Common Tool for Intelligent Scheduling / Critical Chain Project Management for US Navy & Contractor Shipyards

Rob Richards, Ph.D.

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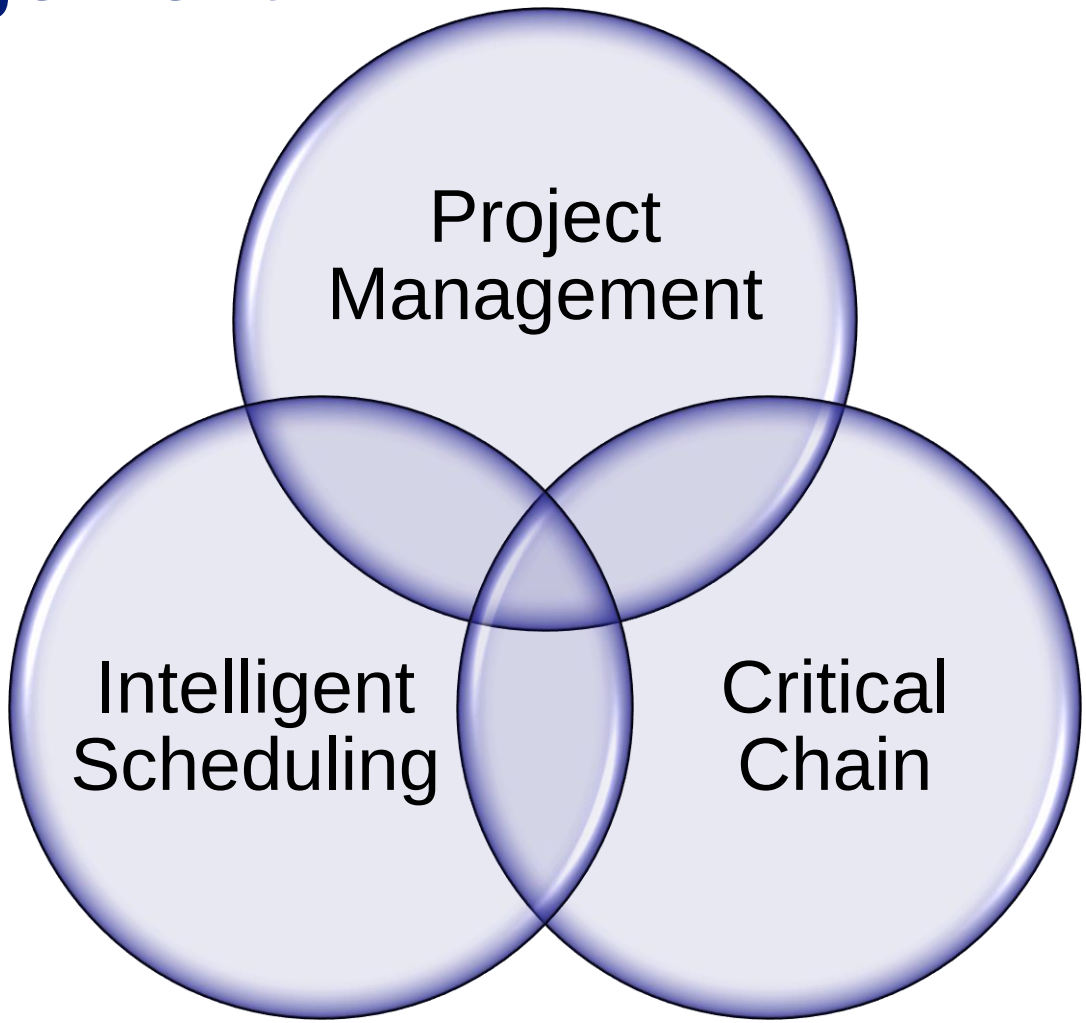
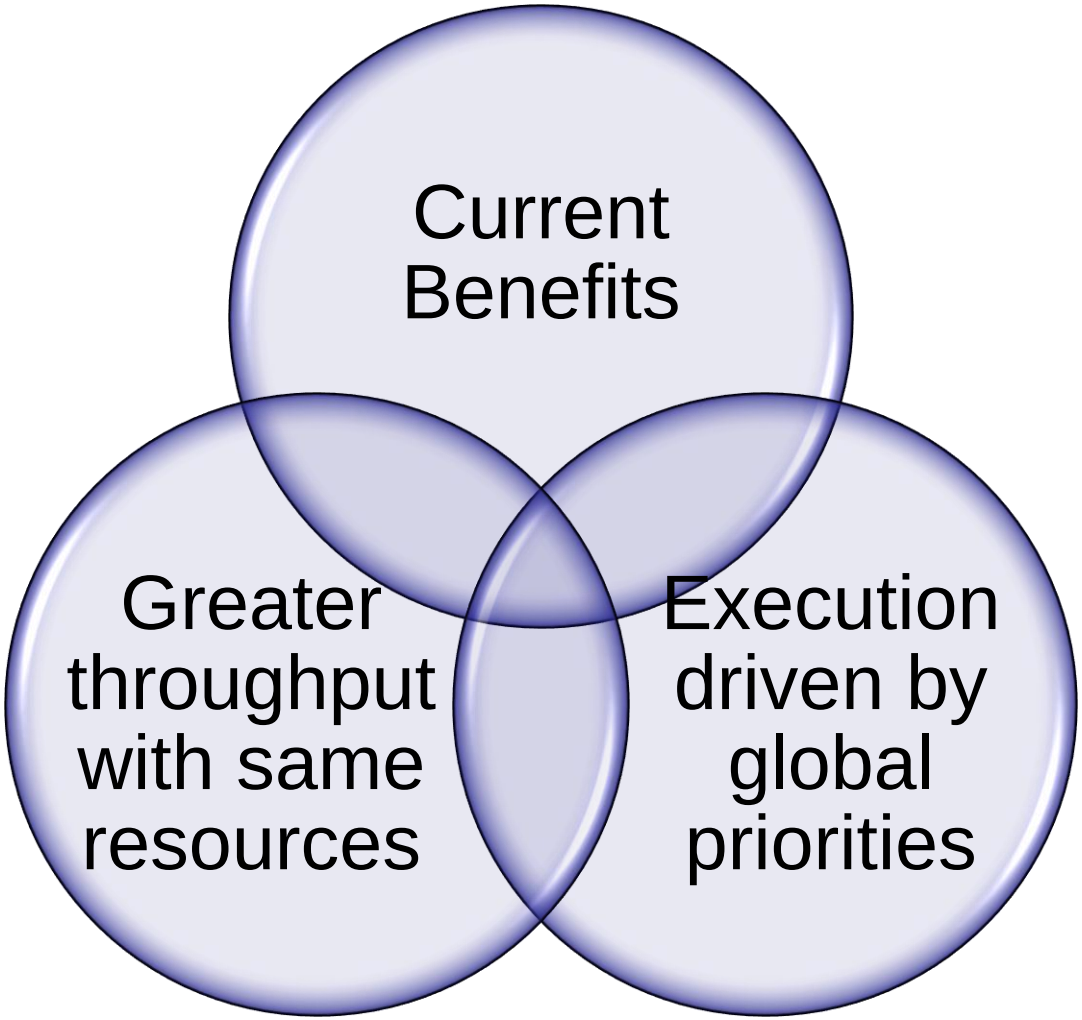
Planning, Production Processes & Facilities Panel (PPP&F) Meeting
19-20 April, 2016
Portland, Oregon

Enhancements to Traditional Project Management



Benefits



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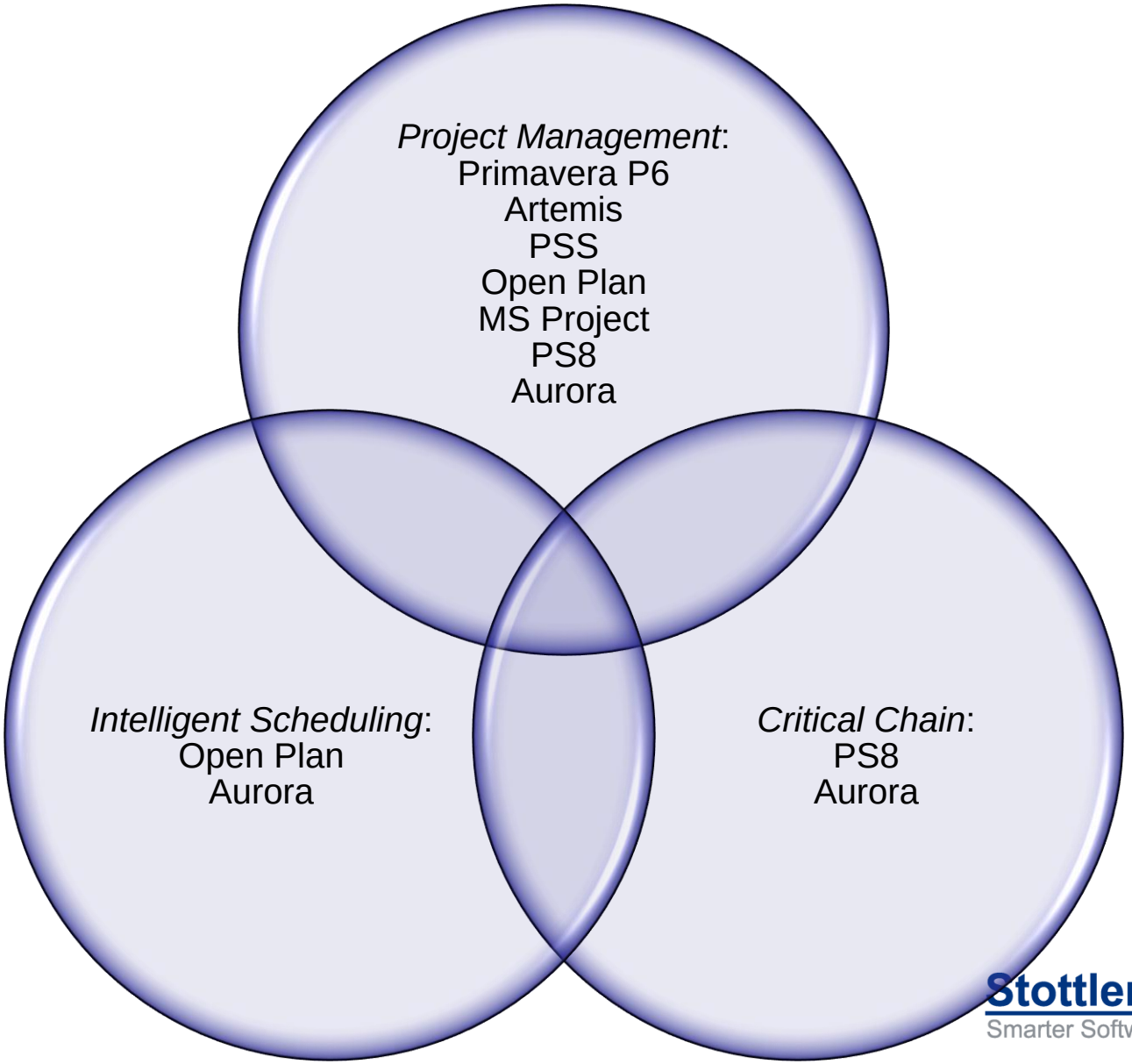
US Navy Shipyards & Contractors Utilize Many Scheduling / Project Management Tools

Primavera P6
Artemis
PS8 (by Sciforma)
Open Plan (by Deltek)
Microsoft Project
PSS
Databases / Non-traditional PM tools: e.g. SQL Server

Navy & Contractor Tools



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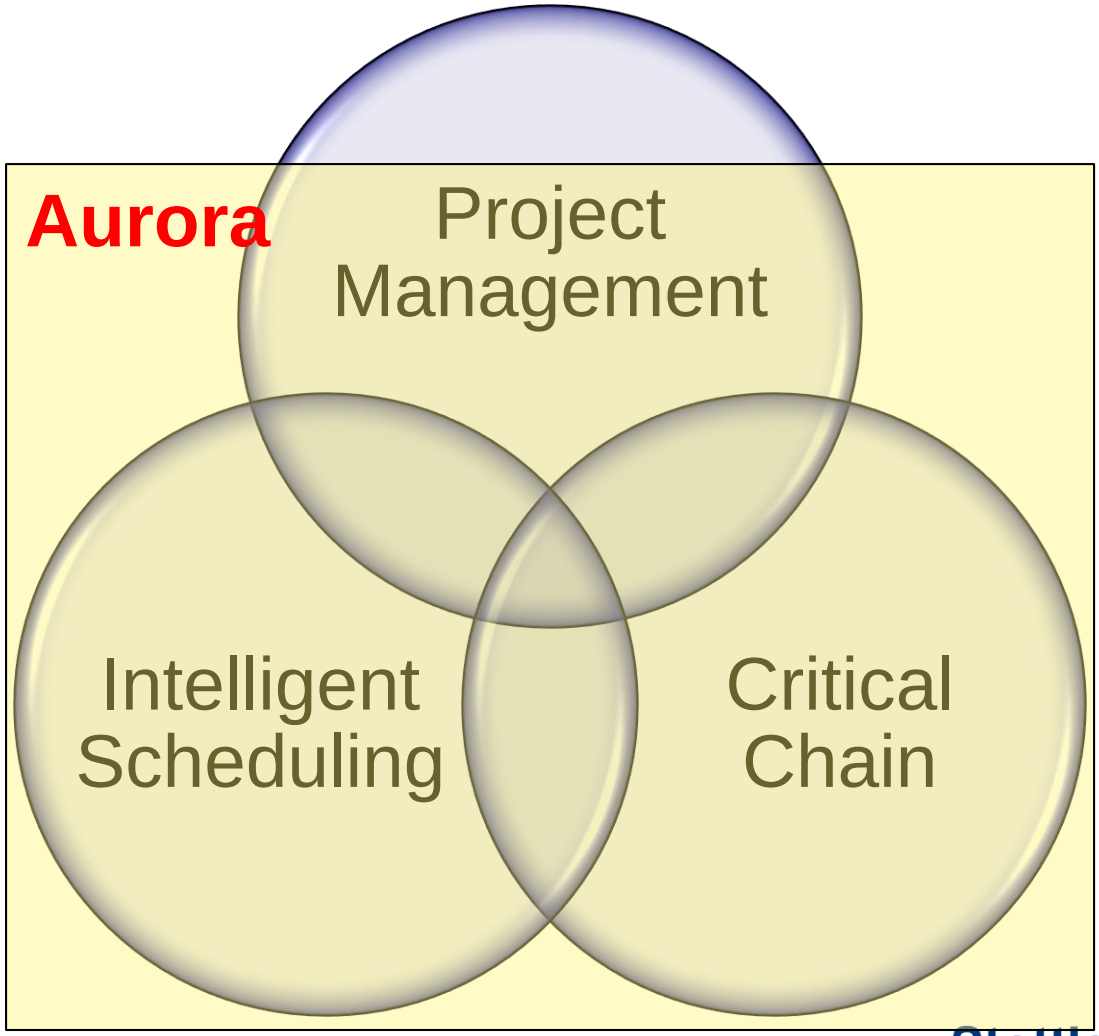
Aurora Functionality



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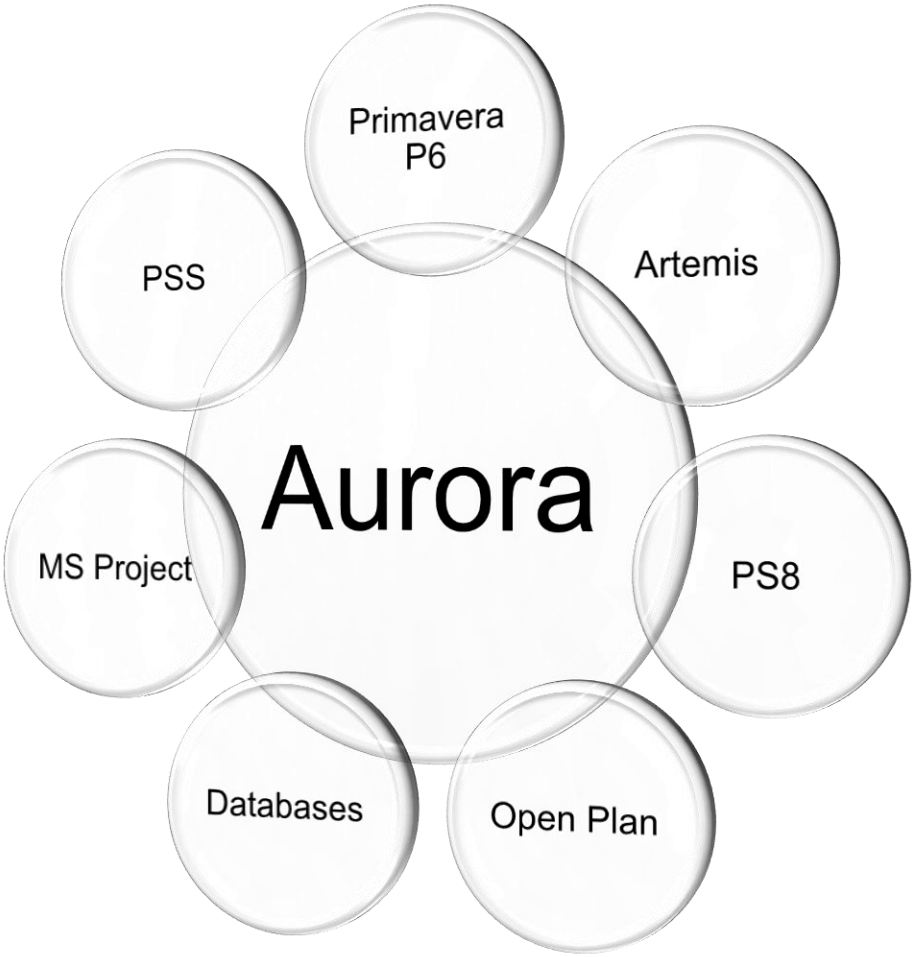
Interfaces: Aurora can interface will all others



