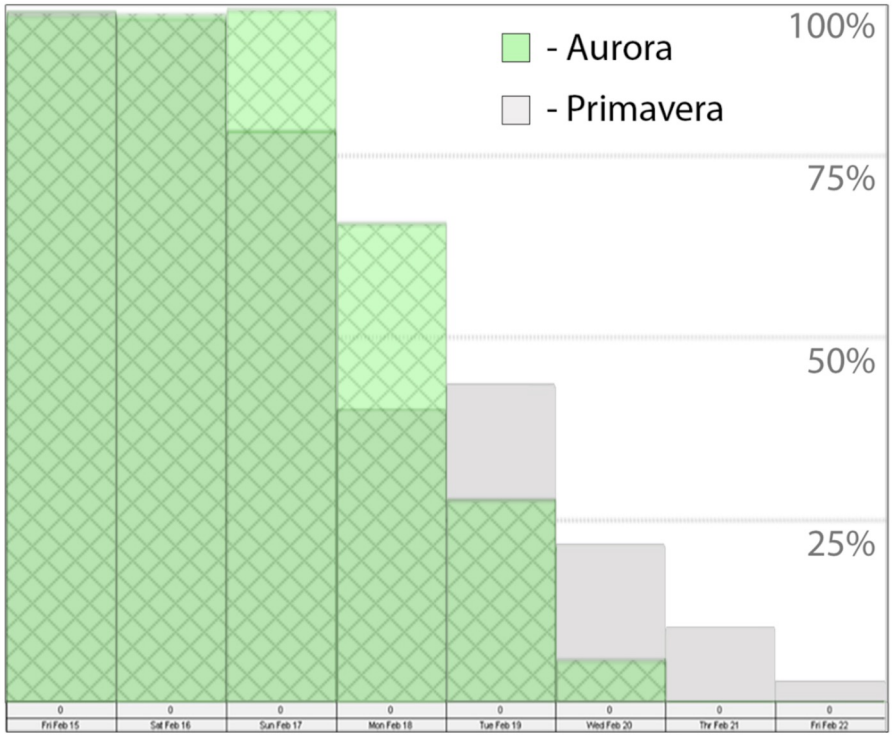
Example: P6 vs Aurora (last set of tasks)





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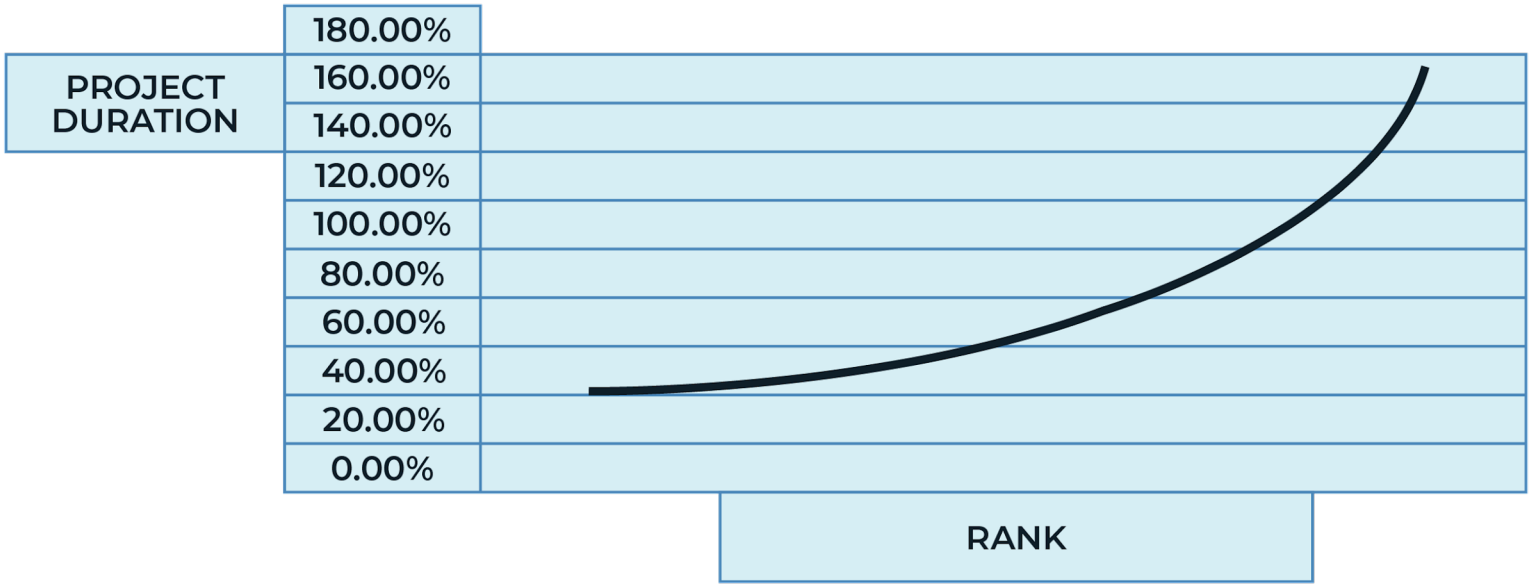
Different Resource-Leveling Techniques

- Deviation from Critical Path Duration



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Benefits of Automatic Intelligent Scheduler

- Results in a better initial schedule
- Execution: Schedule is more flexible and better able to accommodate change.
  - Schedule is “self-aware” of what tasks can most easily be moved. I.e., tasks store information about why it was placed (where it is placed).

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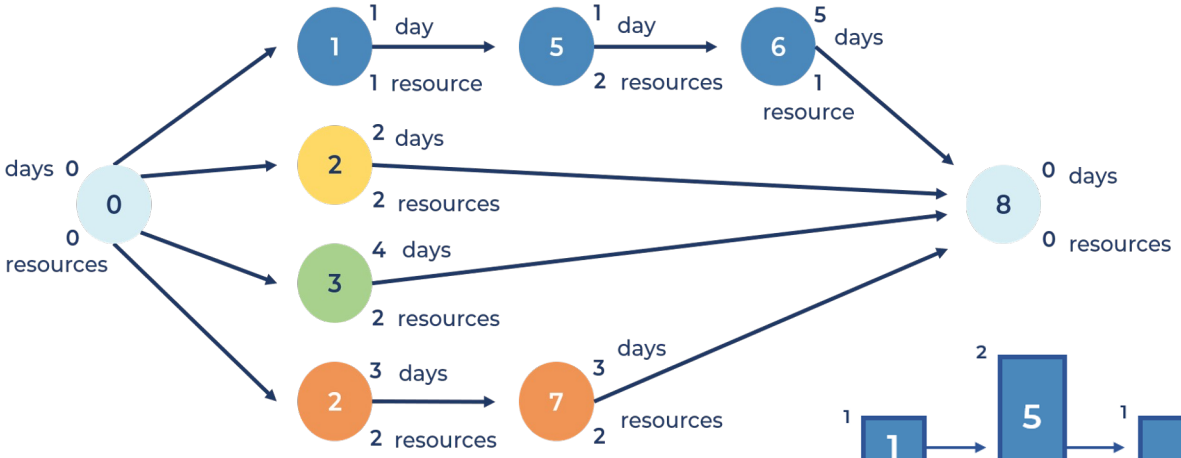
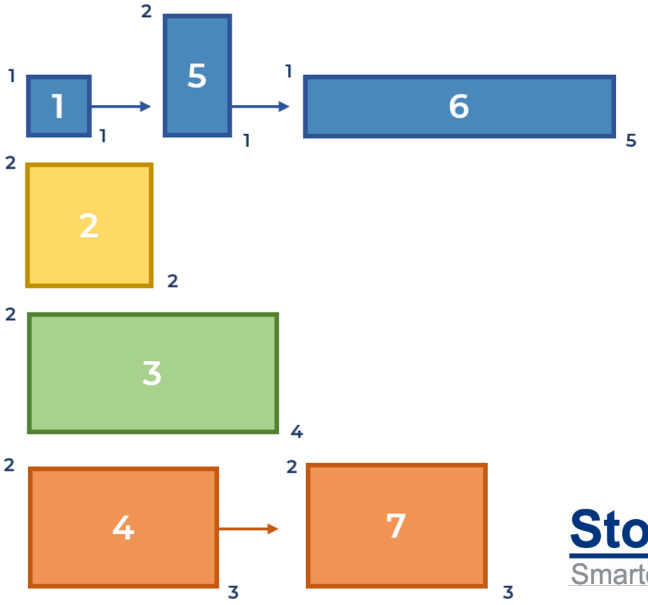
Maybe Only for ‘Big’ Problems?

Let’s look at a toy problem …

‘Simple’ problem with only 7 real tasks and 2 milestones.