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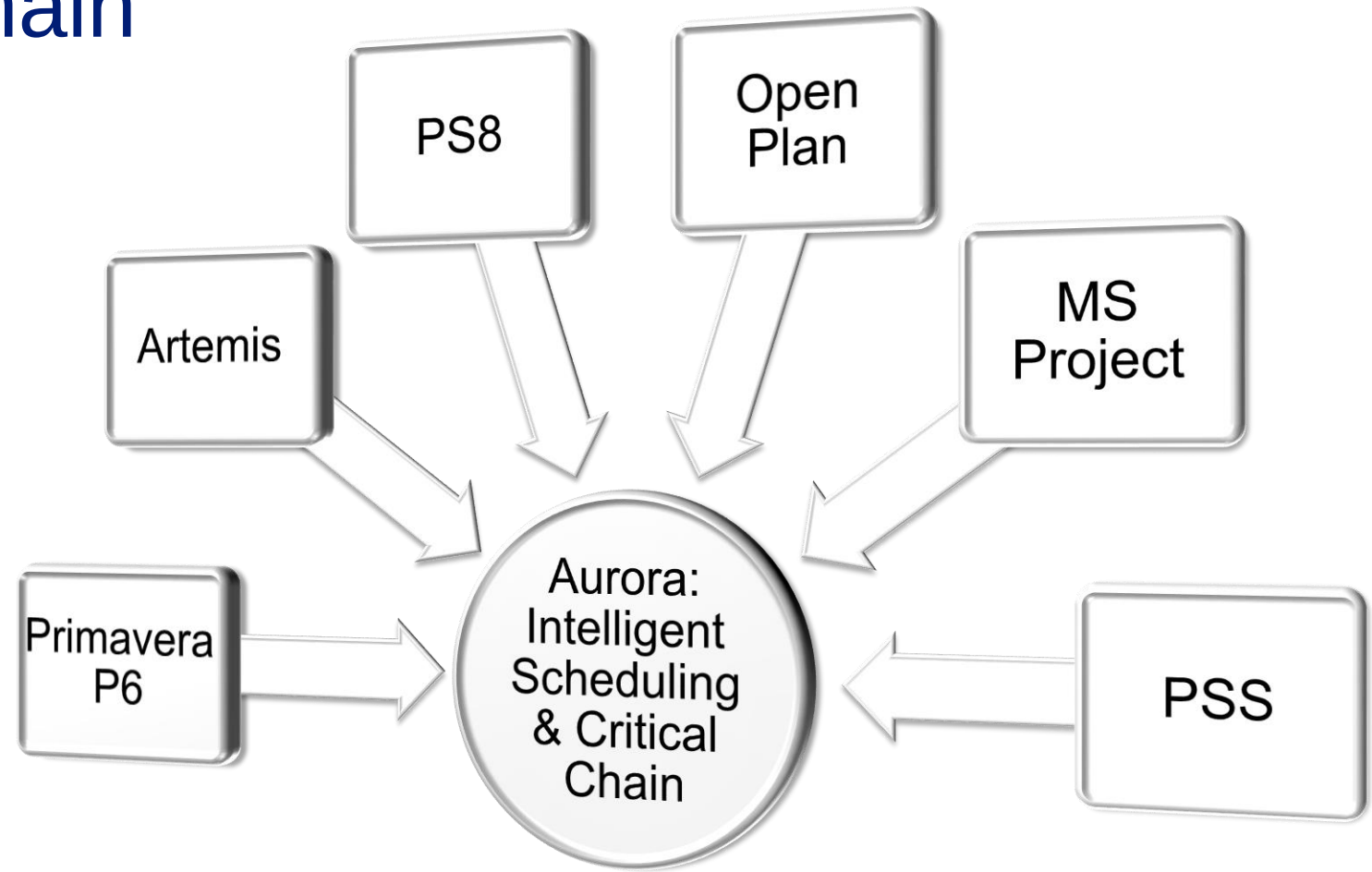
Build in current tool: Benefit from Intelligent Scheduling &/or Critical Chain



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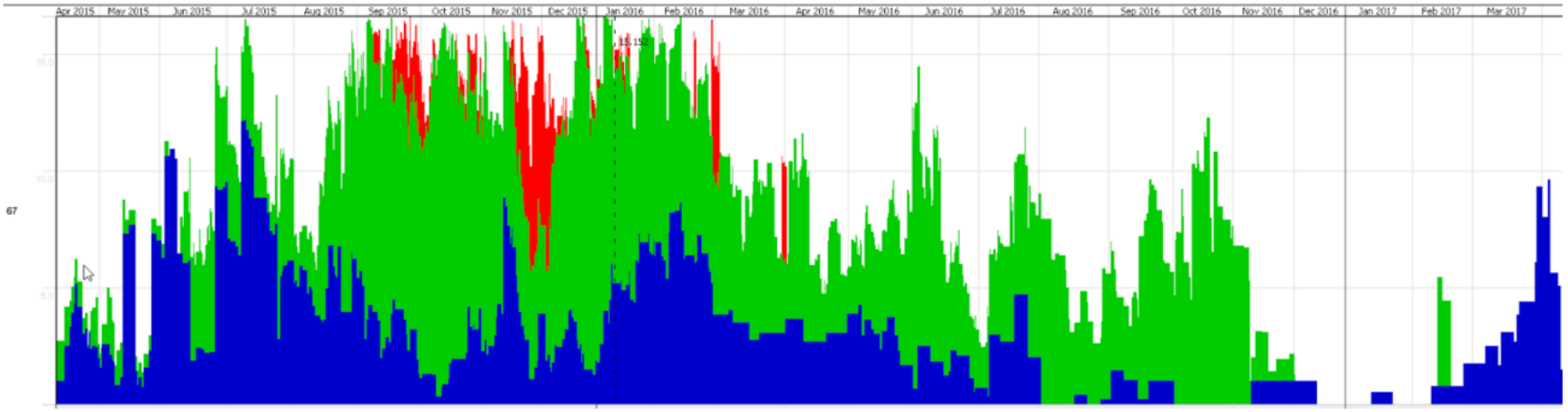
PSS Case Study (1)

- PSS – Solution used by US Navy
  - Single project only
- Developed Aurora import capability
- Successfully scheduled sample PSS provided by the Navy
  - Informed that PSS project models have not been successfully scheduled in other tools

PSS Case Study (2)

- Multi-project: Aurora successfully performs multi-project scheduling from multiple PSS models
  - Over 70,000 total tasks
  - Capability not currently available to the Navy



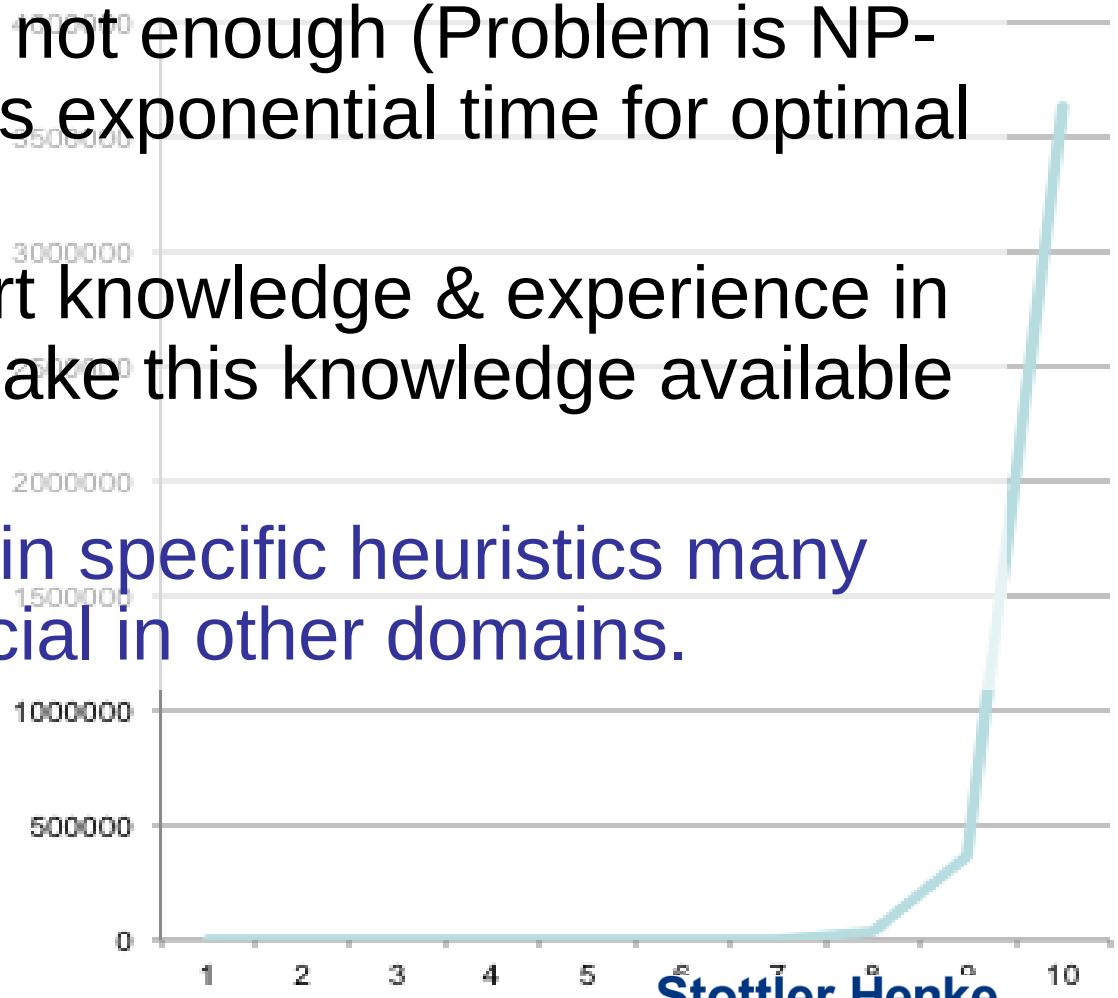
Projects Completed by

- **Synchronized** effort of multiple **resources**
- Goal of *Intelligent Scheduling*: optimize the synchronization of resources and other constraints to minimize the duration of the project

Intelligent Scheduling: Expert Knowledge & Experience Needed

- Mathematics is not enough (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.

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



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Aurora Summary

World's most intelligent scheduling engine and standard project management features

- Multiple-pass intelligent resource-constrained scheduling
- Mixed-mode scheduling providing both forward and backward scheduling, available on a task-by-task basis
- Schedule Rationale – Aurora includes the rationale for each task on why it was schedule where it was schedule
- Designed for customization
- Designed for integration

Aurora Customers (1)

The Boeing Company

The Boeing Company uses Aurora to prioritize production of the Boeing 787 Dreamliner™. Aurora's dynamic assembly schedule adapts to real-time production variations, so Boeing can produce aircraft as efficiently as possible.

Learn More

Aurora-ProPlan

Aurora-ProPlan is a component of the Intelligent based Manufacturing (IbM) initiative at Pfizer. It adds capabilities necessary to perform pharmaceutical production optimally.

Learn More

NASA: Kennedy Space Center

Aurora schedules the use of floor space and other resources at the Space Station Processing Facility, the world's largest low-particle clean room.

Learn More

Air Force Satellite Scheduling

The Aurora intelligent scheduling framework has been applied to Air Force Satellite Control Network (AFSCN) scheduling to create an automatic scheduling and deconfliction capability called MIDAS. Read the MIDAS Story

Learn More

MASS General Hospital

Aurora is used by the Massachusetts General Hospital to schedule its medical residency program. Aurora reduces the time and effort needed to generate schedules, and provides better support for the hospital's complex staffing needs

Learn More

Bombardier Learjet

Aurora helps Bombardier Learjet schedule their airplane assembly operations more quickly, so they can handle production rate changes and component delivery delays more effectively.

Learn More

Aurora Customers (2)

Automobile Industry

A major automobile manufacturer selected Aurora to optimize its vehicles for destructive and non-destructive crash testing.

Learn More

Mitsubishi Heavy Industries

Mitsubishi Heavy Industries (MHI) is using Aurora to accelerate its production of Boeing 787 Composite Wing Boxes.

Learn More

United Space Alliance

United Space Alliance included Aurora in the design of Temporis, a scheduling system targeted for use by NASA crew members on board next generation spacecraft during deep space missions

Learn More

Korean Aerospace Industries

Aurora helps Korean Aerospace Industries (KAI) to schedule production of composite parts for Boeing's Dreamliner.

Learn More

Navy: Submarine Support

The US Navy has selected Aurora-CCPM™ software to schedule submarine maintenance operations at the Naval Submarine Support Facility (NSSF).

Learn More

Clipper Windpower

Clipper Windpower selected Aurora to schedule the manufacturing of its Liberty series wind turbine, the largest wind turbine made in the United States.

Learn More

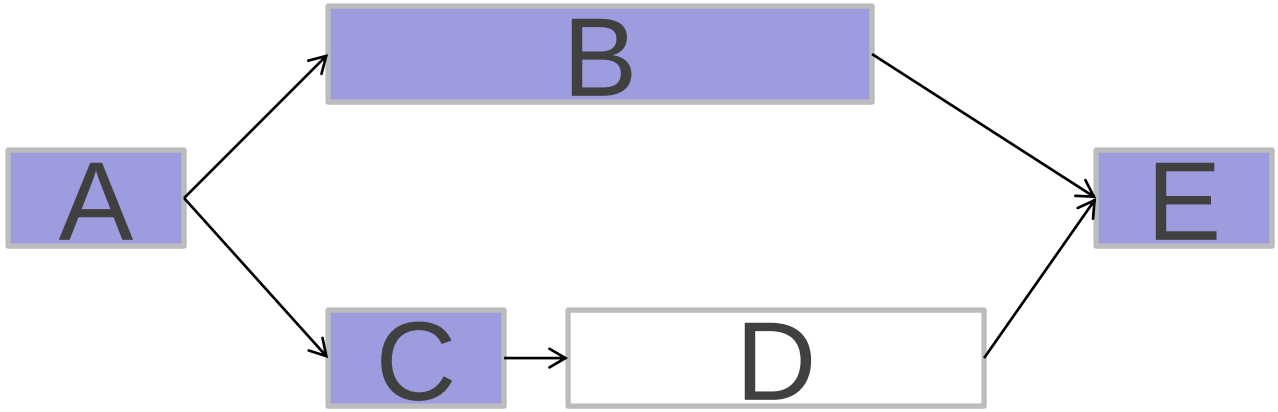
Value Proposition: Aurora

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

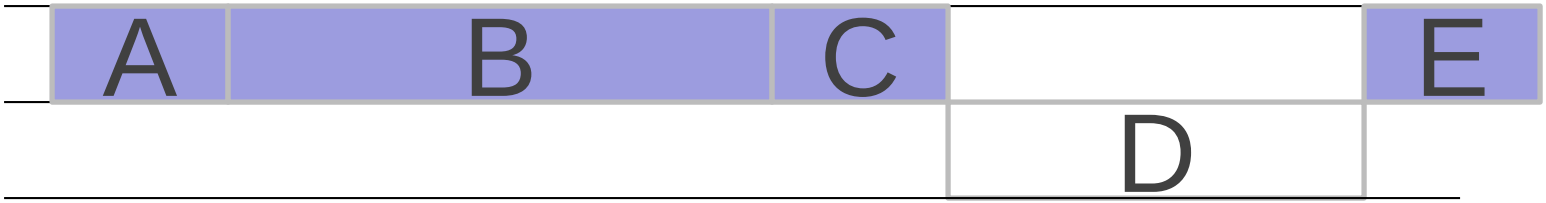
- That is, once the resource-loaded project model is developed, using Aurora will determine a shorter initial schedule, and then by using Aurora during the execution of the project Aurora will make more efficient decisions based on the reality on the ground so the execution results in a shorter project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

Why order matters?

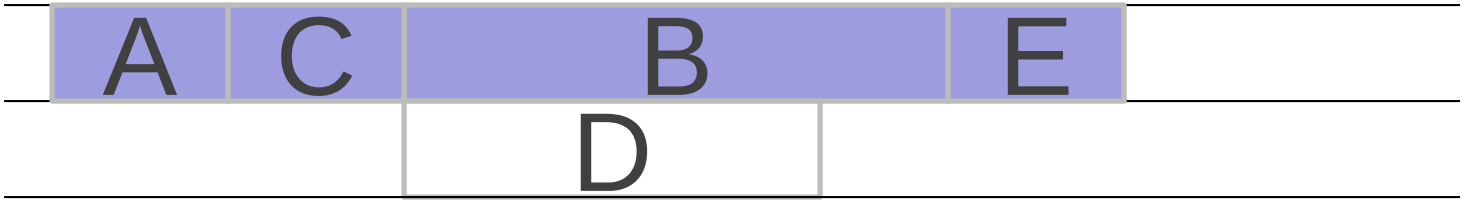
The example below involves jobs using two resources, purple and white



Schedule 1: B before C



Schedule 1: C before B



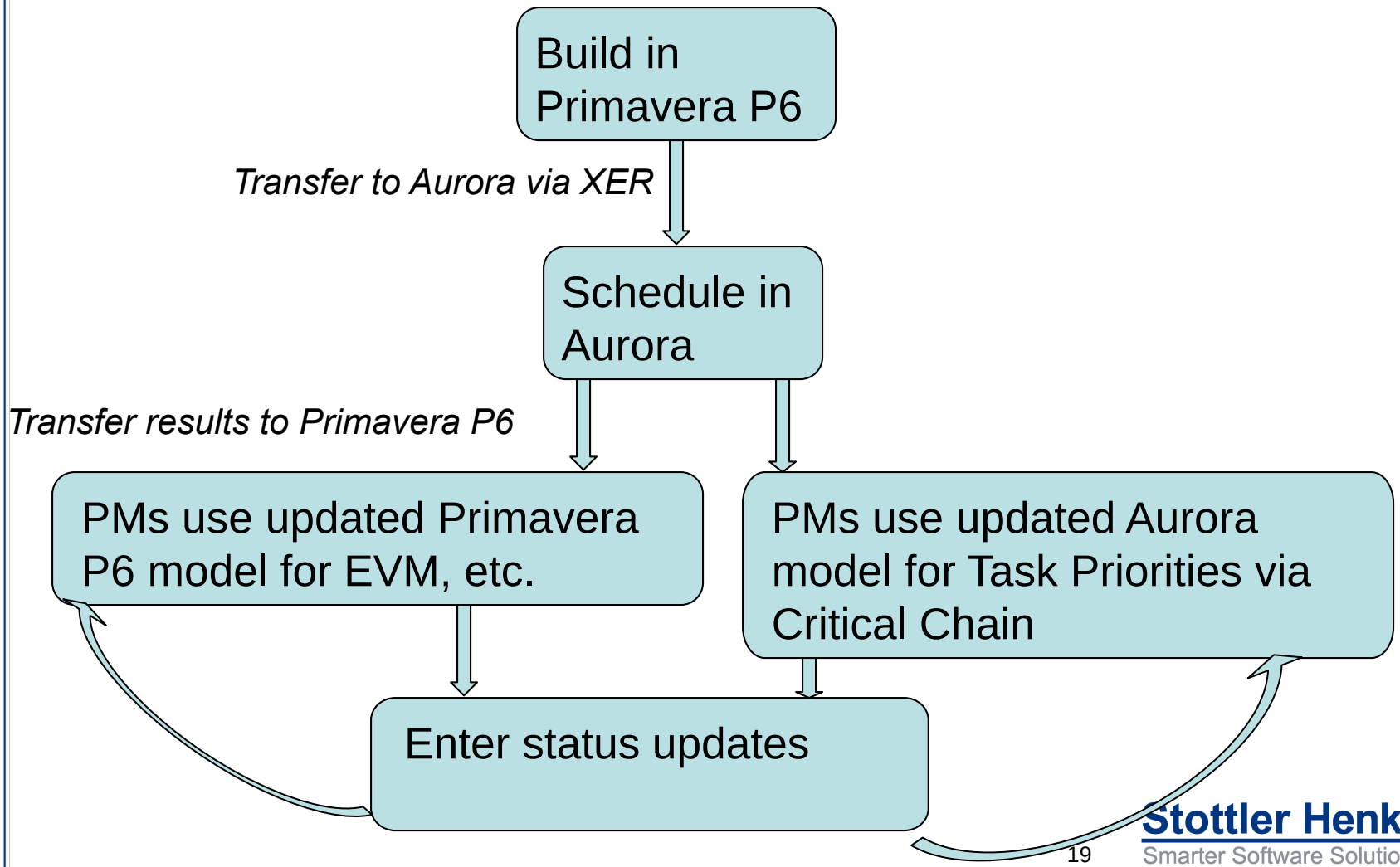
Aurora-CCPM Summary

Enterprise-Level Critical Chain Project Management Software

Multi Project

Provide GLOBAL view of entire project – prioritize execution to maximize overall project benefit

Potential Workflow with P6: Flowchart for Critical Chain



Aurora Unique Capabilities & Benefits (1)

Large project support
- Supports 100,000+ tasks per project

Integrates with Enterprise Software
- Oracle, SAP, proprietary systems

Multiple-pass intelligent resource-constrained scheduling
- Generates shorter project duration & shorter remaining project durations during execution

Mixed-mode scheduling providing both ASAP & ALAP scheduling, available on a task-by-task basis.
- All other critical chain software *only* provides ALAP scheduling

Aurora Unique Capabilities & Benefits (2)

Primavera P6 Integration

- Only Critical Chain software that is designed to work with Primavera P6

Support beyond Finish-to-Start Constraints

- Only software that understands and can perform Critical Chain with S-S, F-F, etc., also supports Leads and Lags.

Schedule Rationale

- Aurora includes the rationale for each task on why it was schedule where it was scheduled

Designed for Customization

- Can be extended to work with enterprise specific needs

Aurora Unique Capabilities & Benefits (3)

Supports More Types of Constraints

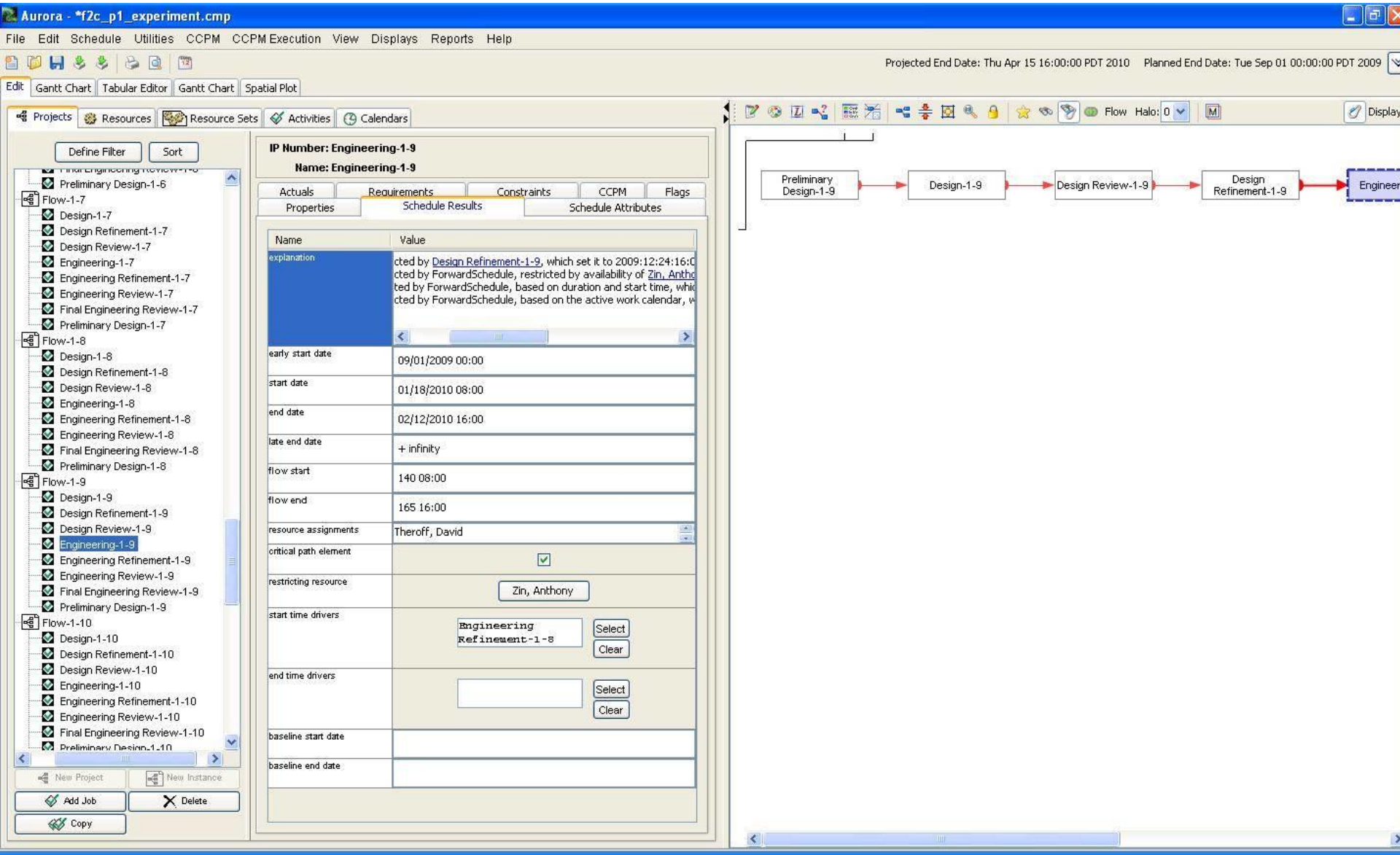
- Resource constraints
- Resource Sets – job can be performed by 2 different specialists or (1 generalist and 1 specialist) or 2 generalists.
- Spatial constraints – e.g.,
  - job requires a certain location or type of space;
  - two elements should (or should not) be next to each other
- Ergonomic constraints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

Aurora Unique Capabilities & Benefits (4)

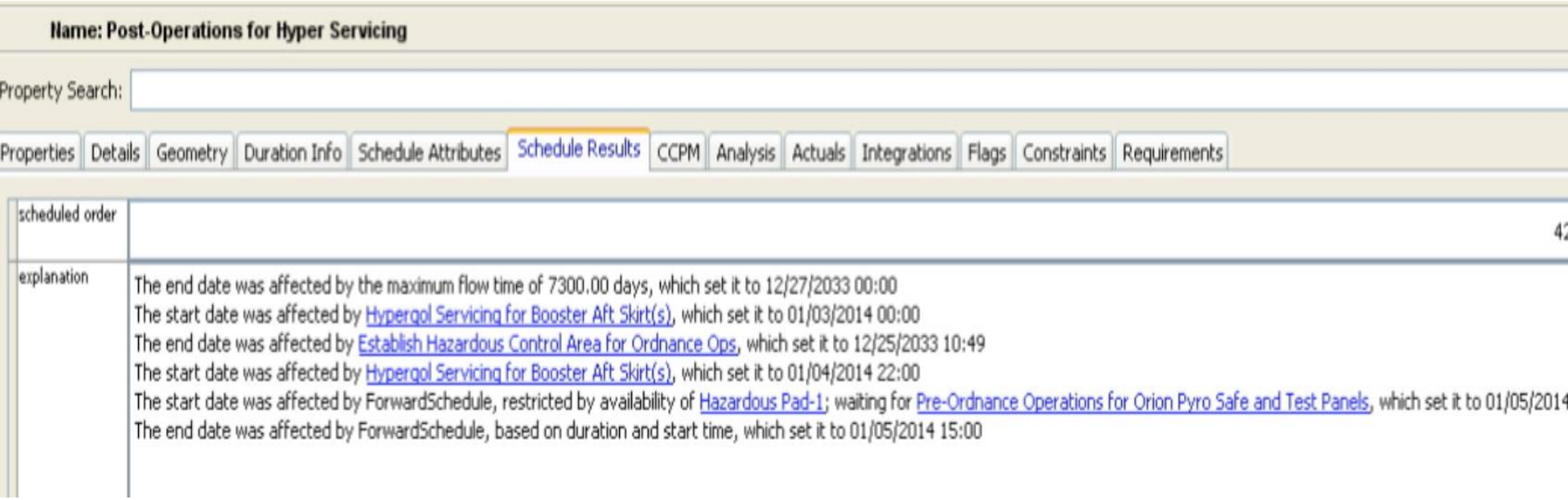
Supports More Types of Constraints

- 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

Explanation of Why each Task was Scheduled Where it was



Schedule Results: Explanation



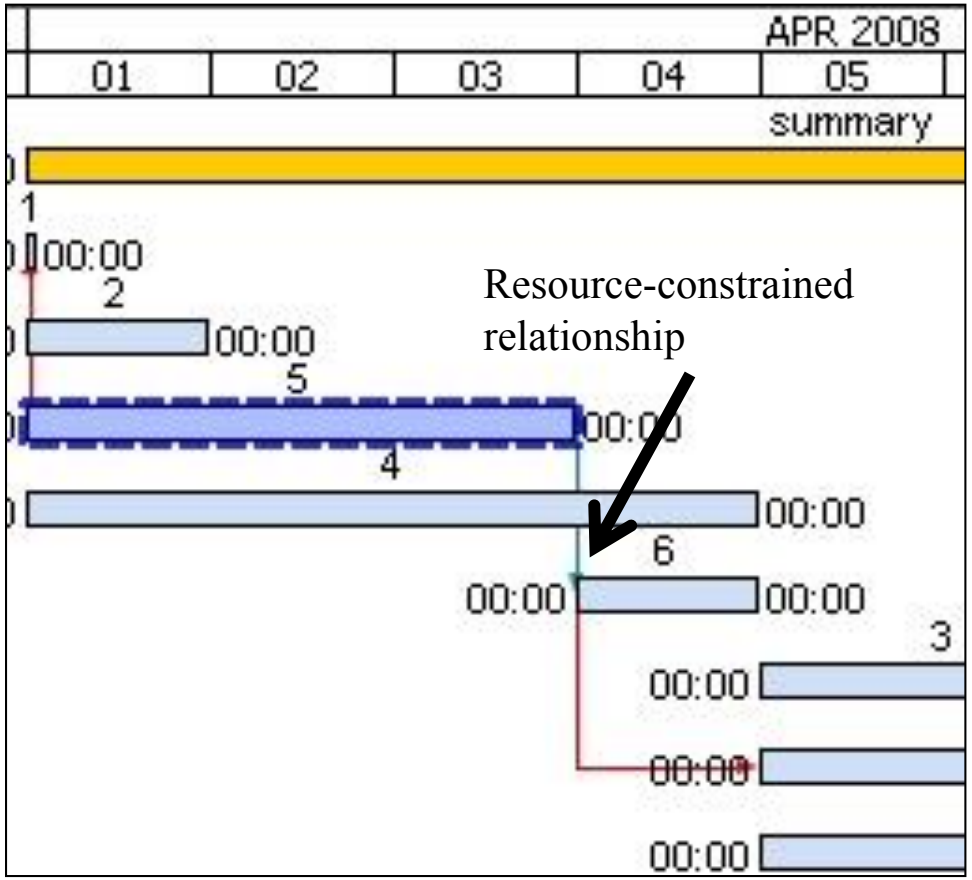
Resource Contention: Visual

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.

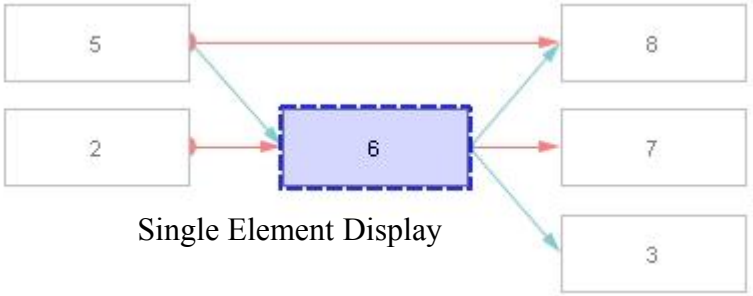
Resource Contention: Task 6

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

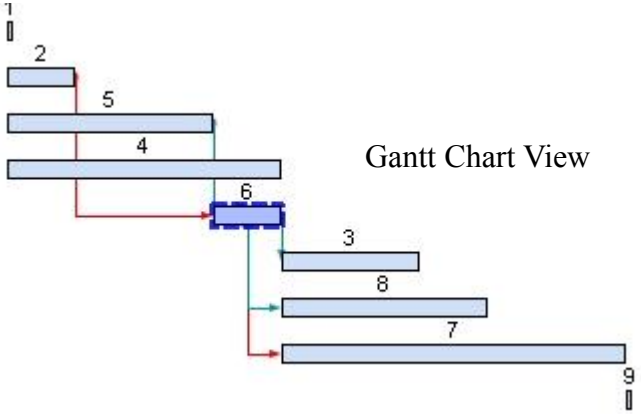
- Blue-grey lines denote a resource-constrained work flow
- Red lines denote temporally-constrained work flow

Referring to the three diagrams to the right:

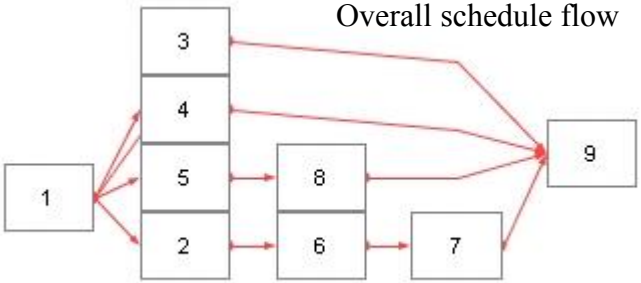
- Task 6 can start any time after Task 2 is completed (red line in Single Element Display), but must wait for Task 5 to release resources (blue-grey line).
- Tasks 3 and 8 must wait for 6 to release resources before they can start, as shown in the Gantt Chart View
- Task 7 starts after Task 6 completes (red line in Single Element Display)