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Set Resource Pool to 5

Only one type of resource to make the problem ‘simple’

Try to optimize at:

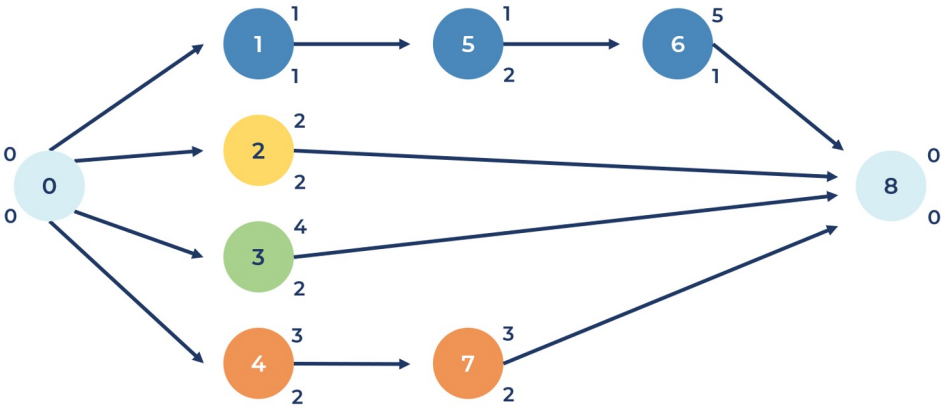
https://stottlerhenke.com/limited-resource-game

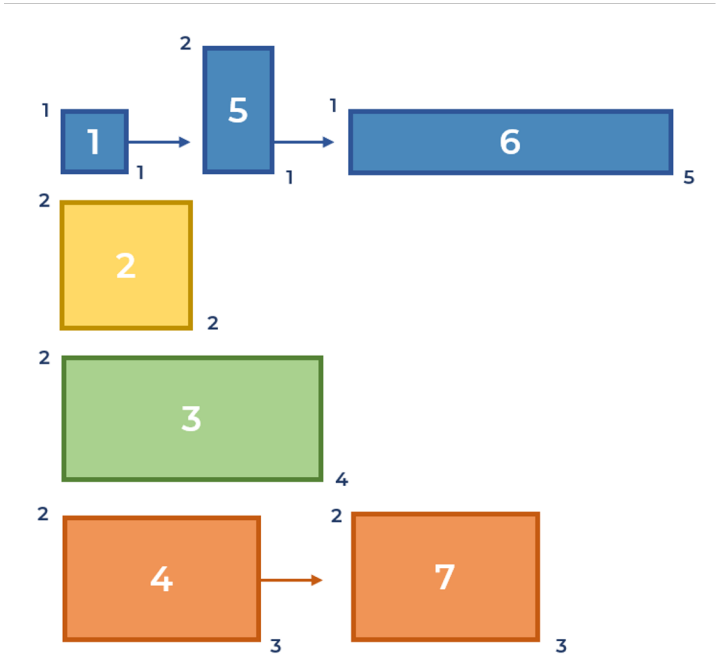
‘Simple’ Network details

Number superscript of circle is duration in days

Number subscript of circle is resources needed

There is only 1 type of resource





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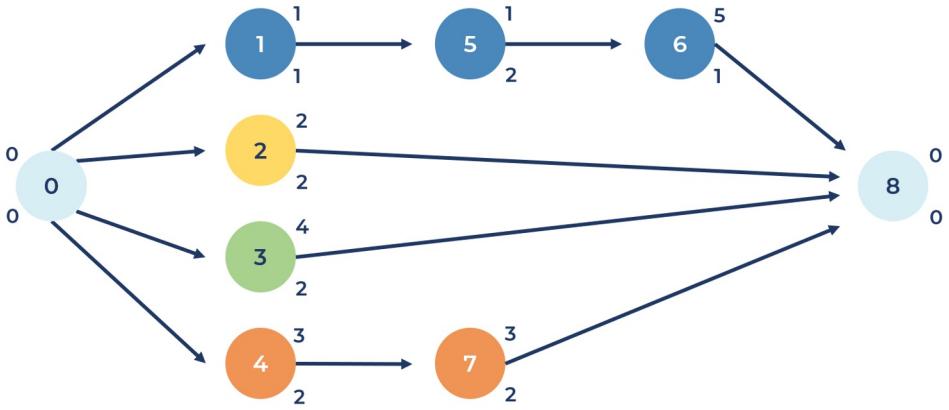
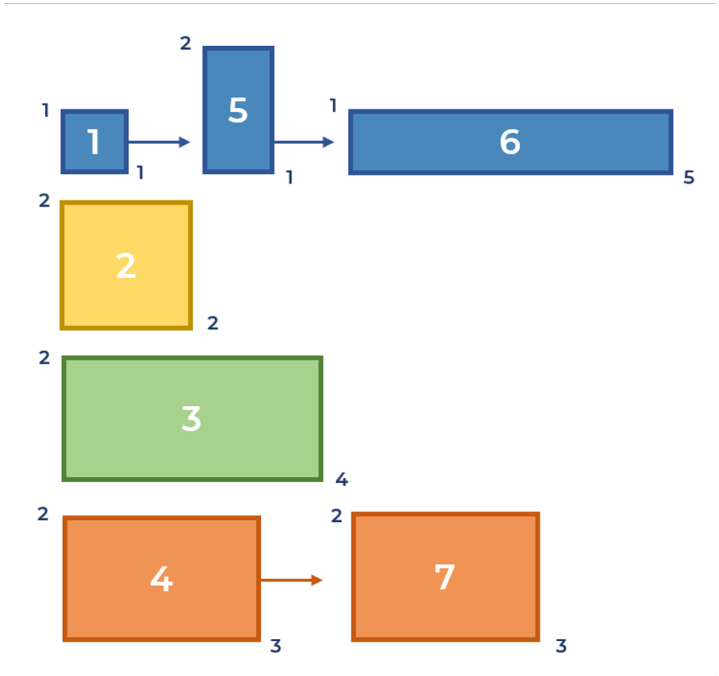
Critical Path of Network

Solution when infinite resources available

- Find longest path = 1 + 1 + 5 = 7

So Critical Path is 7 days





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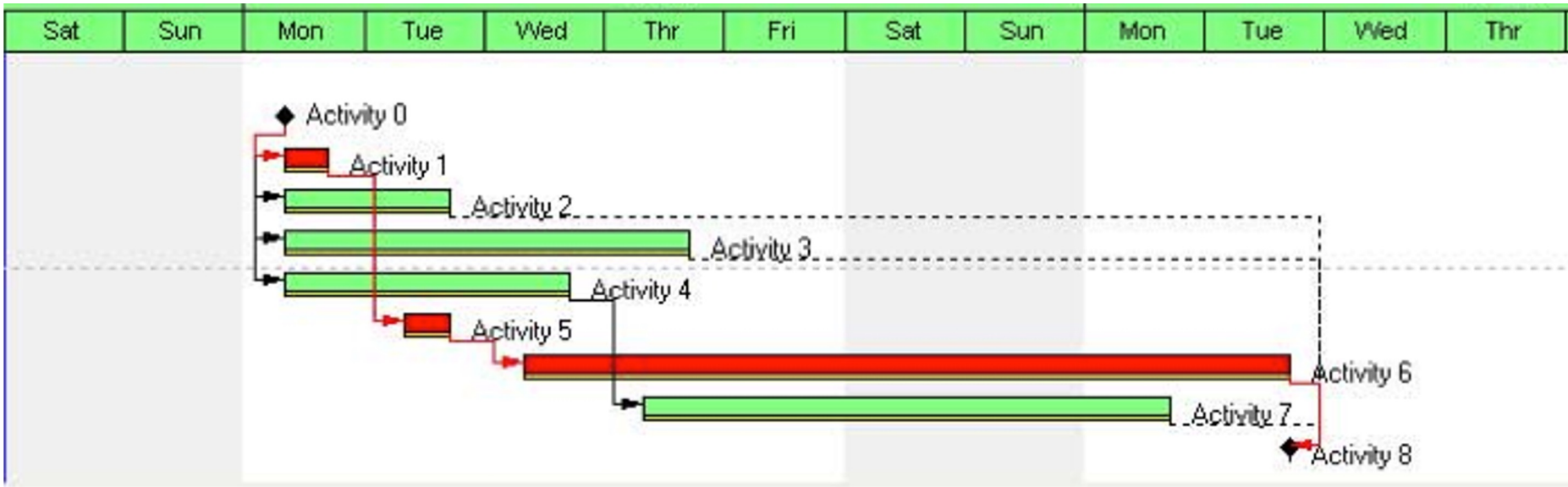
Gantt Chart of Critical Path

Note: Sat/Sun are not workdays



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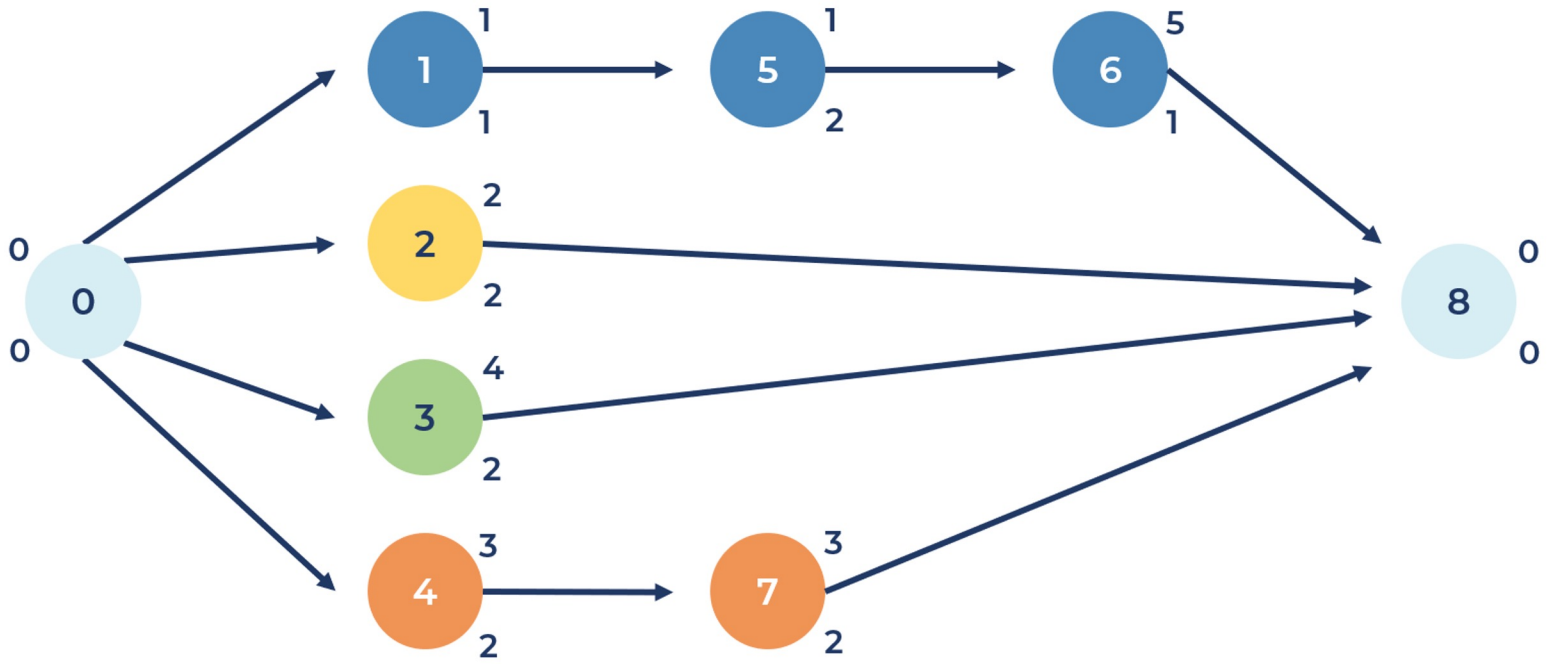
Set Resource Pool to 5