Single Element Display



Gantt Chart View



Overall schedule flow

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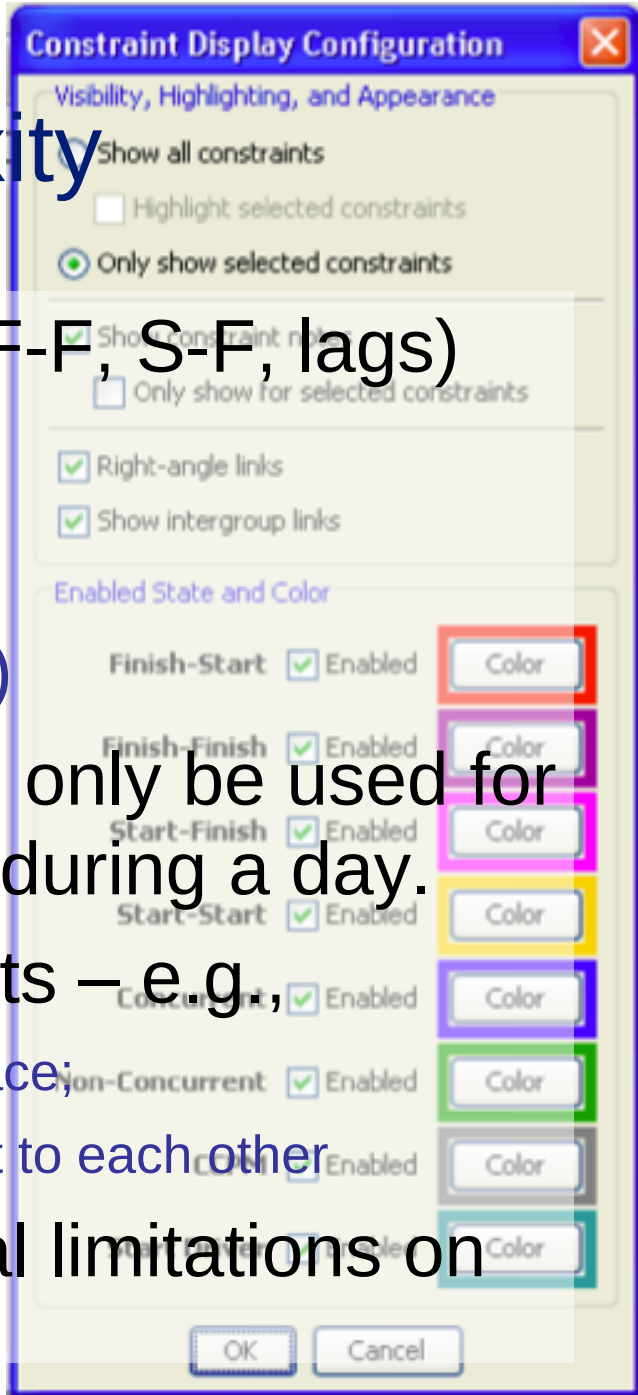
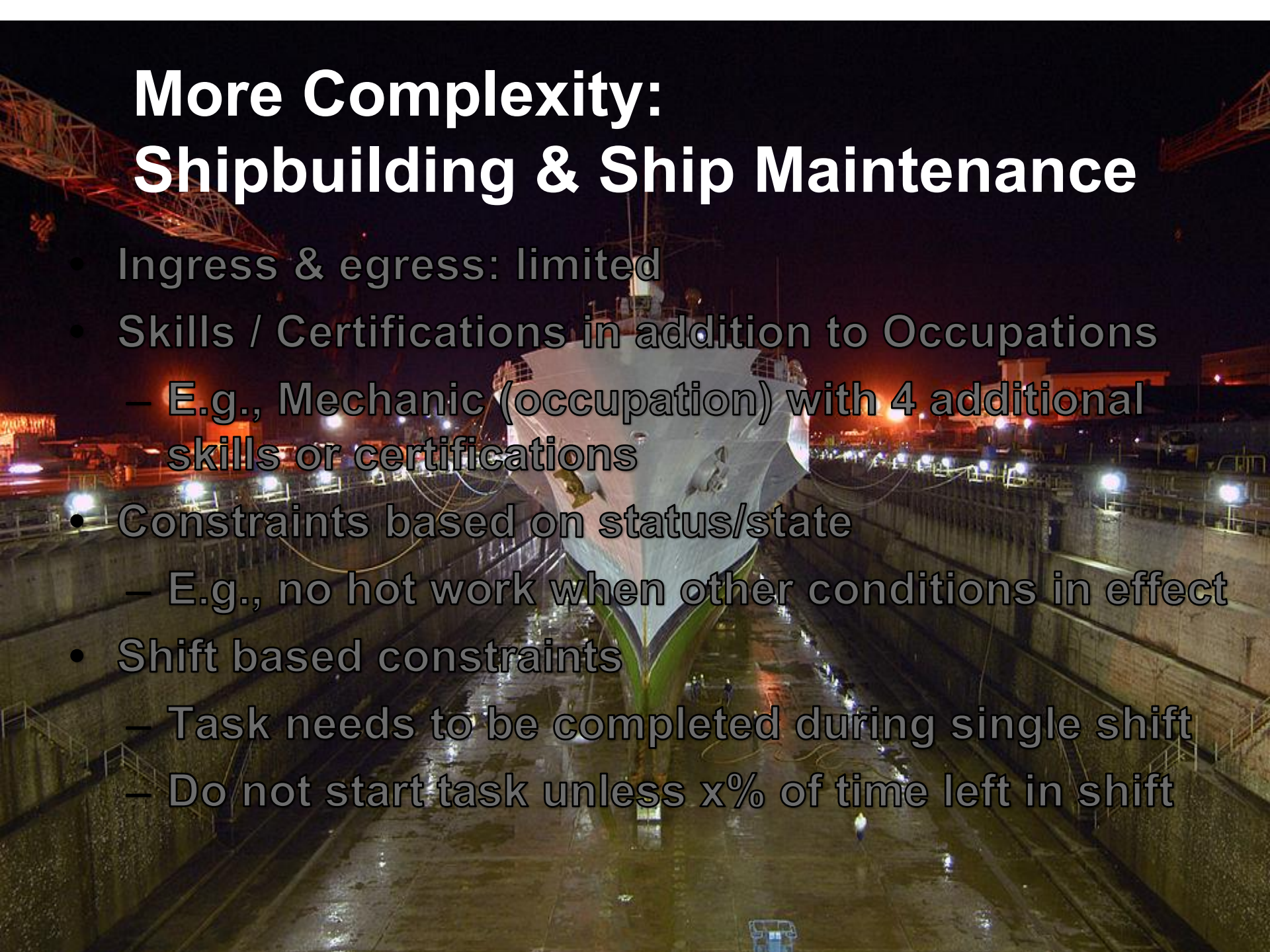
Constraints Add Complexity

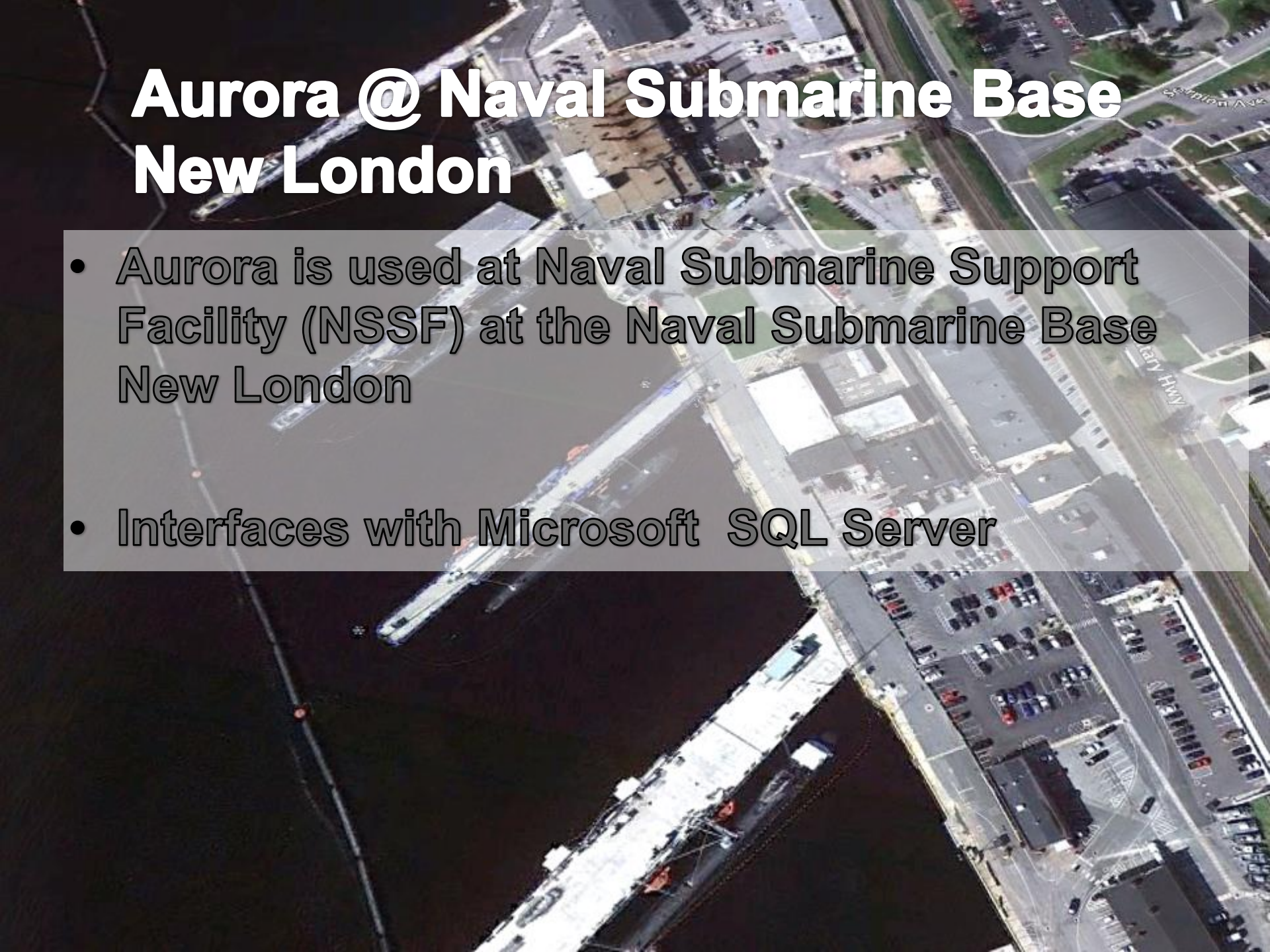
- Technical constraints (E.g., F-S, F-F, S-F, lags)
- Resource constraints
  - Labor constraints
  - Equipment, Tools (e.g., cranes)
- Usage constraints – e.g., tool can only be used for so many hours continuously &/or during a day.
- Spatial / physical space constraints – e.g.,
  - job requires a certain 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



Aurora @ Naval Submarine Base New London

- Aurora is used at Naval Submarine Support Facility (NSSF) at the Naval Submarine Base New London

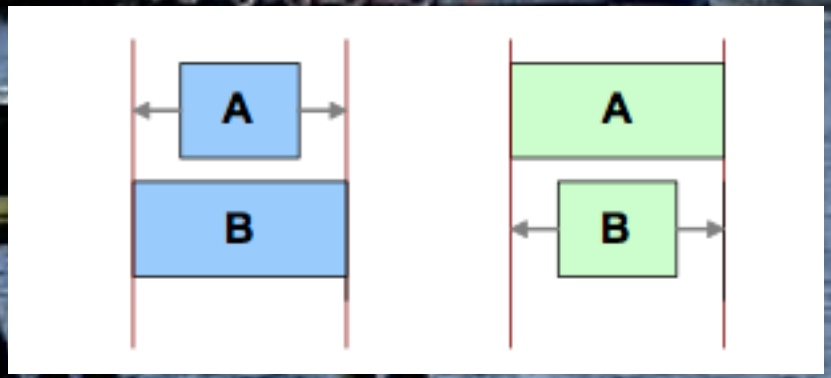
- Interfaces with Microsoft SQL Server

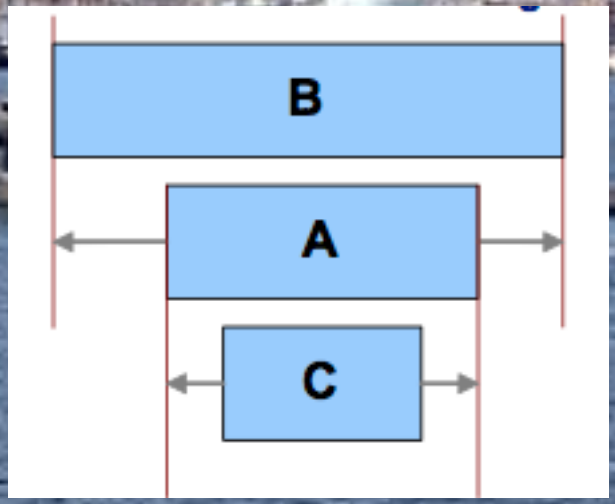
NSSF: Submarine Maintenance

- 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

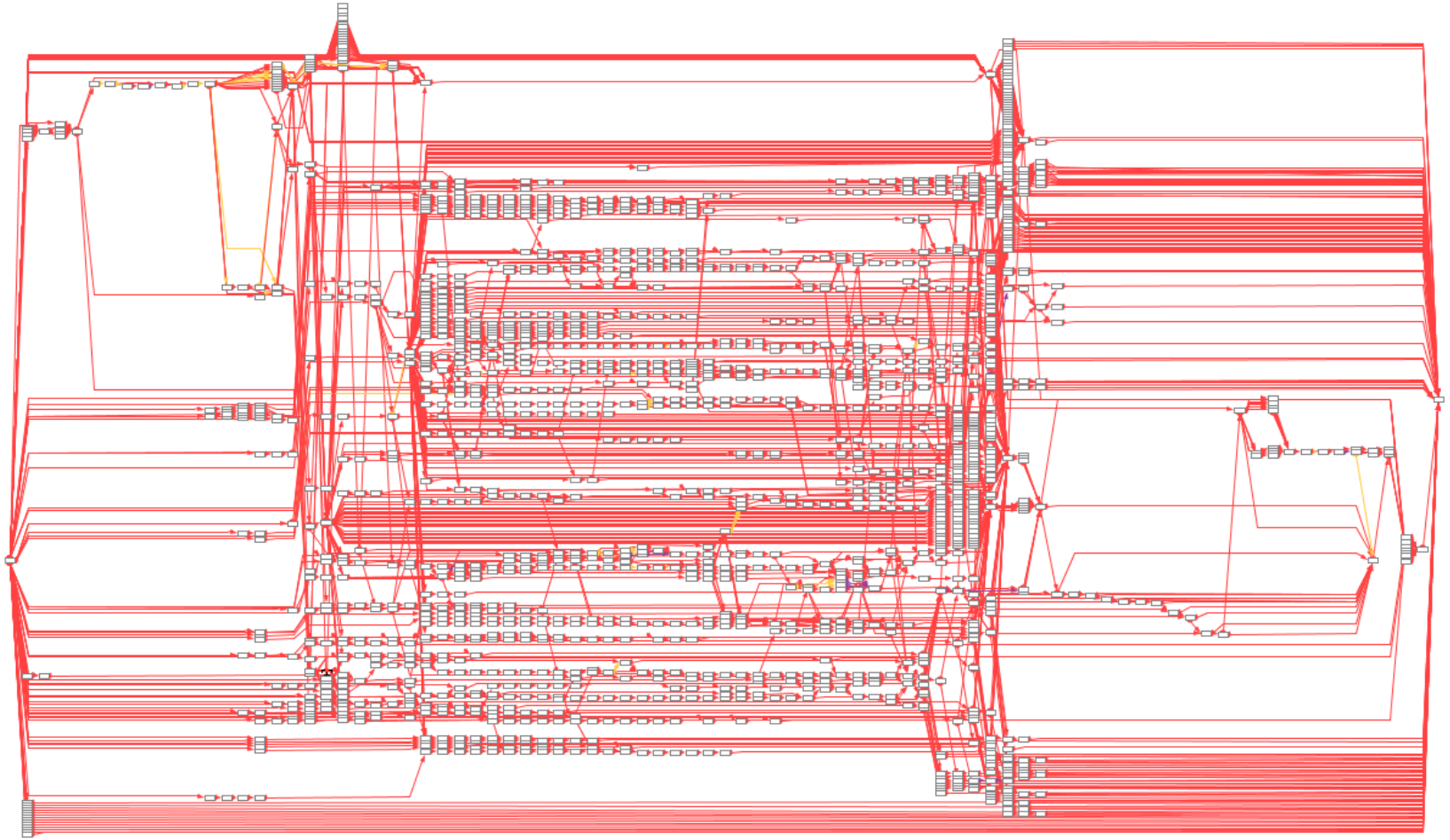
Concurrent & Non-Concurrent

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





Turnaround Project Network 2,500+ Tasks



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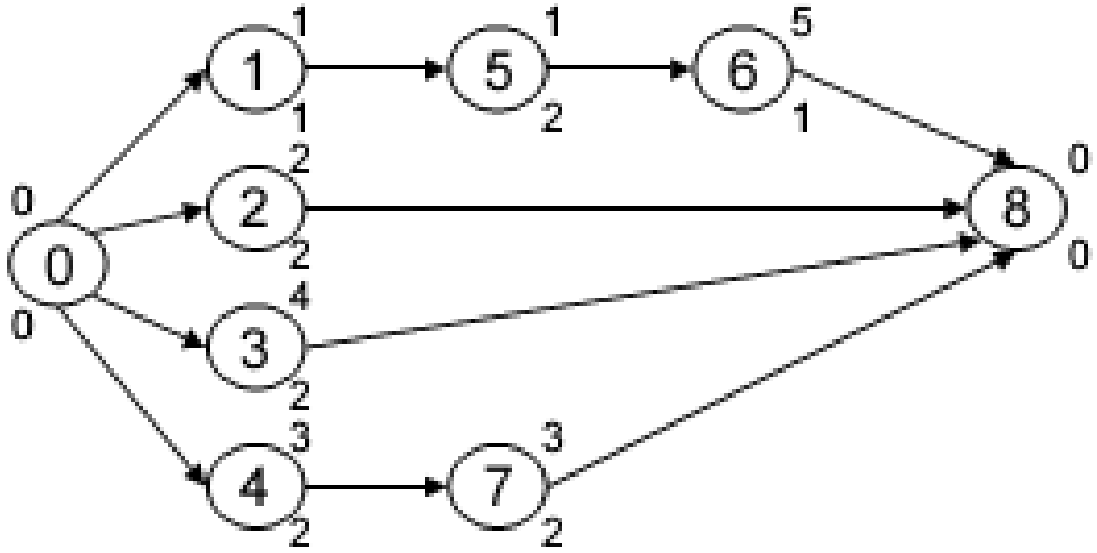
Results: 2,500+ Turnaround

- Primavera P6 **65** days
  - Performed by 3rd party
- Aurora **57** days
- Primavera P6 **14% longer** than Aurora
- Critical Path is 46 days
  - P6 is 19 days longer than CP
  - Aurora is 11 days longer than CP
  - So **% diff over CP is > 73%**

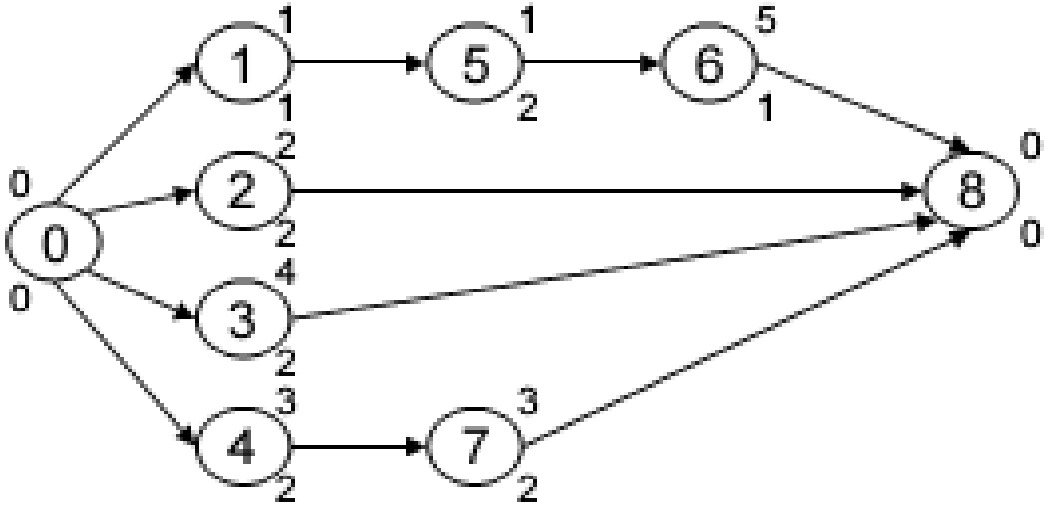
Maybe Only for ‘Big’ Problems?

- Let’s look at a toy problem …
- ‘Simple’ problem with only 7 real tasks and 2 milestones.



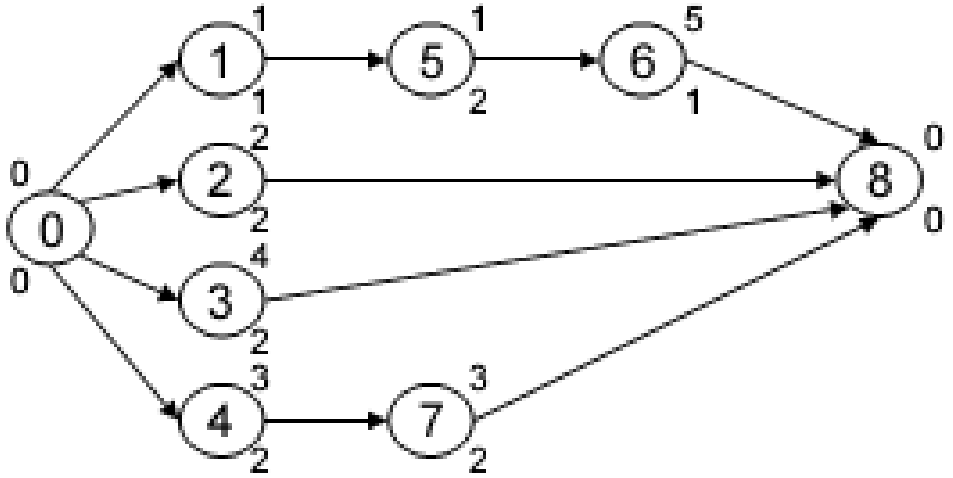
‘Simple’ Network details

- Number superscript of circle is duration in days
- Number subscript of circle is resources needed
- There is only 1 type of resource



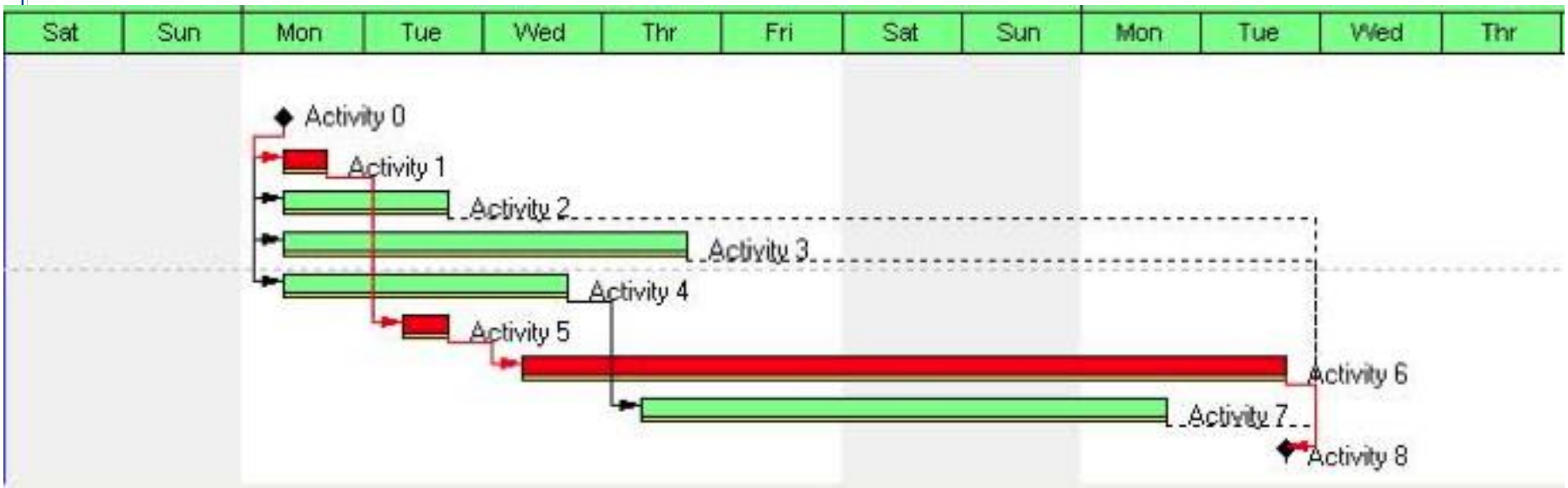
Critical Path of Network

- Solution when infinite resources available
  - Find longest path = 1 + 1 + 5 = 7
- So Critical Path is 7 days



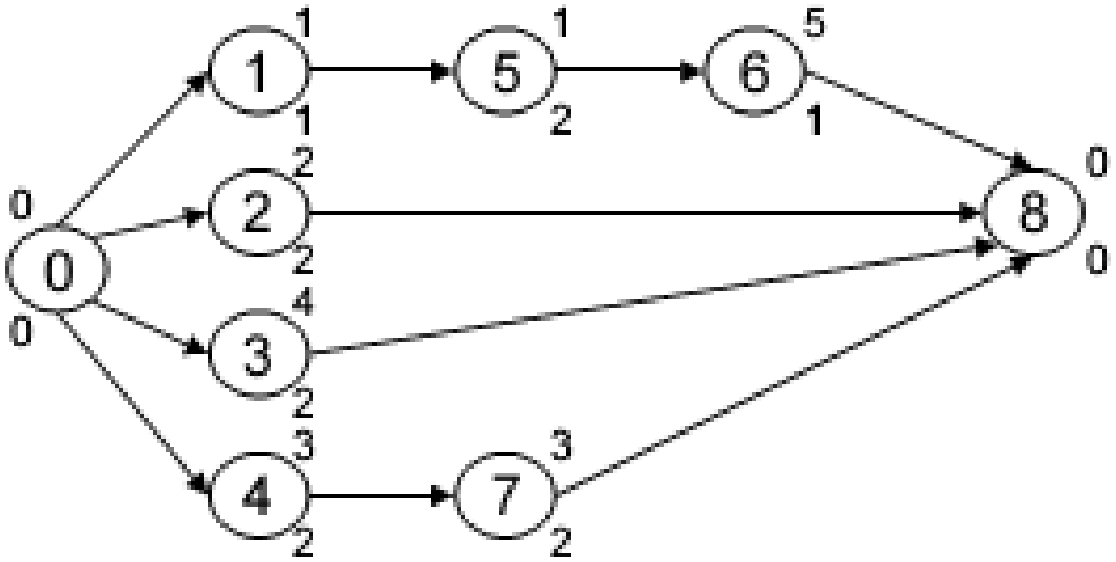
Gantt Chart of Critical Path

- Note: Sat/Sun are not workdays



Set Resource Pool to 5

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

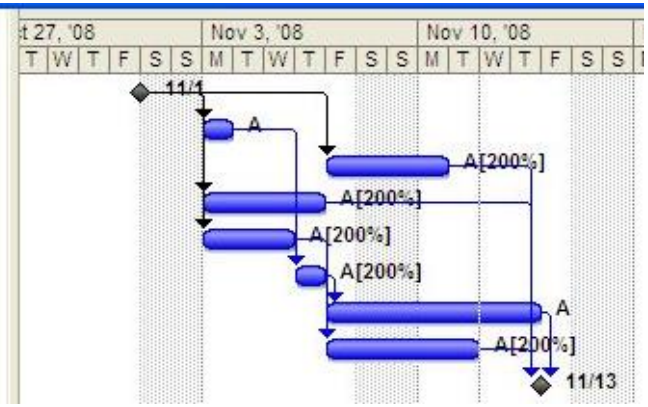


Gantt Chart Showing the Critical Path & Histogram

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

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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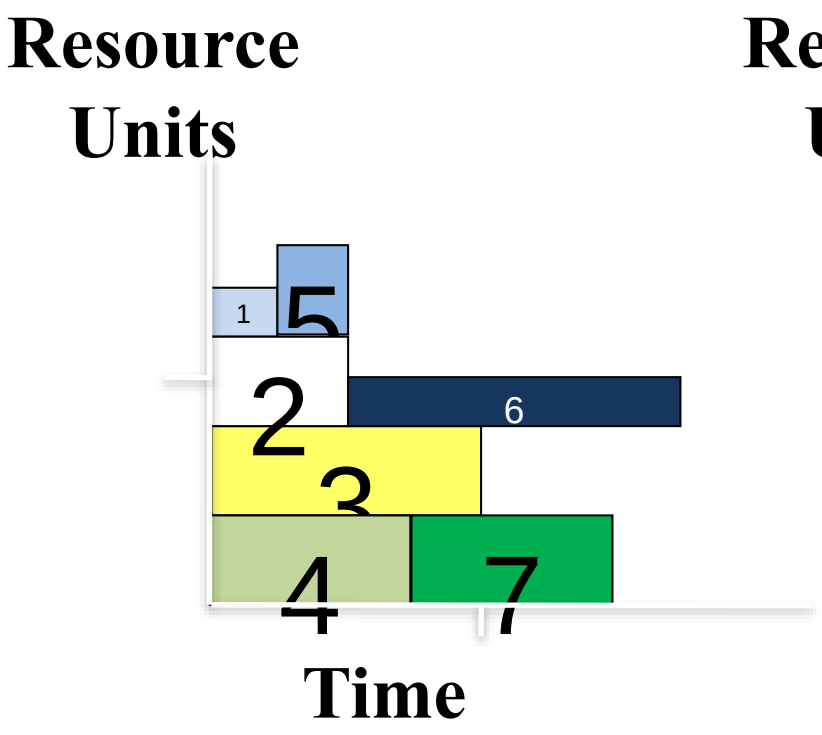
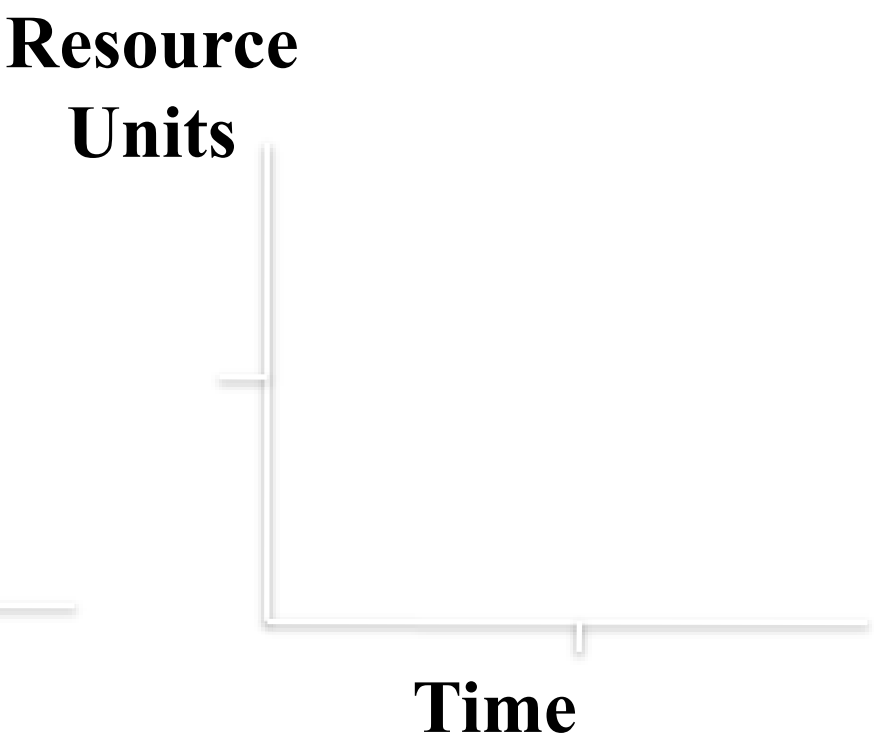
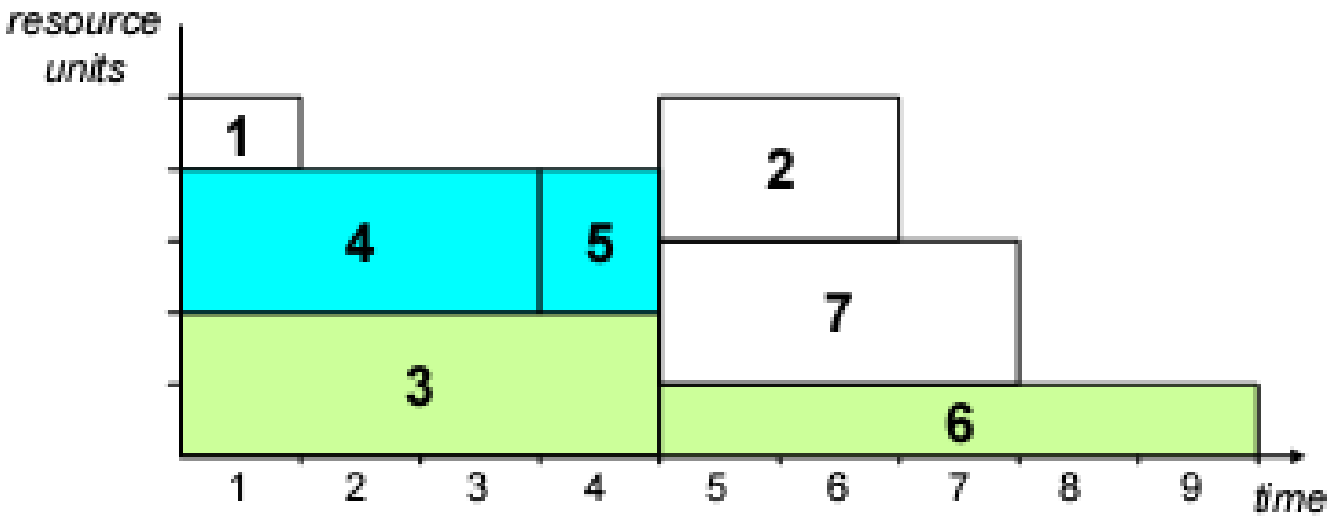

Resource
Units
1
5
2
6
3
4
7
Time


Resource
Units
Time

Simple Enough, Right?

- Another view of the solution



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

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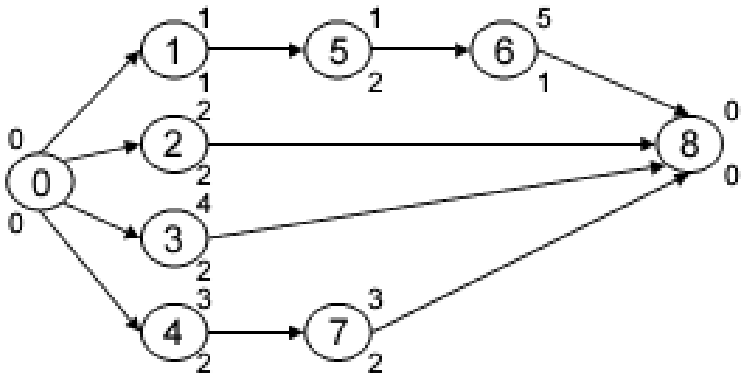
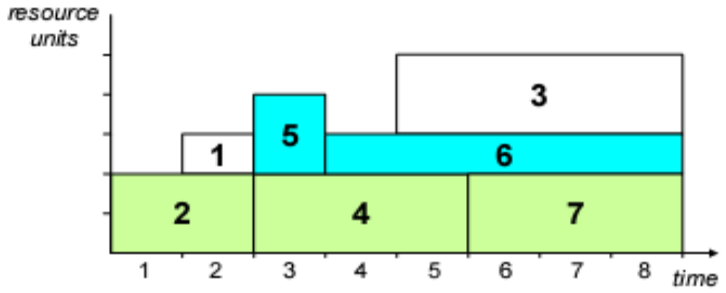
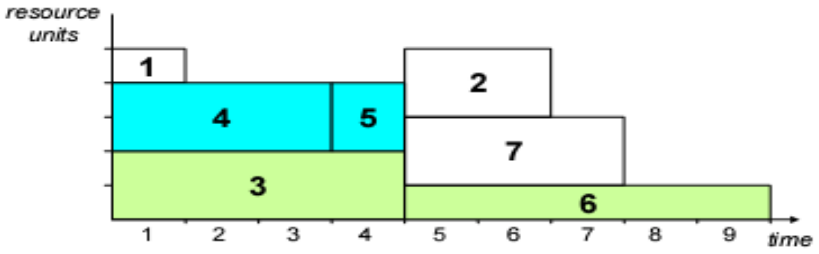
Simple?