Only one type of resource to make the problem ‘simple’



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Gantt Chart Showing the Critical Path & Histogram

- Note: now some resources are overloaded
- Resource level to solve over allocation

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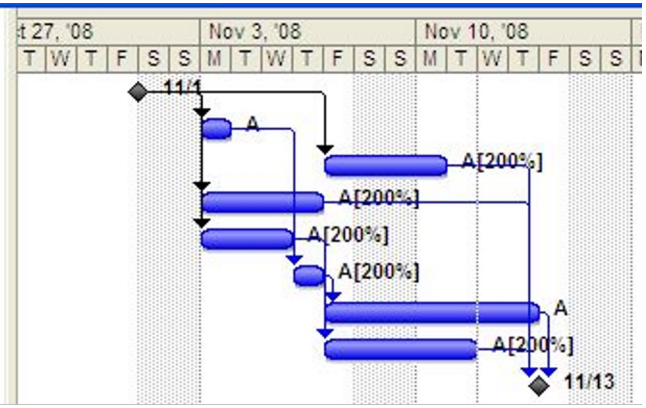
Resource-Leveled in MS Project = 9 days

	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	T0	0 hrs	Sat 11/1/08 12:00 AM	Sat 11/1/08 12:00 AM		
2	T1	8 hrs	Mon 11/3/08 8:00 AM	Mon 11/3/08 5:00 PM	1	A
3	T2	16 hrs	Fri 11/7/08 8:00 AM	Mon 11/10/08 5:00 PM	1	A[200%]
4	T3	32 hrs	Mon 11/3/08 8:00 AM	Thu 11/6/08 5:00 PM	1	A[200%]
5	T4	24 hrs	Mon 11/3/08 8:00 AM	Wed 11/5/08 5:00 PM	1	A[200%]
6	T5	8 hrs	Thu 11/6/08 8:00 AM	Thu 11/6/08 5:00 PM	2	A[200%]
7	T6	40 hrs	Fri 11/7/08 8:00 AM	Thu 11/13/08 5:00 PM	6	A
8	T7	24 hrs	Fri 11/7/08 8:00 AM	Tue 11/11/08 5:00 PM	5	A[200%]
9	T8	0 hrs	Thu 11/13/08 5:00 PM	Thu 11/13/08 5:00 PM	7,8,3,4	



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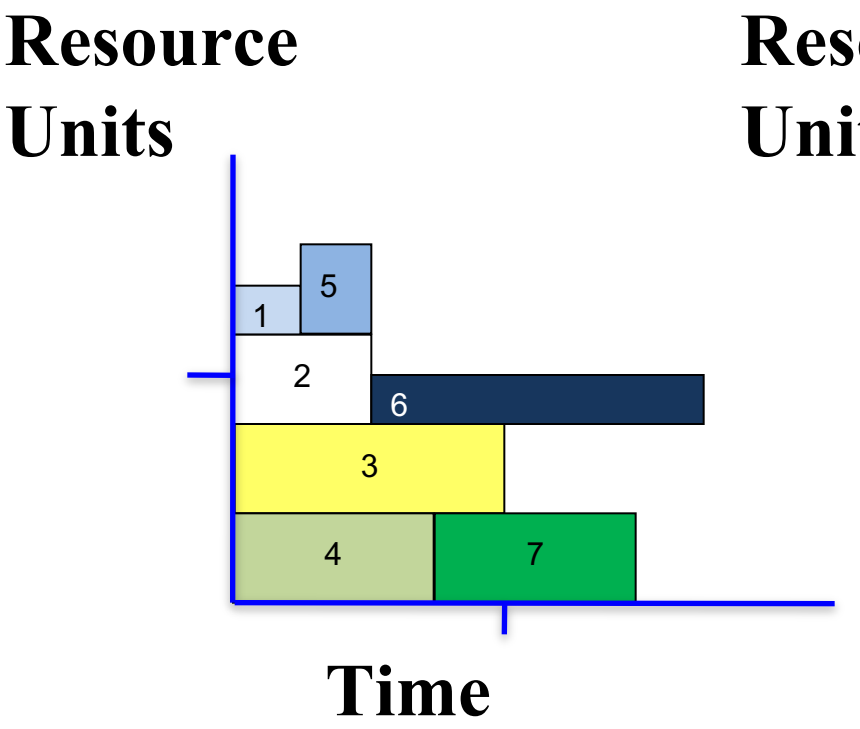
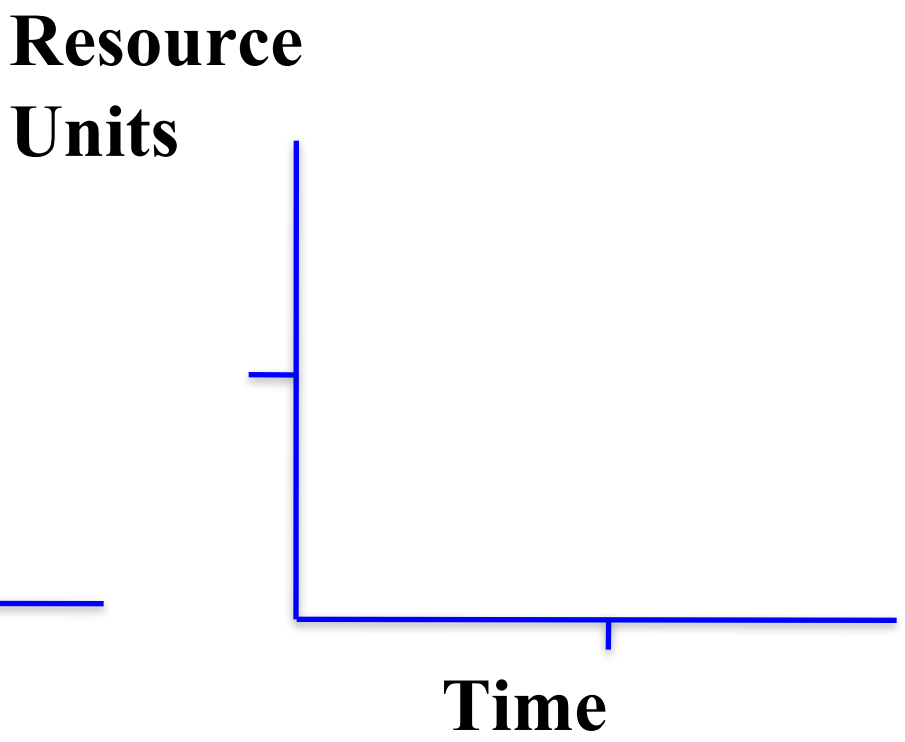
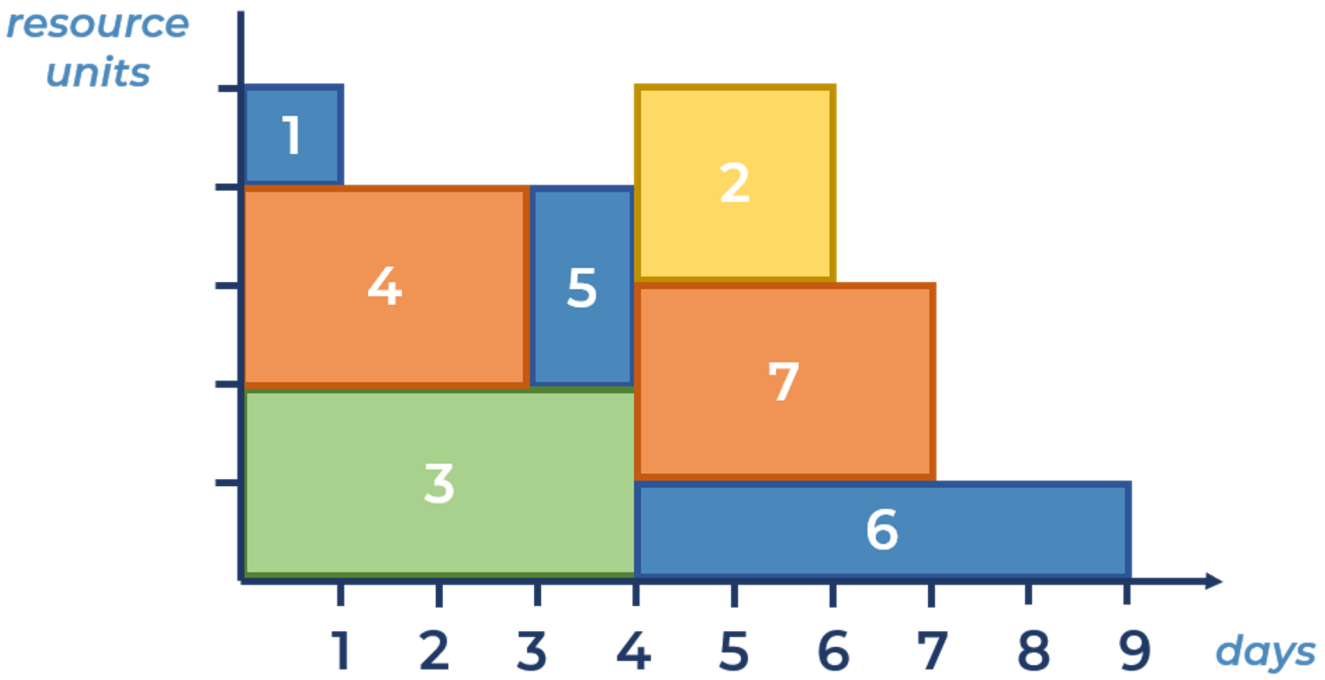
Taking a Closer Look





Simple Enough, Right?