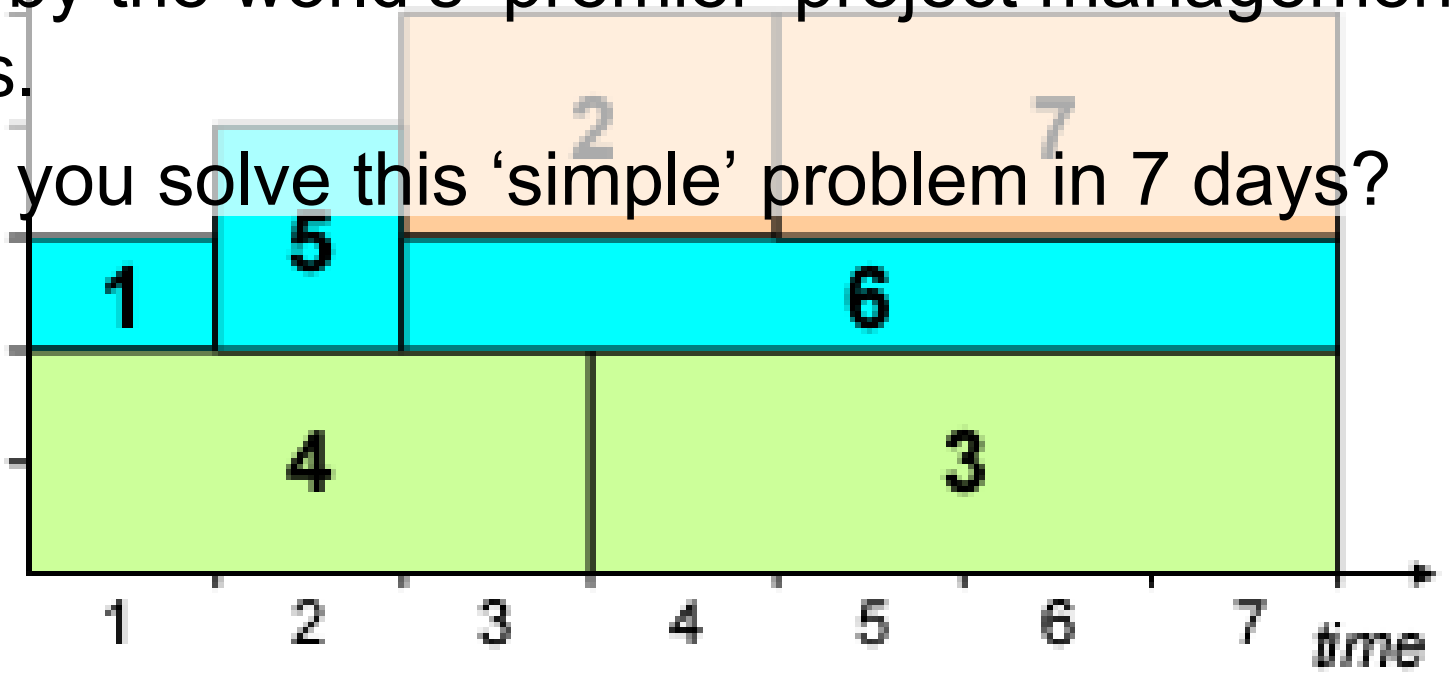




- Critical Path =
  1 + 1 + 5 =7
- 1 resource
  5 total units

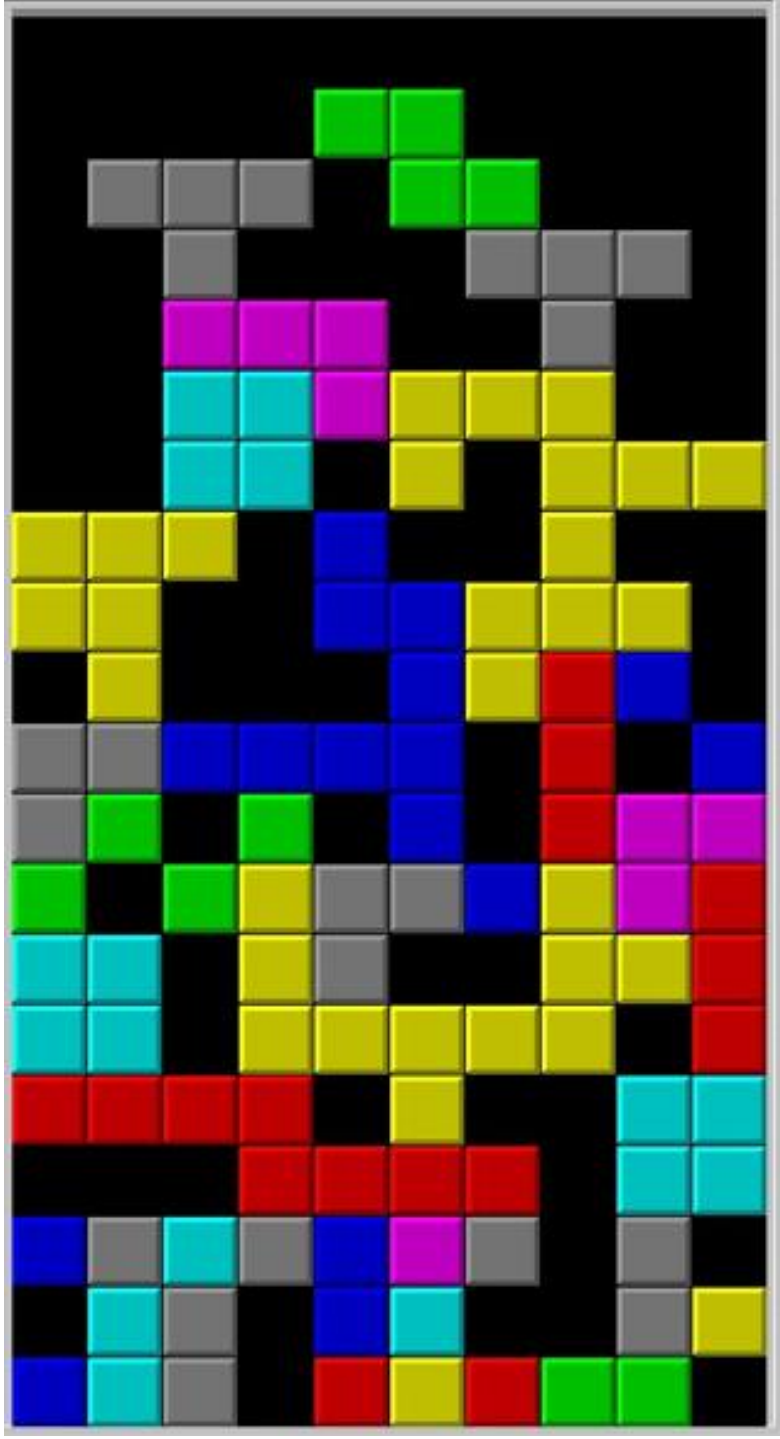
End of Story… Not quite

- 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?

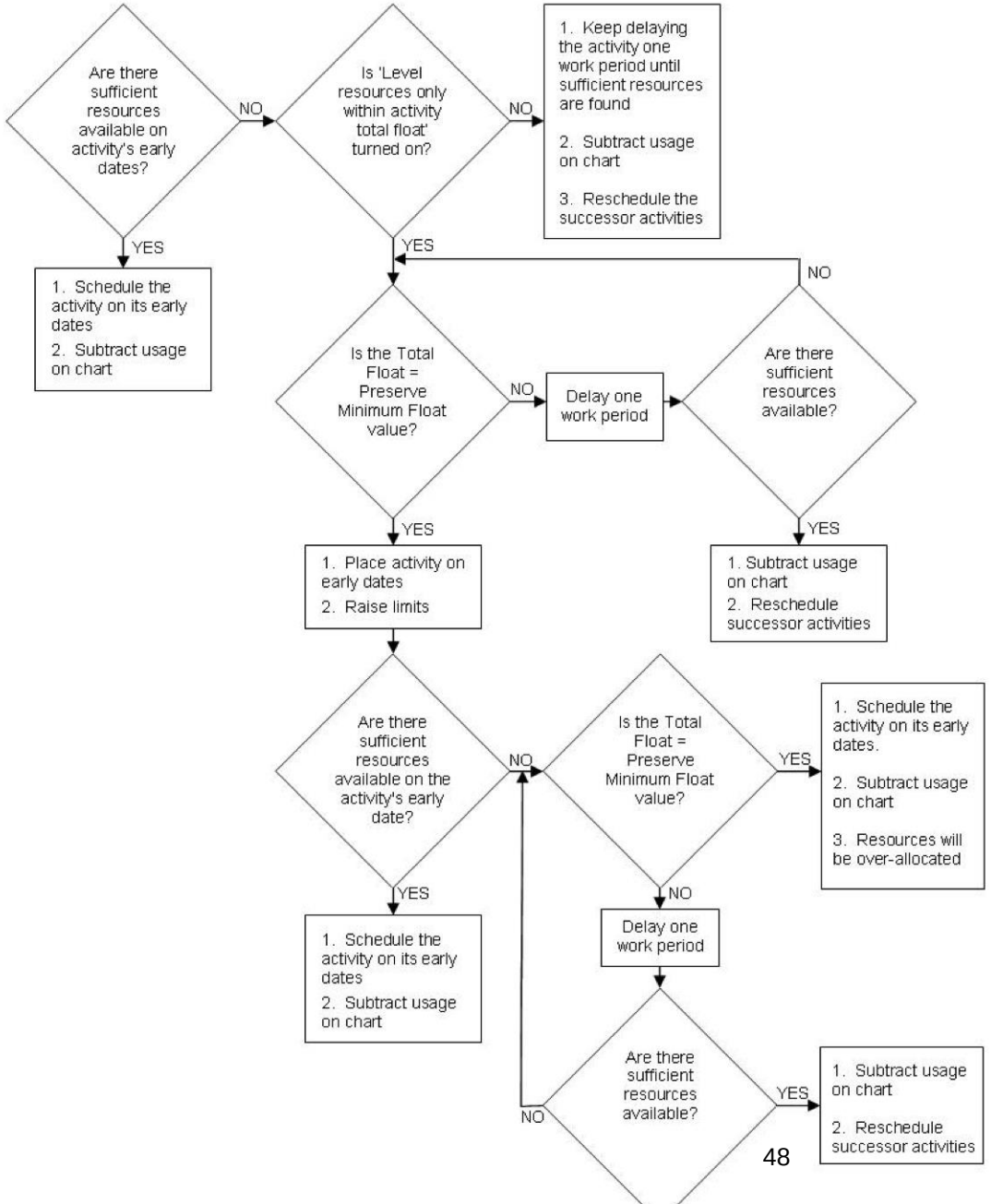


Tetris

- 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



Primavera Resource Leveling flowchart

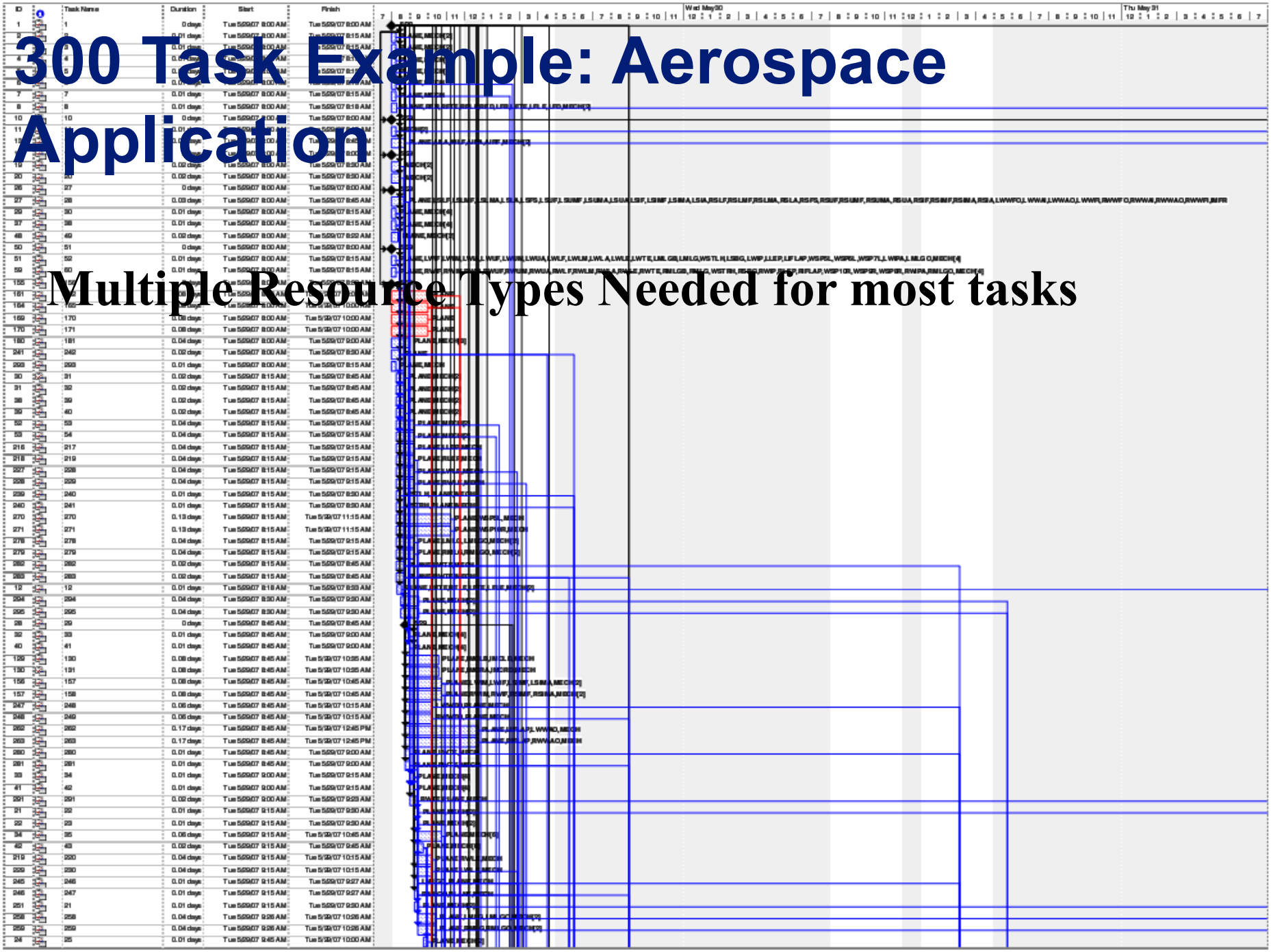


Long-Term Refinery-Related Upgrade

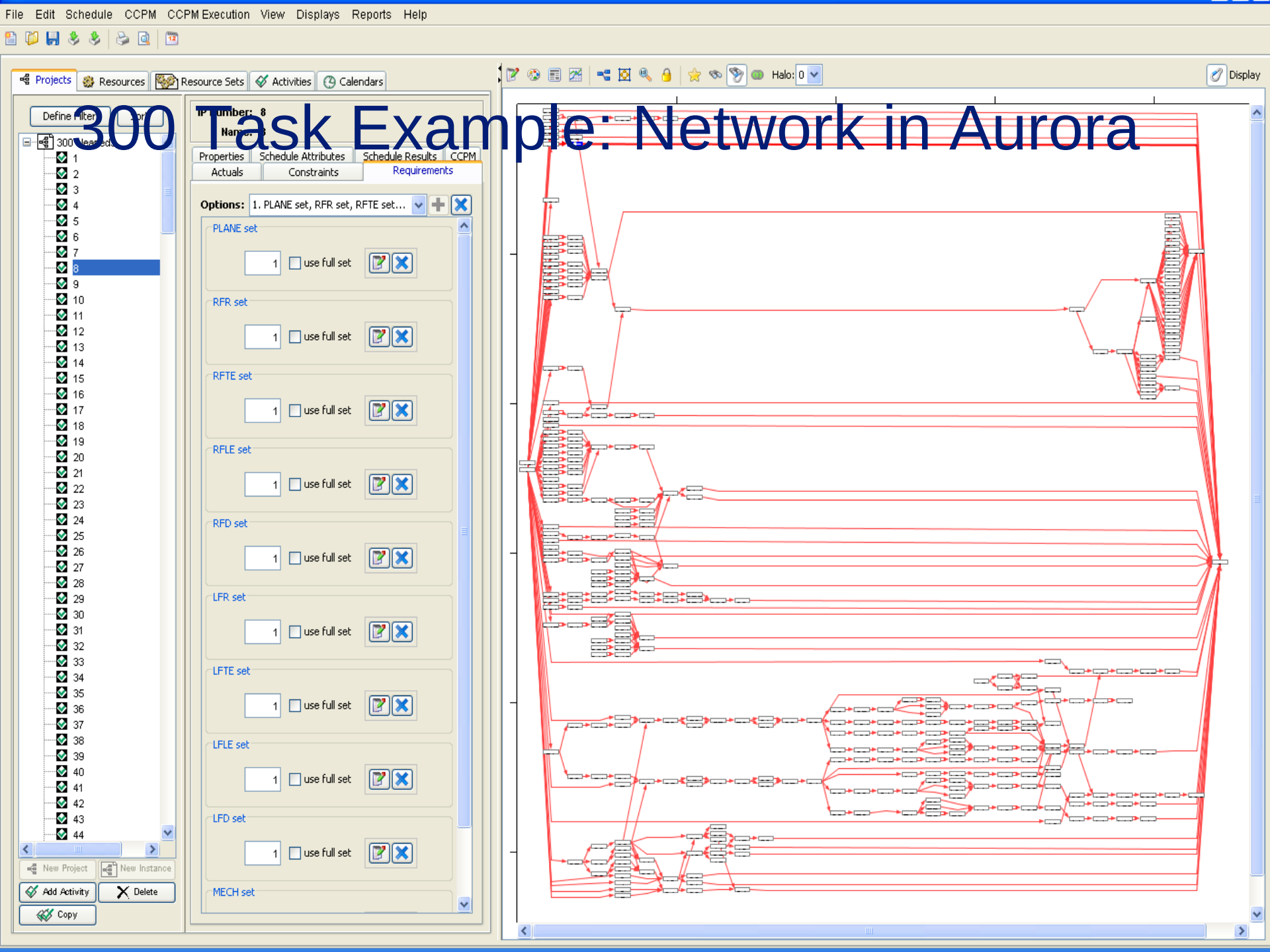
MS Project 2007	=	1,627 days
Primavera P6	=	1,528 days
Intelligent scheduling (Aurora)	=	1,240 days