Another view of the solution



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But there is a better solution …
P6 Model: Resource Leveled = 8 days

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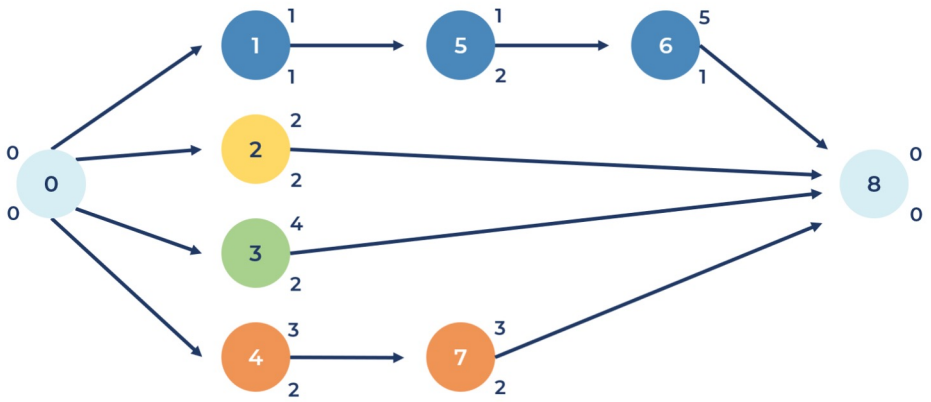
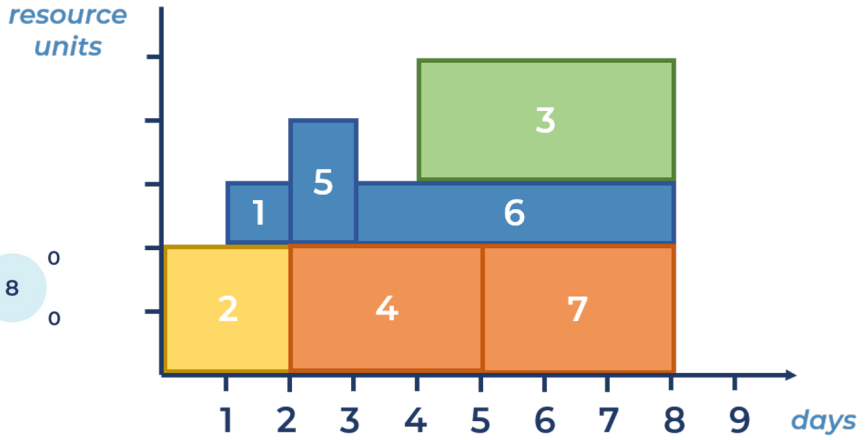
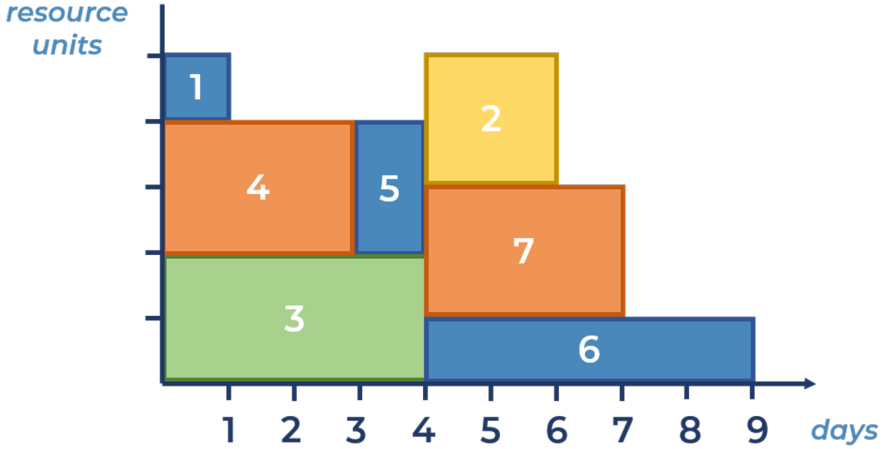
Simple?







- Critical Path = 1 + 1 + 5 =7
- 1 resource
- 5 total units

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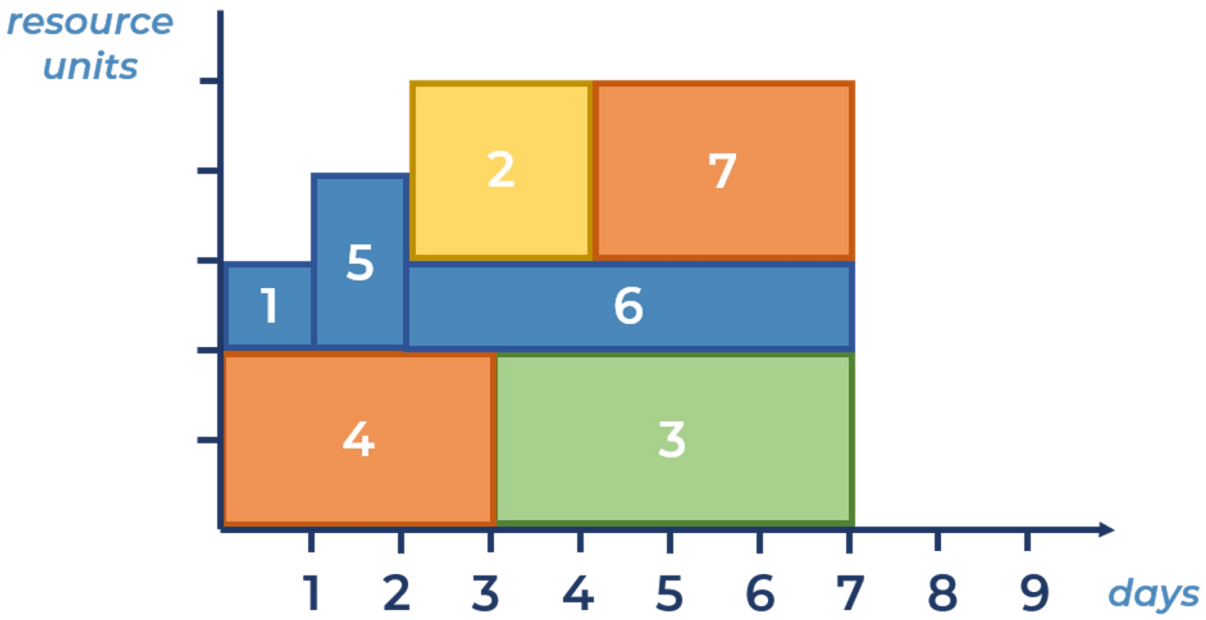
End of Story… Not quite

- There is an even better solution
  - **7 days**
- So, this ‘simple’ problem could not even be solved well by the world’s ‘premier’ project management tools.
- Can you solve this ‘simple’ problem in 7 days?



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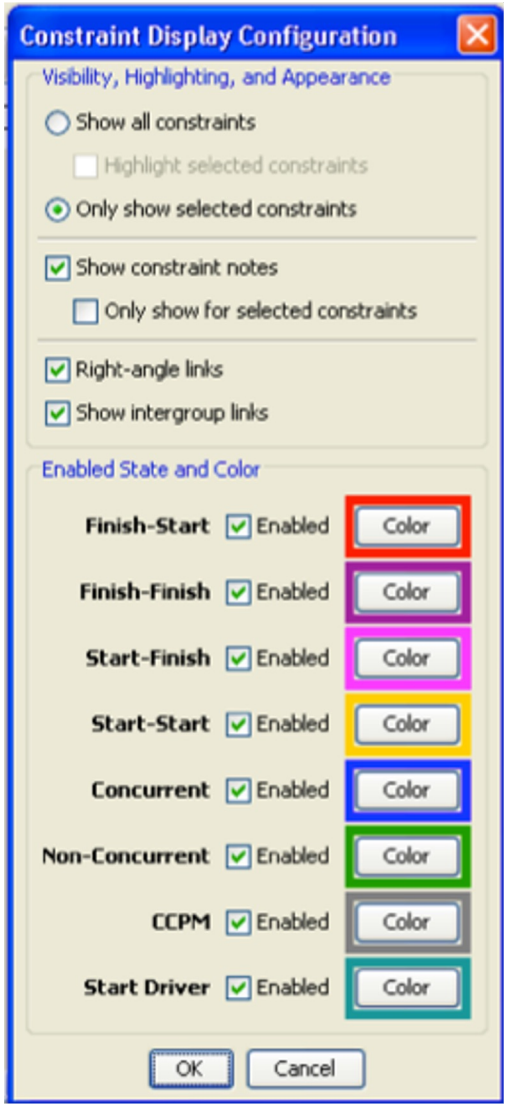
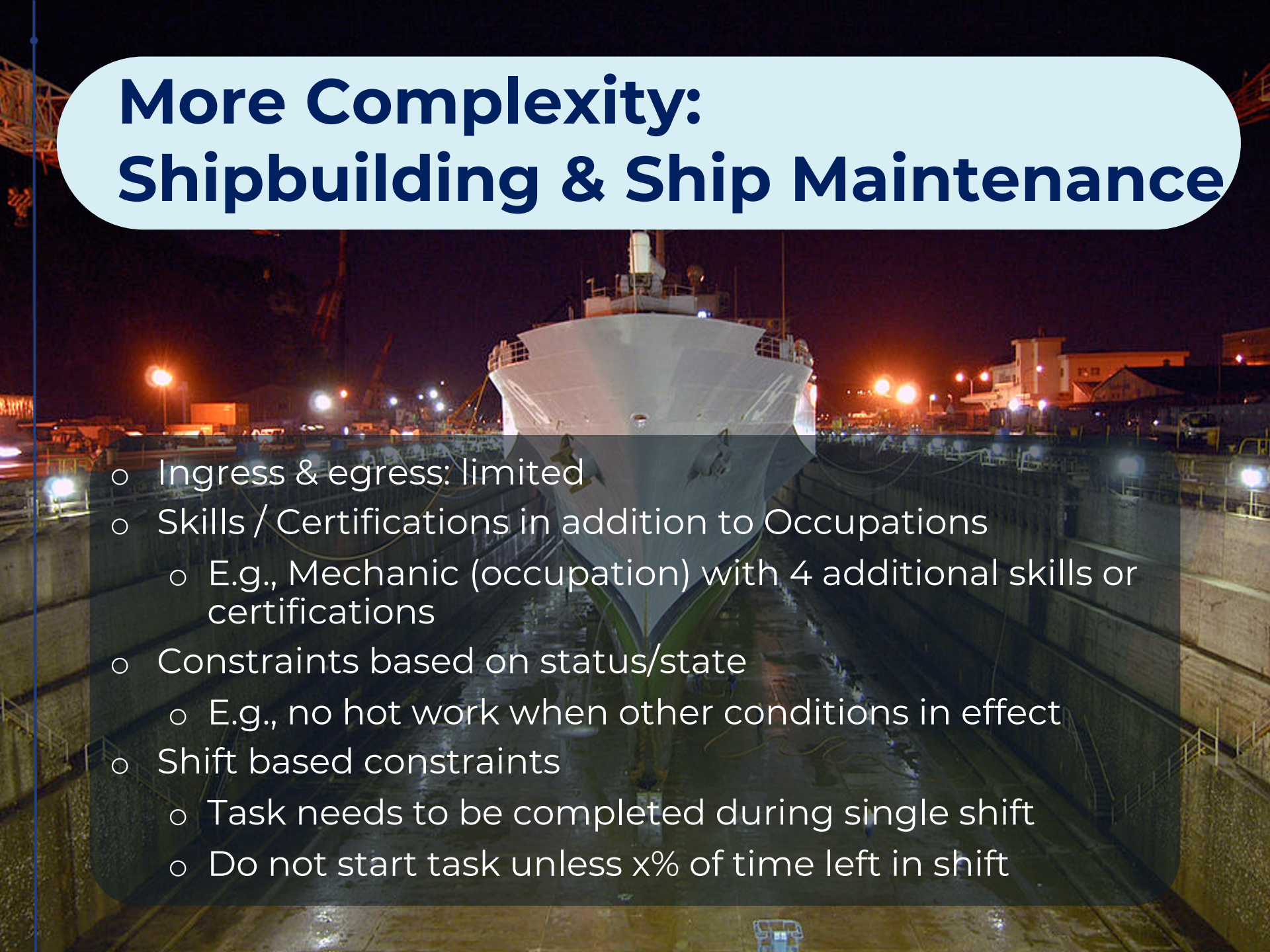
Constraints Add Complexity