300 Task Example: Aerospace Application

Multiple Resource Types Needed for most tasks



300 Task Example: Network in Aurora



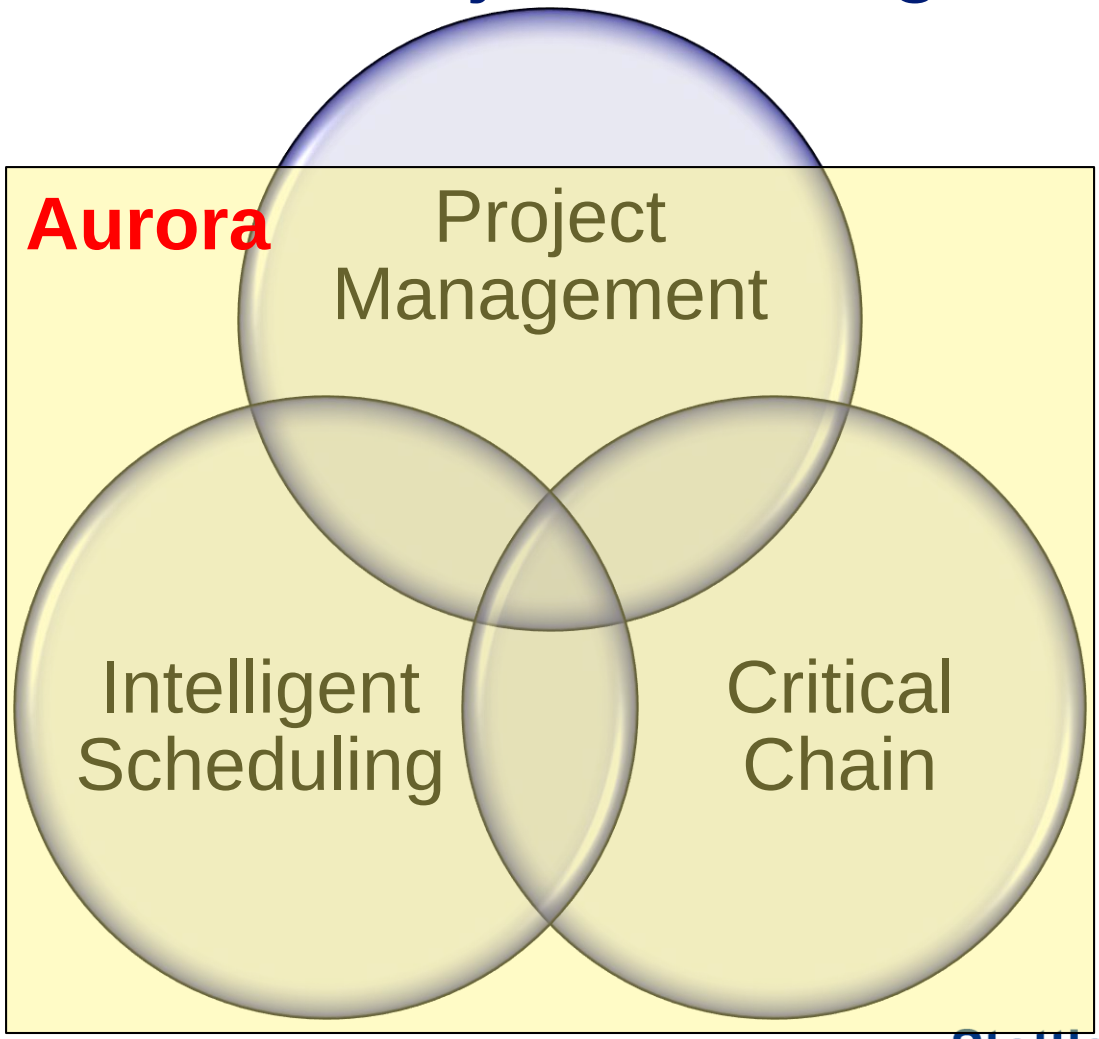
Results: 300 Task Example

- MS Project 2003 **145.6** days
- MS Project 2007 **145.6** days
- Primavera P6 **115** days
  - Performed by 3rd party
- Deltek Open Plan **110** days
  - Performed by Deltek
- Aurora **102.5** days

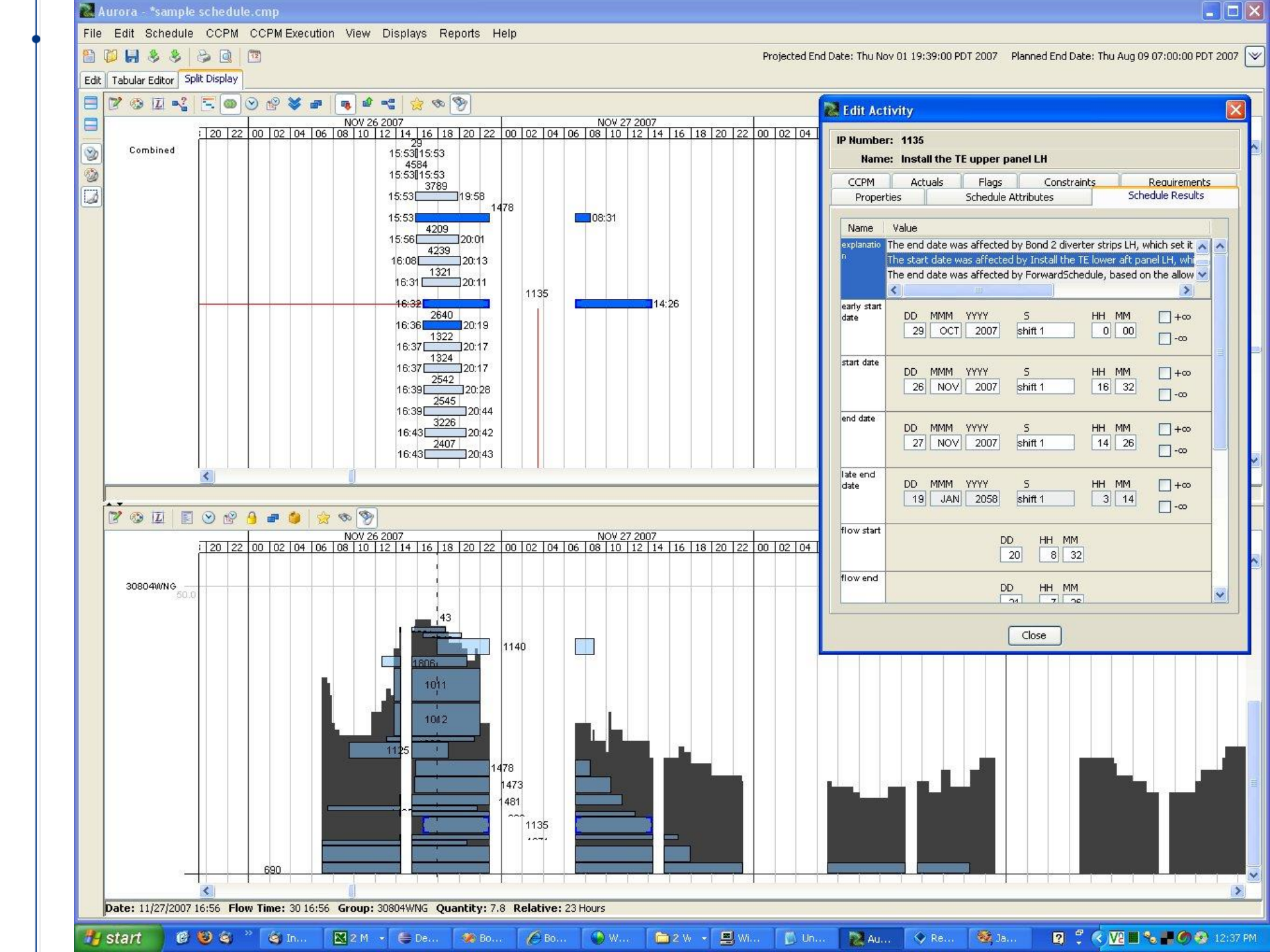
Take Aways

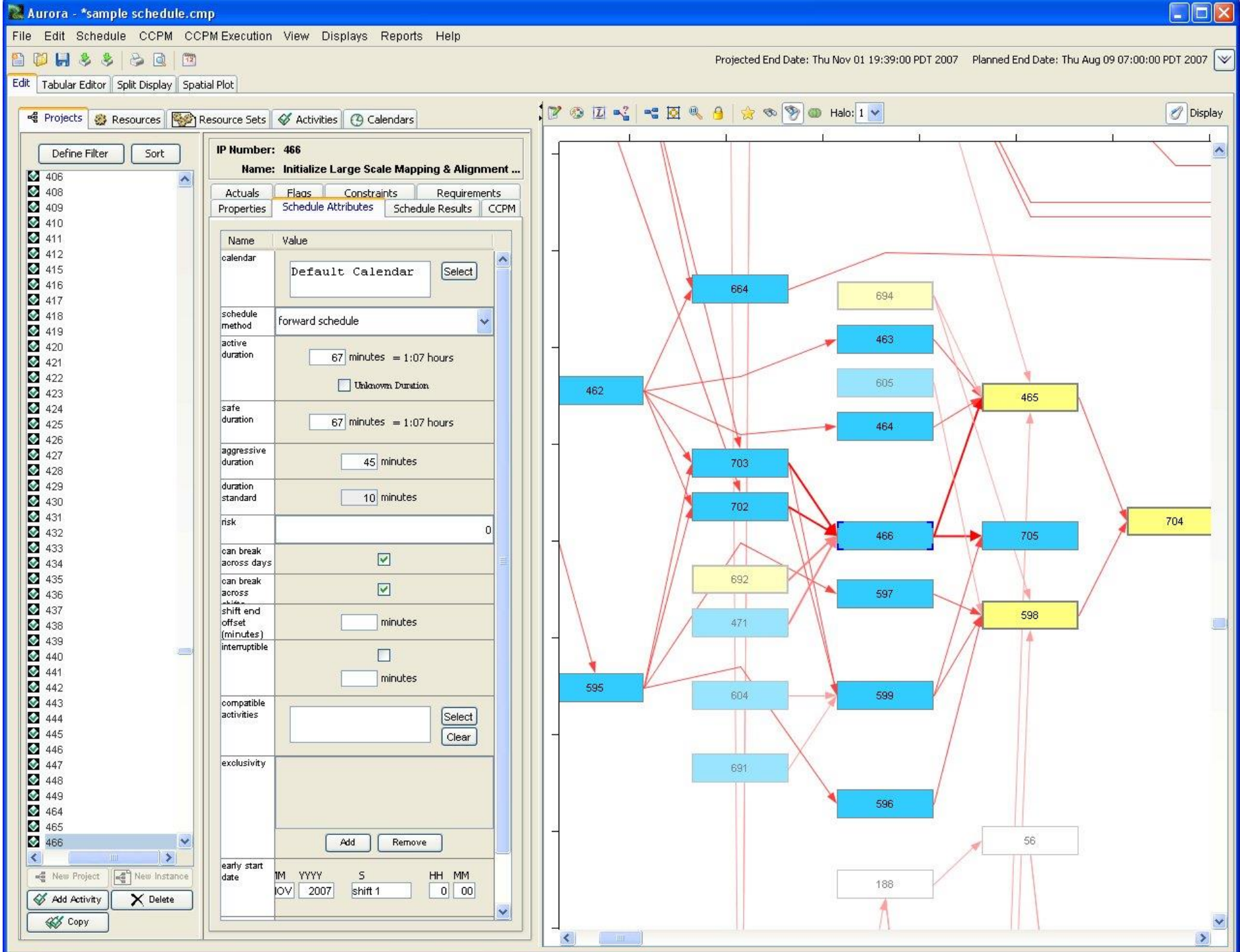
- Scheduling engine is critical
- Paying up to 100% penalty due to the scheduling engine
- Changing to an improved scheduling engine may be the greatest potential improvement available to your project
  - Just press a different button
- Provide an unfair competitive advantage

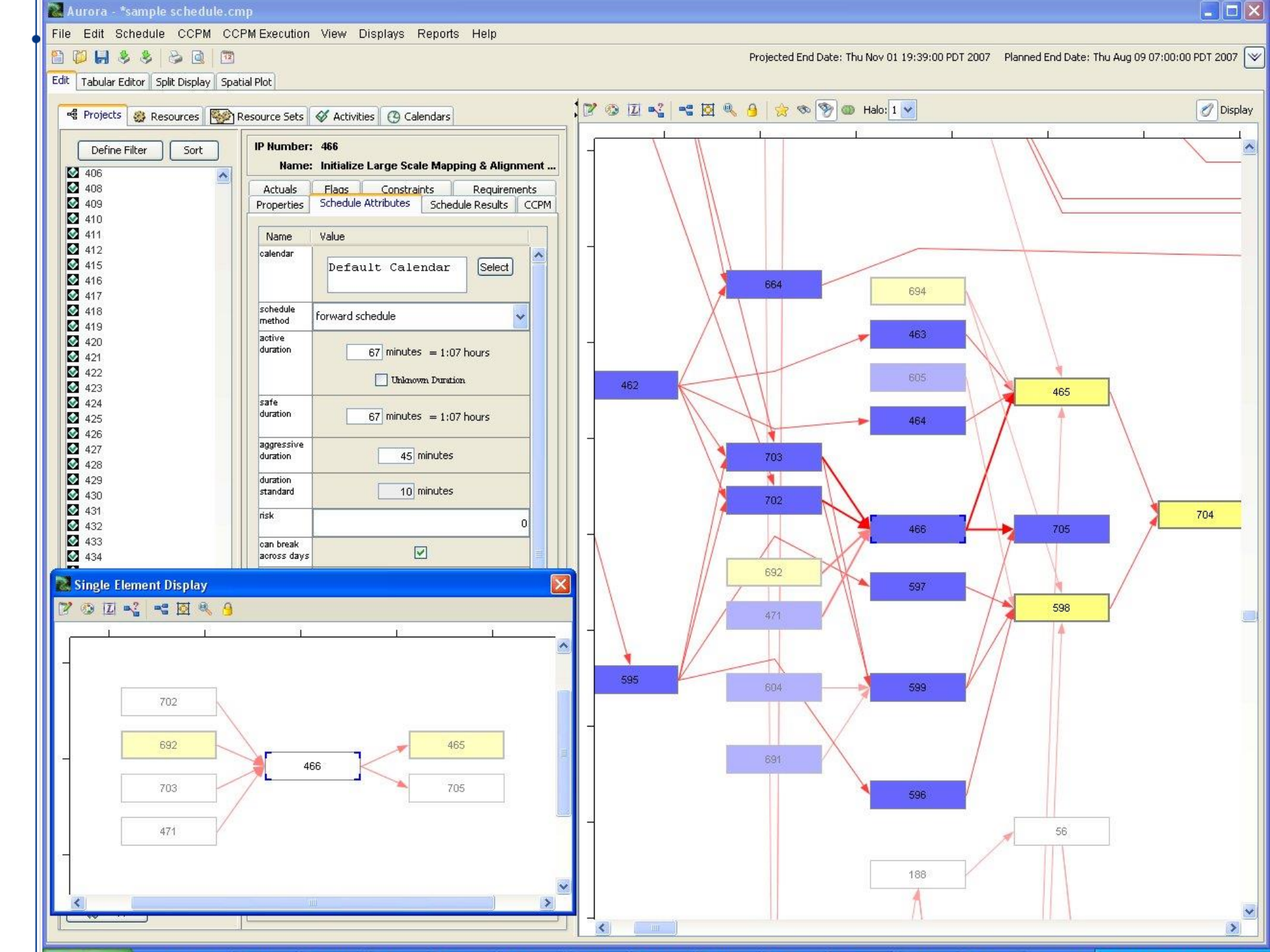
Aurora: Intelligent Scheduling / Critical Chain Project Management