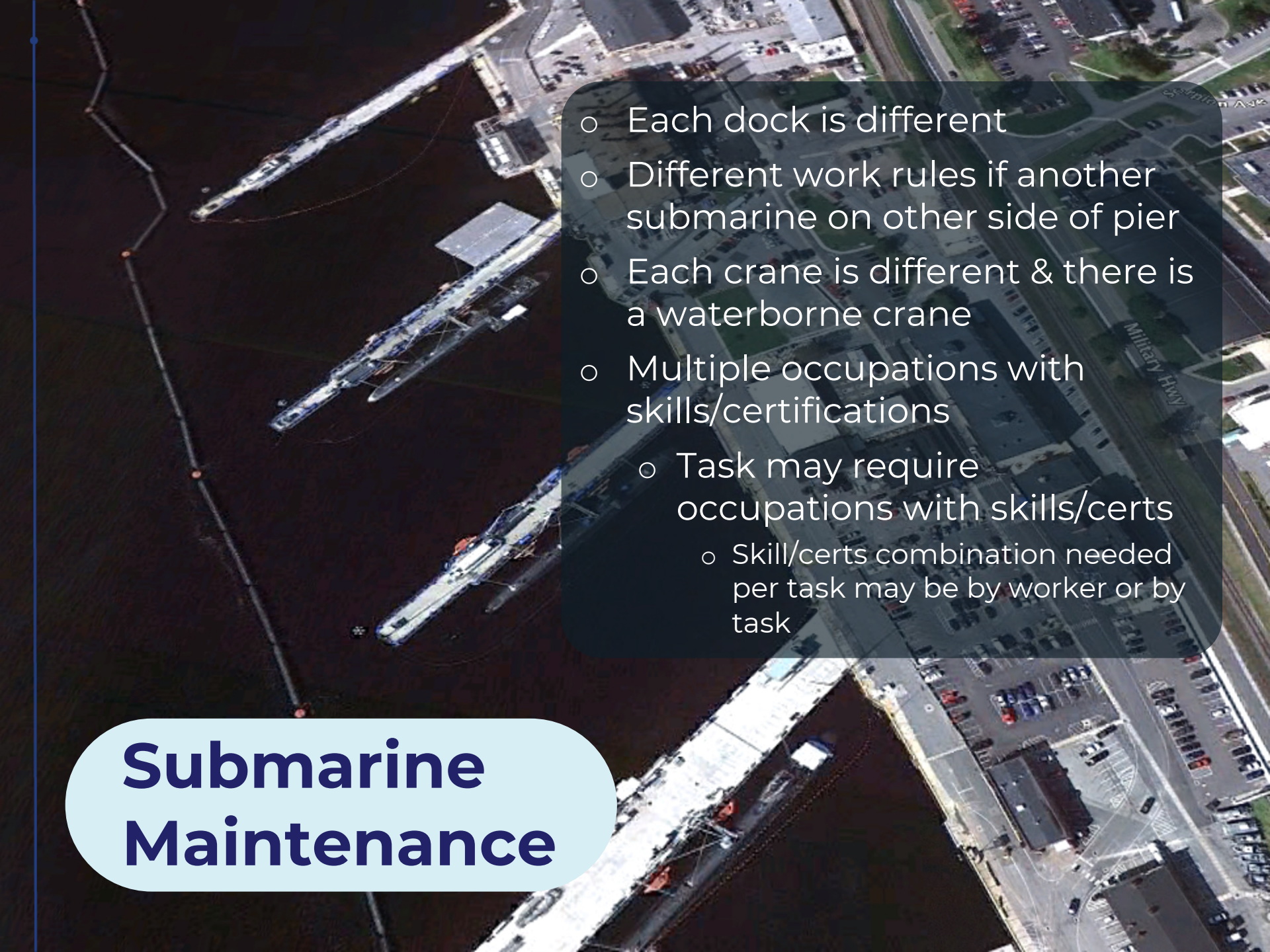
- Technical constraints (E.g., F-S, F-F, S-F, lags)
- Resource constraints
  - Labor constraints
  - Equipment, Tools (e.g., cranes)
- Usage constraints – e.g., tool can only be used for so many hours continuously &/or during a day.
- Spatial / physical space constraints – e.g.,
  - job requires a certain location or type of space;
  - two elements should (or should not) be next to each other
- Ergonomic constraints – individual limitations on work conditions



More Complexity: Shipbuilding & Ship Maintenance

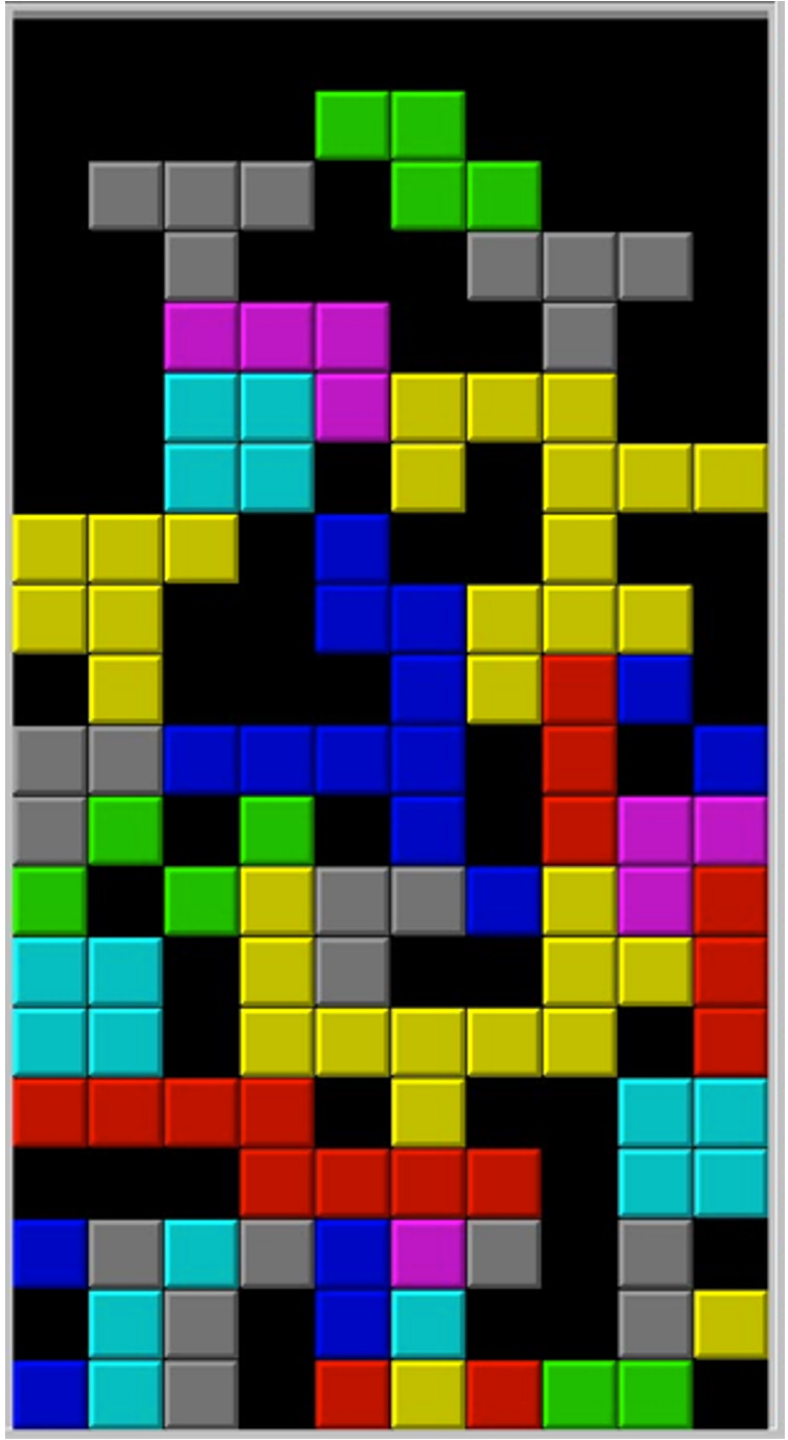


- Ingress & egress: limited
- Skills / Certifications in addition to Occupations
  - E.g., Mechanic (occupation) with 4 additional skills or certifications
- Constraints based on status/state
  - E.g., no hot work when other conditions in effect
- Shift based constraints
  - Task needs to be completed during single shift
  - Do not start task unless x% of time left in shift



Submarine Maintenance

- Each dock is different
- Different work rules if another submarine on other side of pier
- Each crane is different & there is a waterborne crane
- Multiple occupations with skills/certifications
    - Task may require occupations with skills/certs
        - Skill/certs combination needed per task may be by worker or by task



Tetris

- Shapes similar to resource profile of individual tasks
- Holes when playing Tetris represent resource allocation inefficiencies.
  - E.g., black regions in figure to the right
- Try https://www.freetetris.org/ for yourself.

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Tetris Cube

- More realistic to scheduling multiple types of resources per task is the Tetris Cube
- If not pieced together properly then will not fit in box.
- Video:

http://www.youtube.com/watch?v=Eq45310ZncQ

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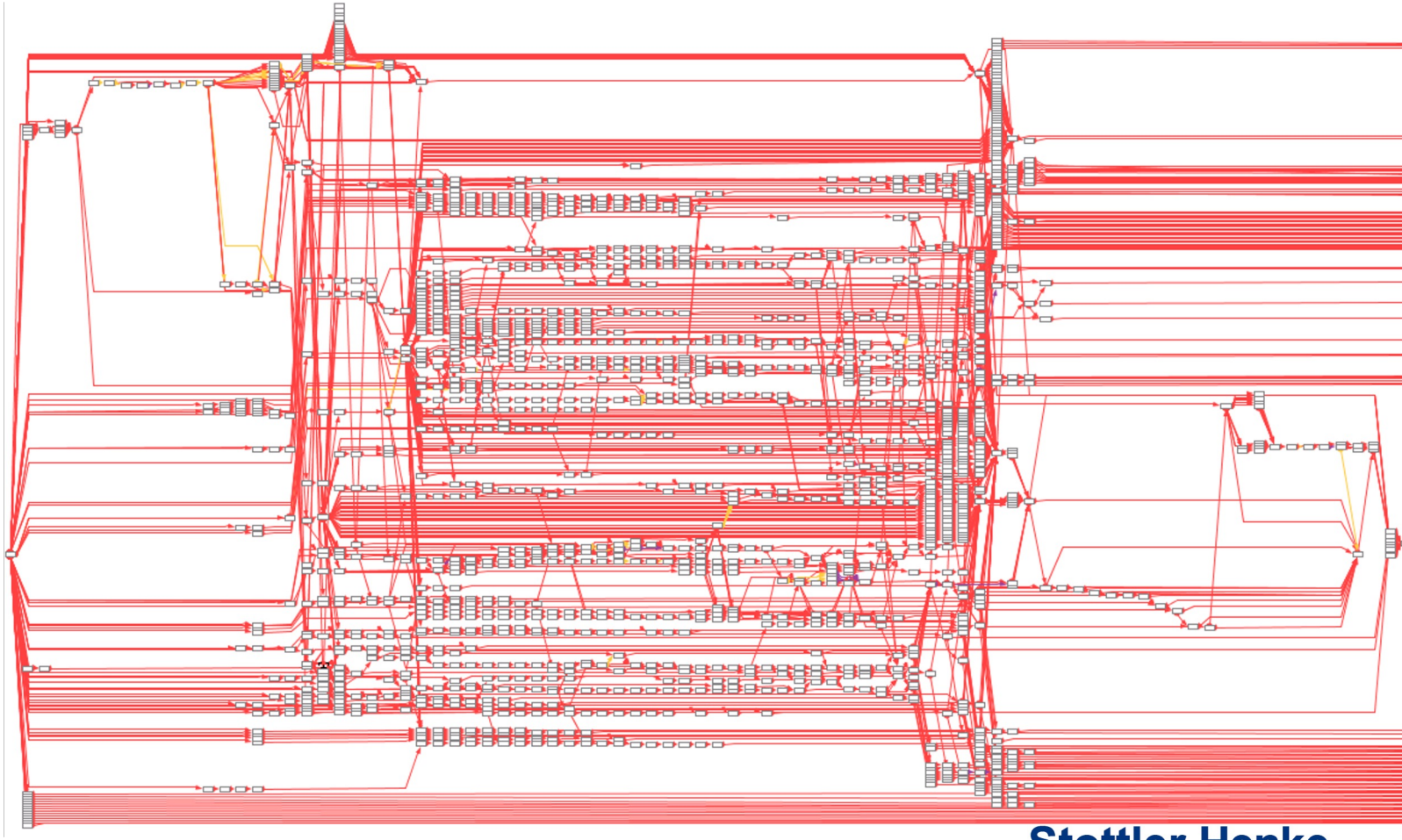
Refinery Turnaround Leveraging Intelligent Scheduling Technology

Turnaround Project Network
2,500+ Tasks



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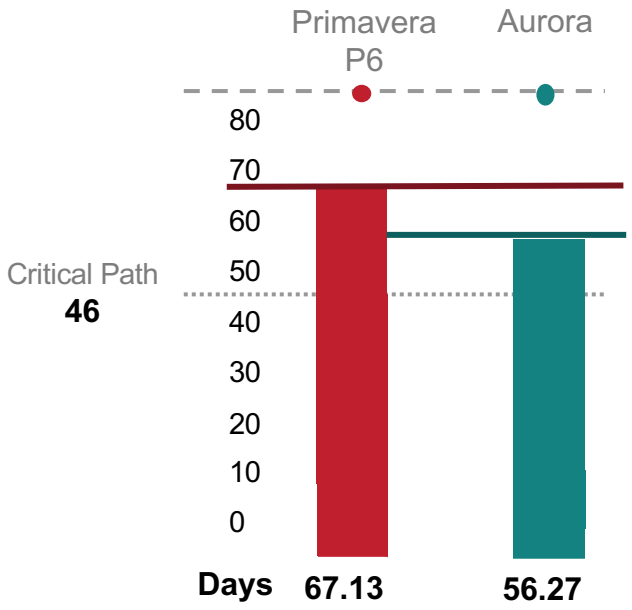
Results: 2,500+ Turnaround

- Primavera P6 **67.125** days
  - Performed by 3rd party
- Aurora **56.27** days
- Primavera P6 **19.3% longer** than Aurora
- Critical Path is 46 days
  - P6 is 21.125 days longer than CP
  - Aurora is 10.27 days longer than CP
  - So **% diff over CP is > 100%**

REFINERY TURNAROUND
2,500+ TASKS

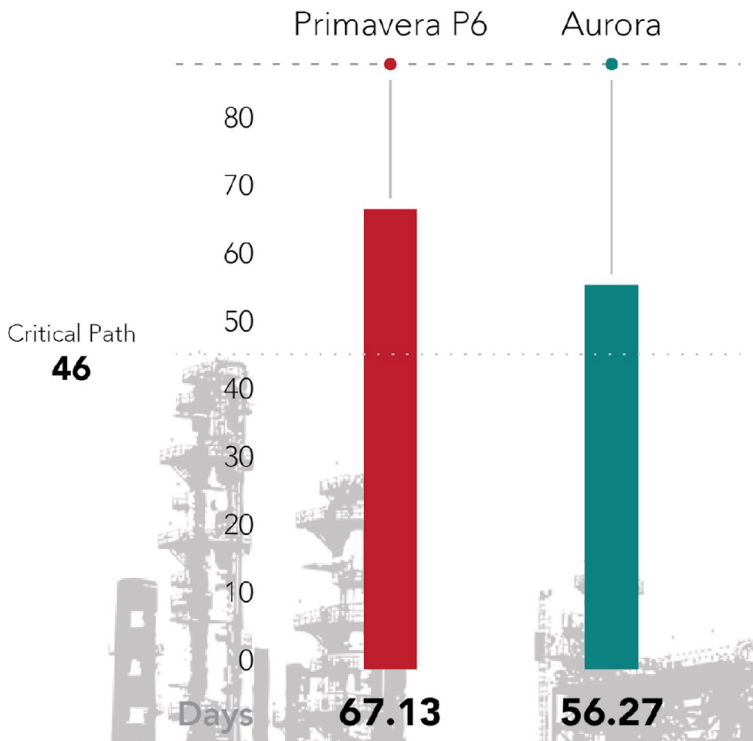


Aurora saves over

10 days

versus Primavera P6

REFINERY TURNAROUND
2,500+ TASKS



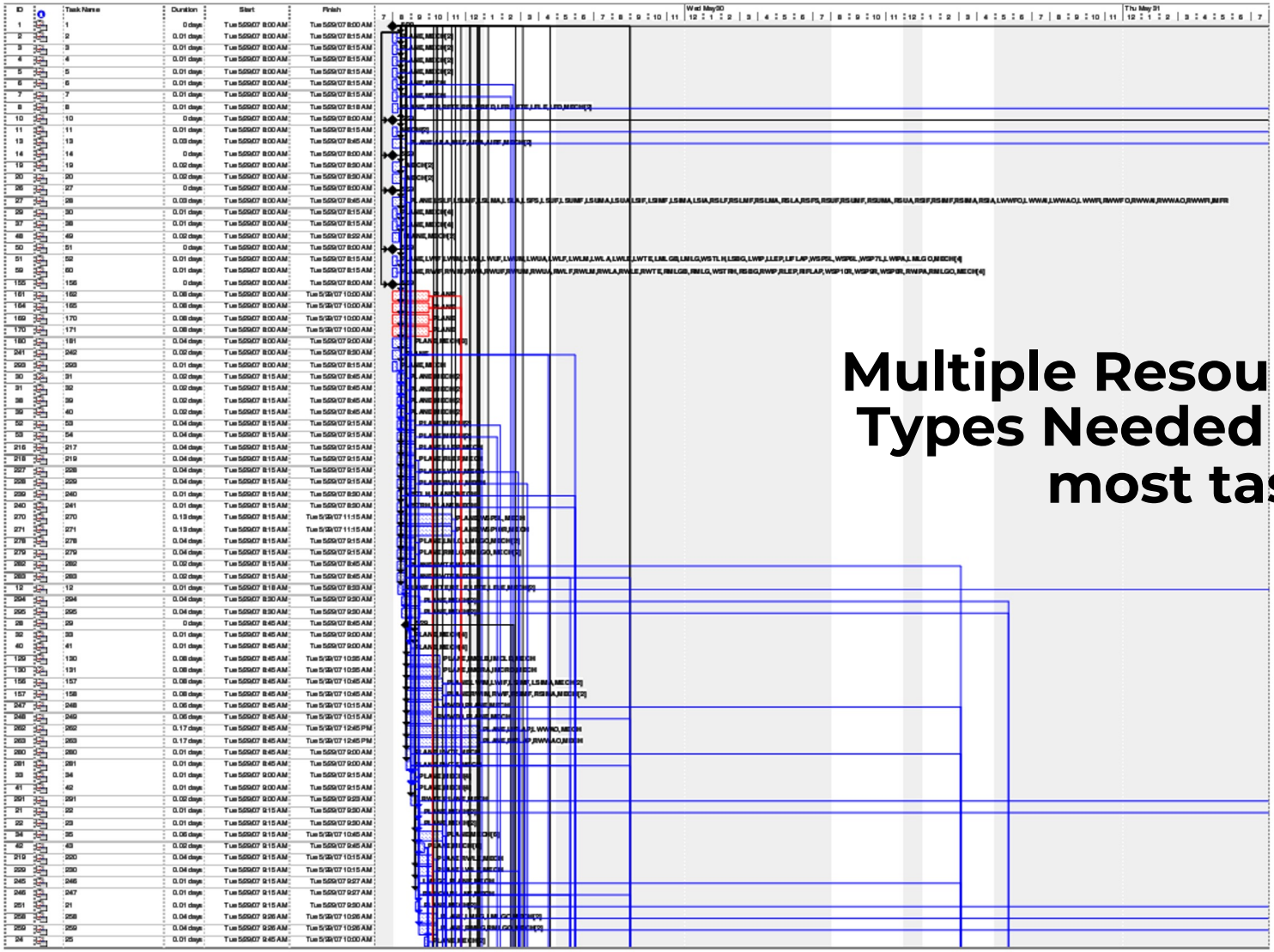
Aurora saves over

10

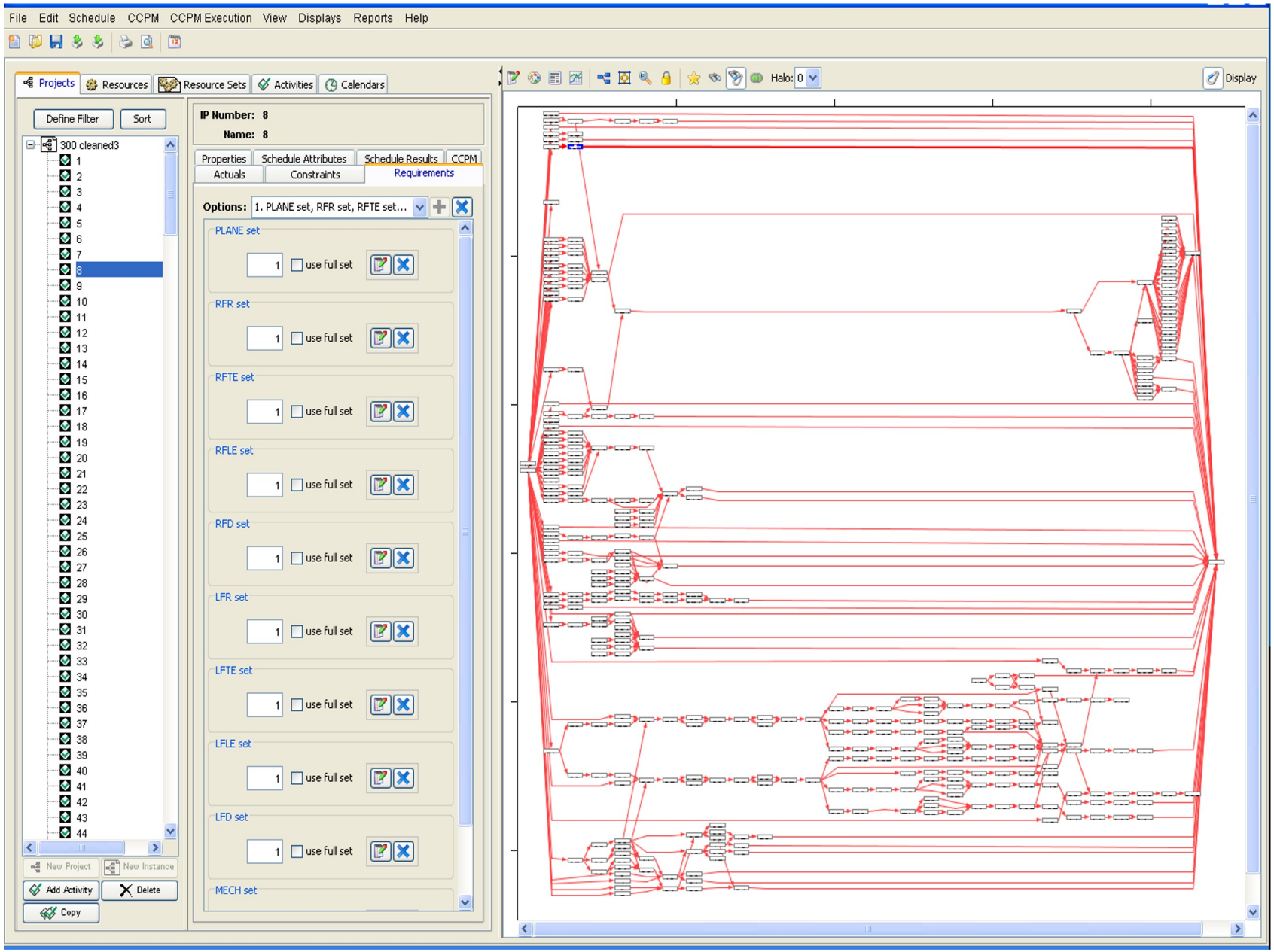
days versus Primavera P6

All tests done by third party

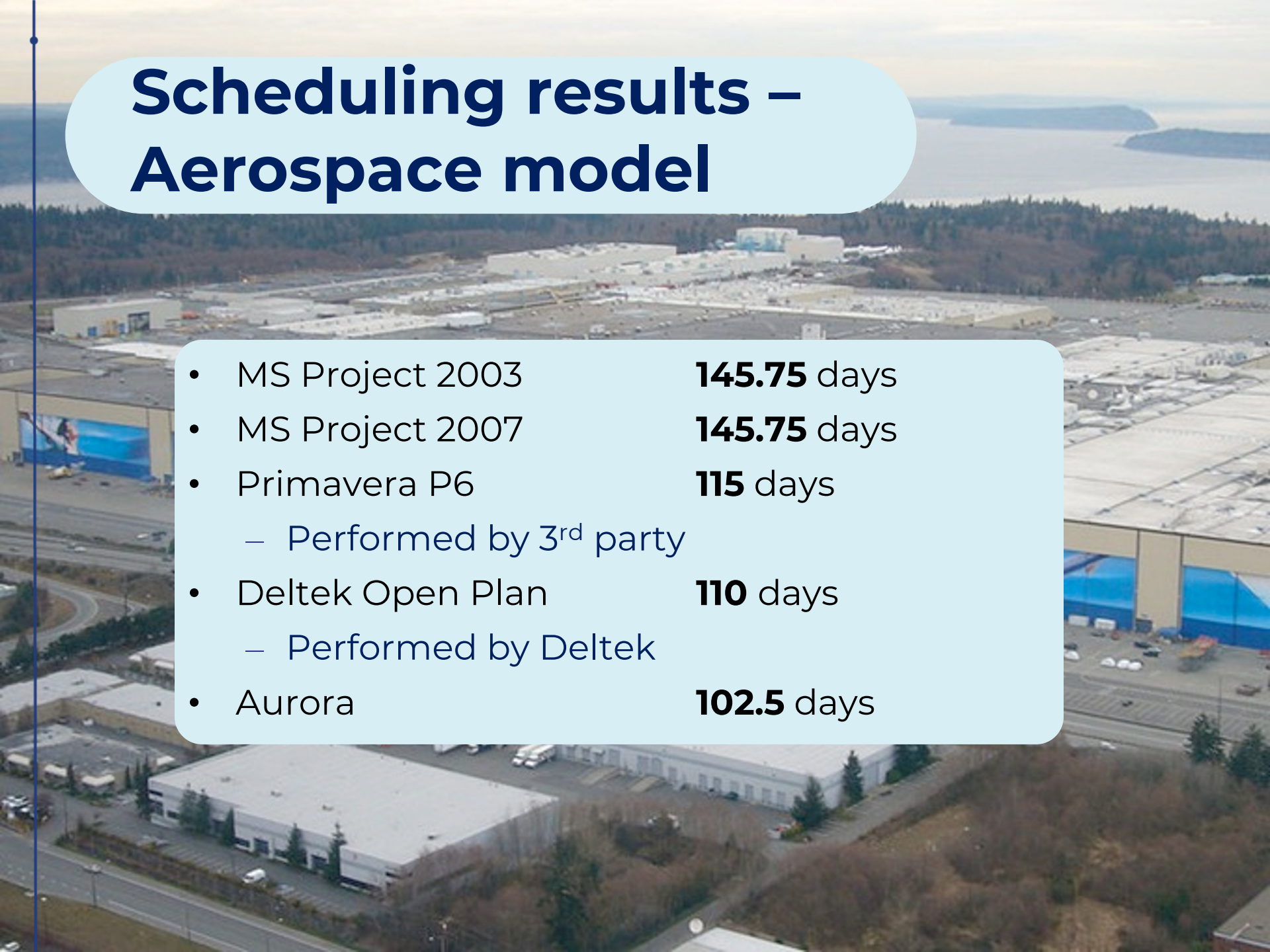
300 Task Example: Aerospace Application



300 Task Example: Network in Aurora



Scheduling results – Aerospace model

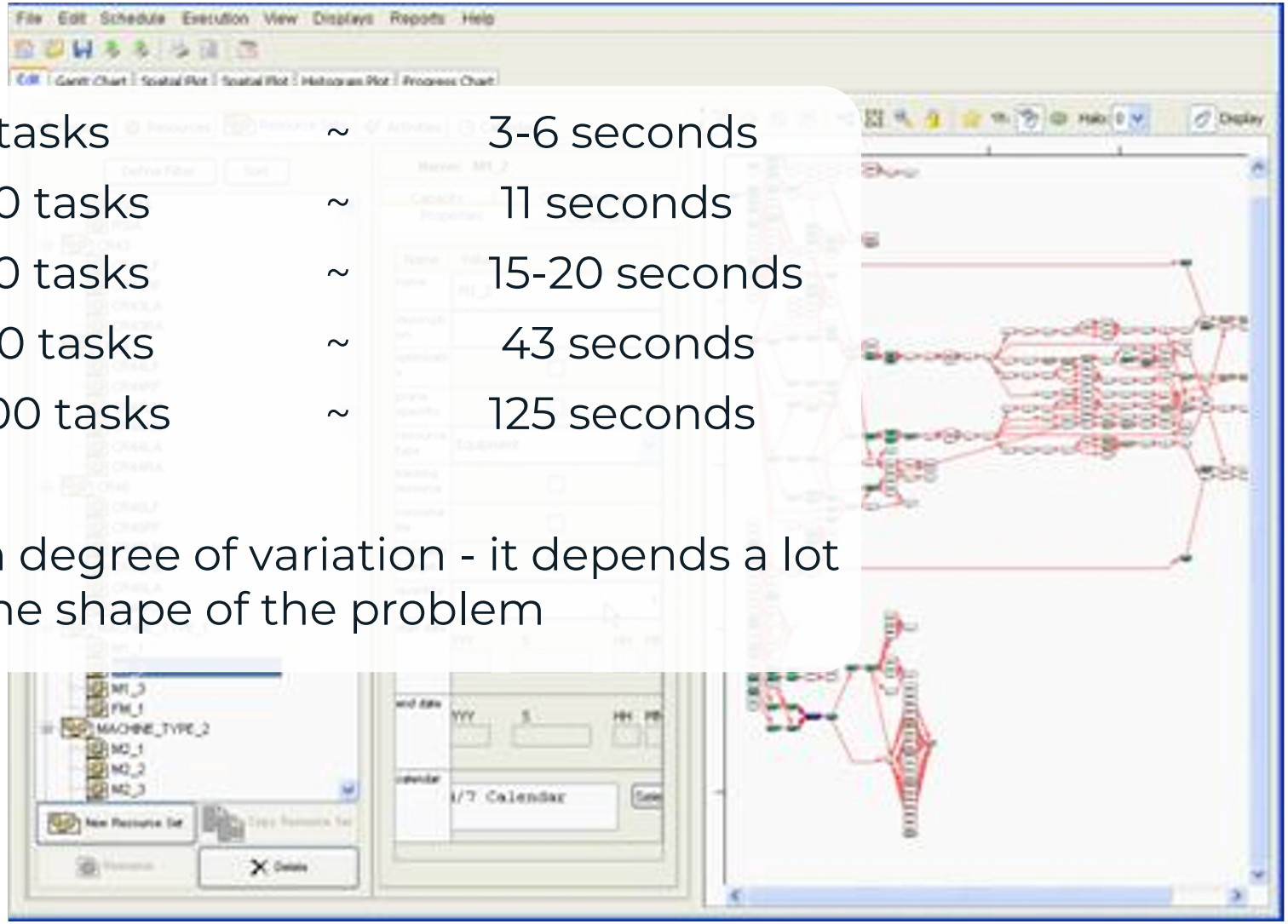


- MS Project 2003 **145.75** days
- MS Project 2007 **145.75** days
- Primavera P6 **115** days
  - Performed by 3rd party
- Deltek Open Plan **110** days
  - Performed by Deltek
- Aurora **102.5** days

Scheduling is Fast

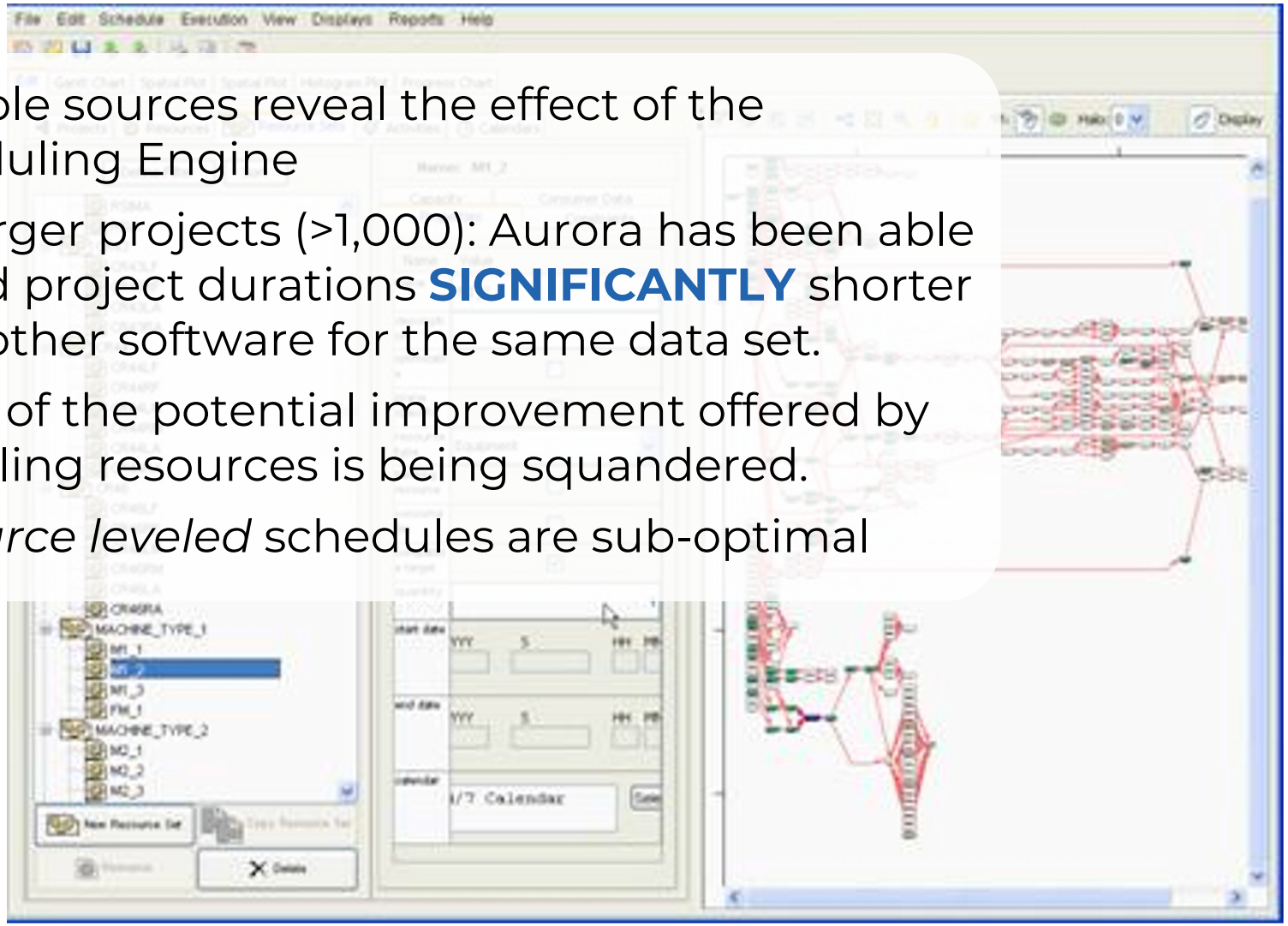
- 300 tasks ~ 3-6 seconds
- 2,000 tasks ~ 11 seconds
- 3,000 tasks ~ 15-20 seconds
- 4,000 tasks ~ 43 seconds
- 10,000 tasks ~ 125 seconds

- High degree of variation - it depends a lot on the shape of the problem



Results

- Multiple sources reveal the effect of the Scheduling Engine
- For larger projects (>1,000): Aurora has been able to find project durations **SIGNIFICANTLY** shorter than other software for the same data set.
- Much of the potential improvement offered by modeling resources is being squandered.
- *Resource leveled* schedules are sub-optimal



Benefits of Sophisticated Underlying Scheduler: Planning & Execution

- Results in a better **initial** schedule
- **Execution**: Schedule is more flexible and better able to accommodate change.
  - If scheduler is inefficient, every delay will be magnified because re-allocation of resources will be deficient
  - Schedule is “self-aware” of what tasks can most easily be moved. I.e., tasks store information about what placed it where it is placed.

Take Aways

- Scheduling engine is critical
- Paying up to 100% penalty due to the scheduling engine
- Changing to an improved scheduling engine is probably the greatest potential improvement available to your project
  - Just press a different button
- **Aurora provides an unfair competitive advantage**

QUESTIONS?

Rob Richards, PhD

Stottler Henke Associates, Inc.