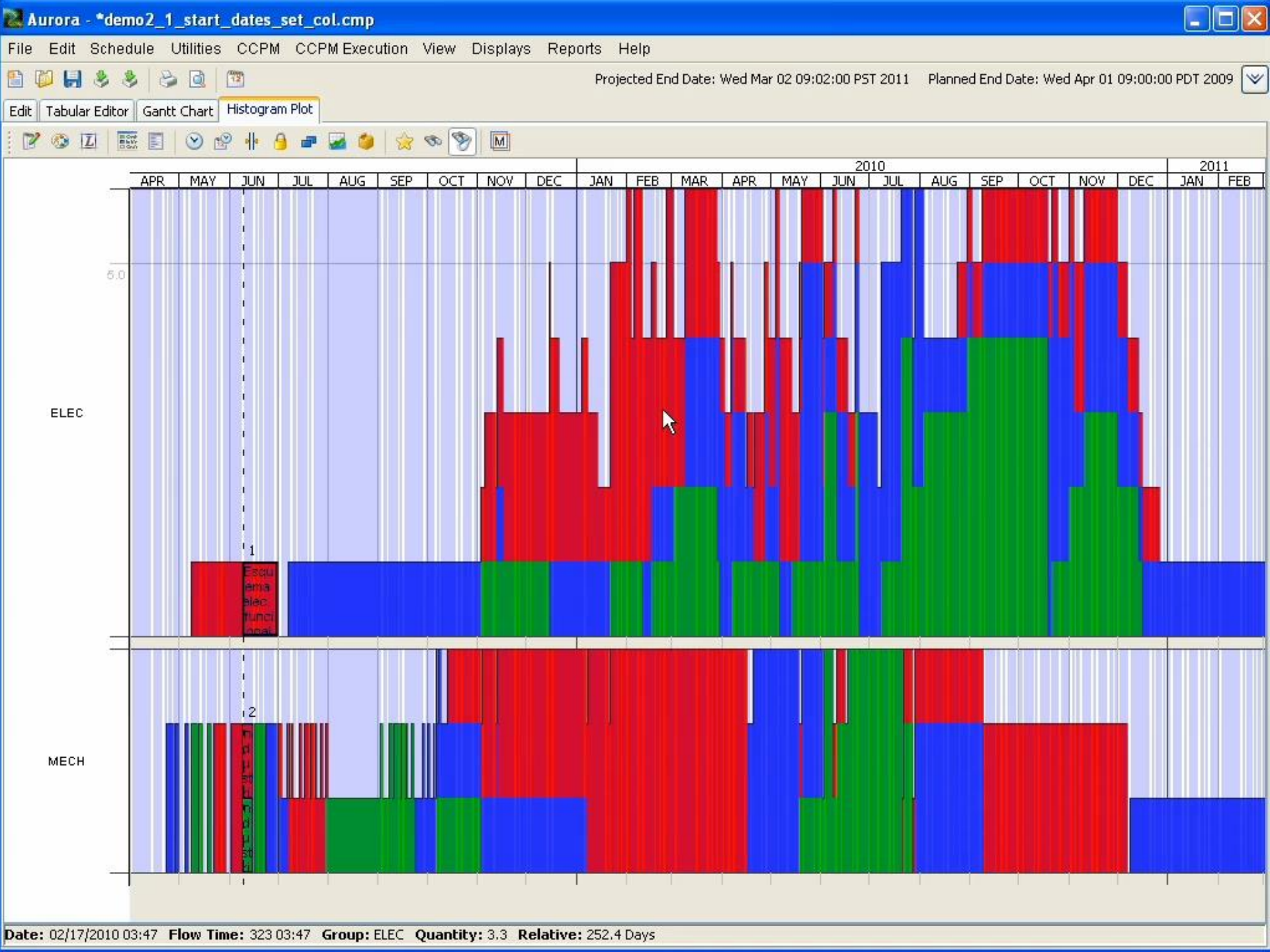


Stottler Henke
Smarter Software Solutions

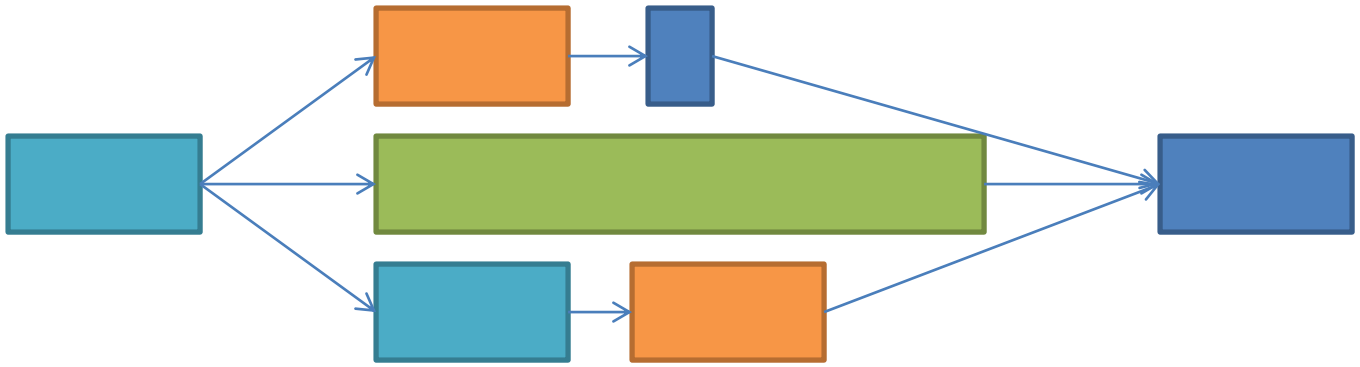

Aurora - *sample schedule.cmp
File Edit Schedule CCPM CCPM Execution View Displays Reports Help
Projected End Date: Thu Nov 01 19:39:00 PDT 2007 Planned End Date: Thu Aug 09 07:00:00 PDT 2007
Edit Tabular Editor Split Display
NOV 26 2007
NOV 27 2007
Combined
29 15:53 15:53
4584 15:53 15:53
3789 15:53 19:58
1478 15:53 08:31
4209 15:56 20:01
4239 16:08 20:13
1321 16:31 20:11
1135
16:32 14:26
2640 16:36 20:19
1322 16:37 20:17
1324 16:37 20:17
2542 16:39 20:28
2545 16:39 20:44
3226 16:43 20:42
2407 16:43 20:43
Edit Activity
IP Number: 1135
Name: Install the TE upper panel LH
CCPM Actuals Flags Constraints Requirements
Properties Schedule Attributes Schedule Results
Name Value
explanation
The end date was affected by Bond 2 diverter strips LH, which set it
The start date was affected by Install the TE lower aft panel LH, whi
The end date was affected by ForwardSchedule, based on the allow
early start date
DD MMM YYYY S HH MM +∞ -∞
29 OCT 2007 shift 1 0 00
start date
26 NOV 2007 shift 1 16 32
end date
27 NOV 2007 shift 1 14 26
late end date
19 JAN 2058 shift 1 3 14
flow start
DD HH MM
20 8 32
flow end
Close
30804WNG
1140
1125
1478
1473
1481
1135
690
Date: 11/27/2007 16:56 Flow Time: 30 16:56 Group: 30804WNG Quantity: 7.8 Relative: 23 Hours
start
12:37 PM


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
406 408 409 410 411 412 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 464 465 466
New Project New Instance
Add Activity Delete
Copy
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
can break across
shift end offset (minutes) minutes
interruptible minutes
compatible activities Select Clear
exclusivity Add Remove
early start date YYYY S HH MM
2007 shift 1 0 00
Halo: 1
Display
664 694 463 605 462 465 464 703 702 466 705 704 692 597 471 598 595 604 599 691 596 56 188


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

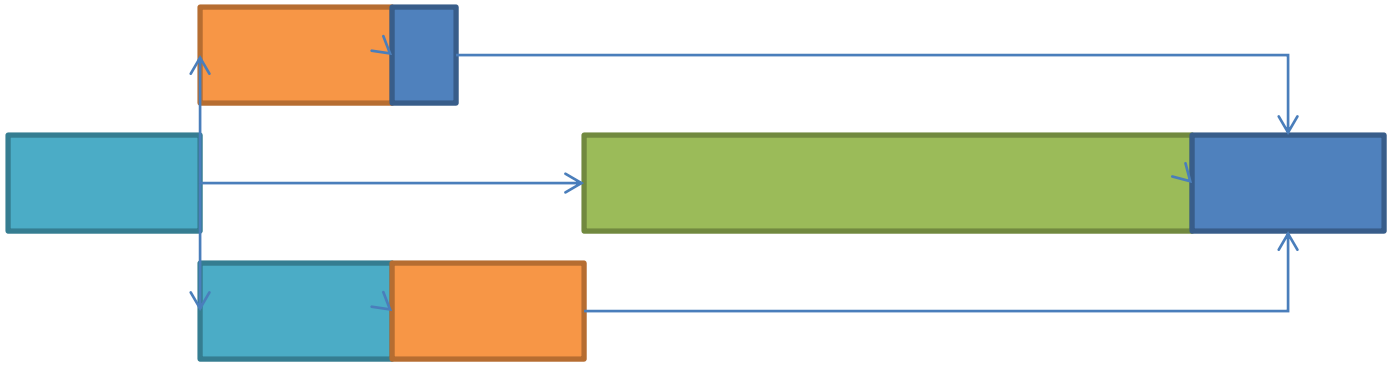

Aurora - *demo2_1_start_dates_set_col.cmp
File Edit Schedule Utilities CCPM CCPM Execution View Displays Reports Help
Projected End Date: Wed Mar 02 09:02:00 PST 2011
Planned End Date: Wed Apr 01 09:00:00 PDT 2009
Edit
Tabular Editor
Gantt Chart
Histogram Plot
2010
2011
APR MAY JUN JUL AUG SEP OCT NOV 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

Critical Chain – Example 3



Requires resource 1 Requires resource 2 Requires resource 1 and 2

As scheduled:

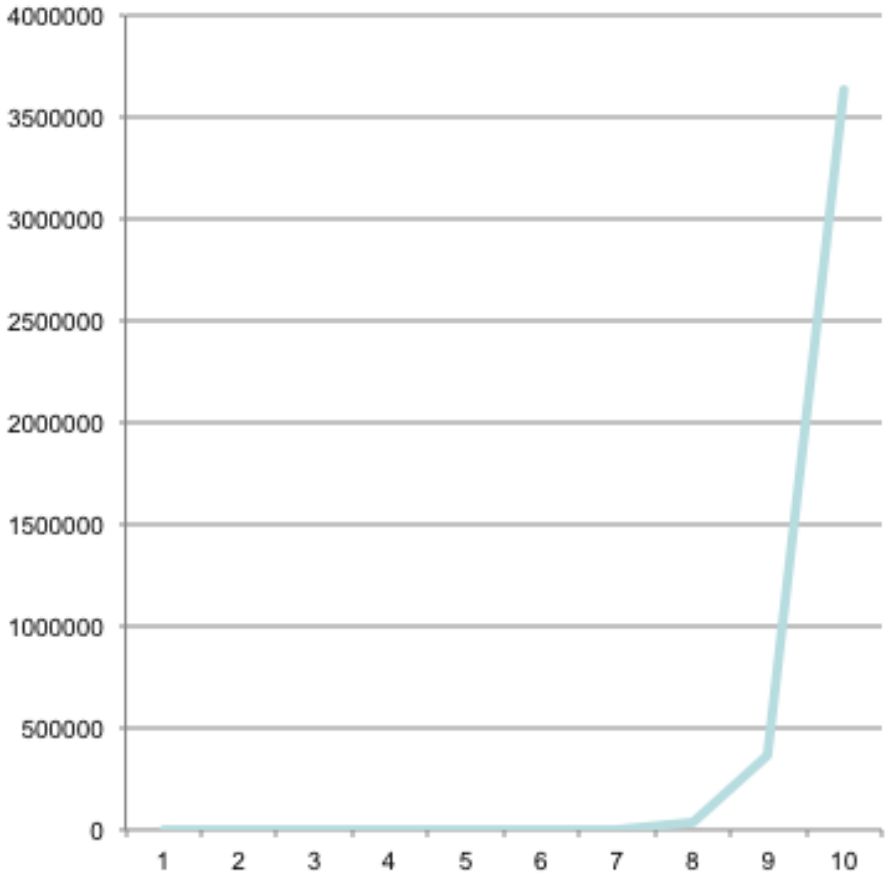


Critical chain:

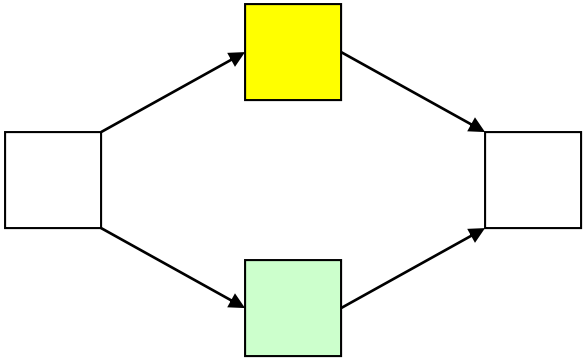
Why can’t you search for the best order?

- Ordering options scale as N!

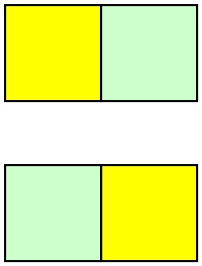
1	1
2	2
3	6
4	24
5	120
6	720
7	5040
8	40320
9	362880
10	3628800



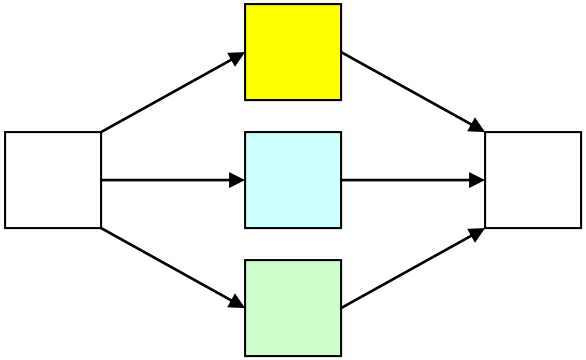
Two tasks that can occur in either order (one at a time)



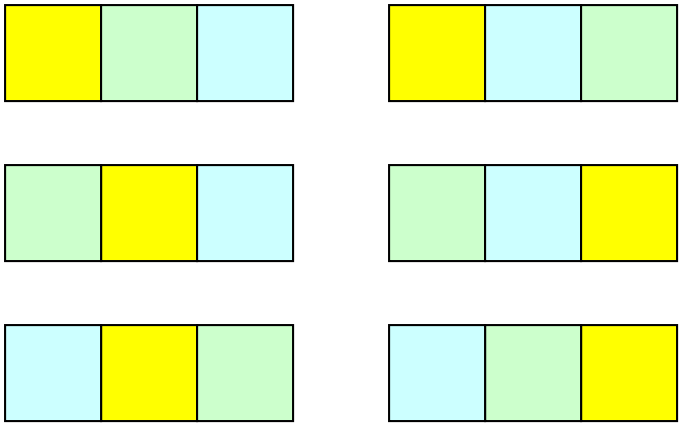
results in two options



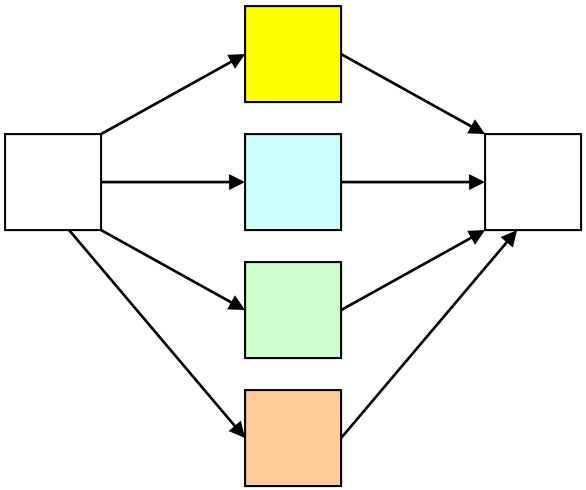
Three tasks that can occur in any order (one at a time)



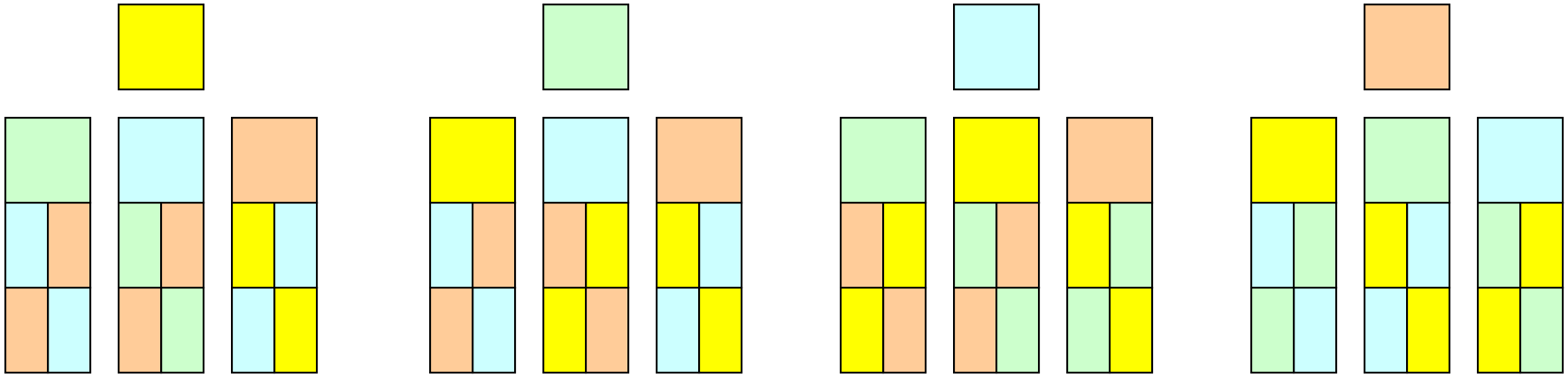
results in six options



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



results in twenty-four options



Why Intelligent Scheduling?

Resource-loaded scheduling is difficult

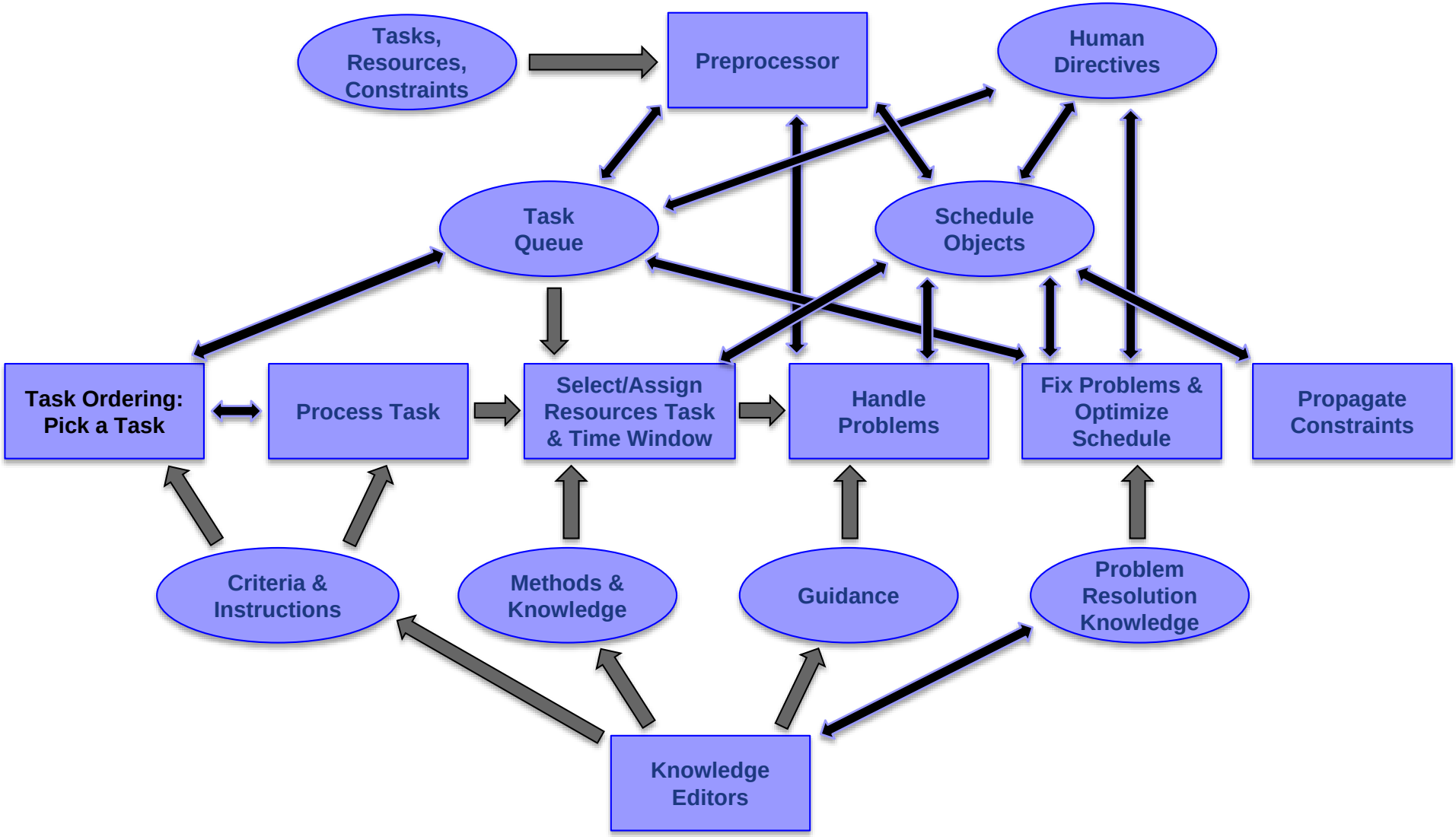
- Whole field of Operations Research

Not leveraged in the Project Management domains that Primavera serves

Usually demand is generated from knowledgeable users

Not promoted by solution providers

Aurora Architecture



Benefits of Sophisticated Underlying 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).

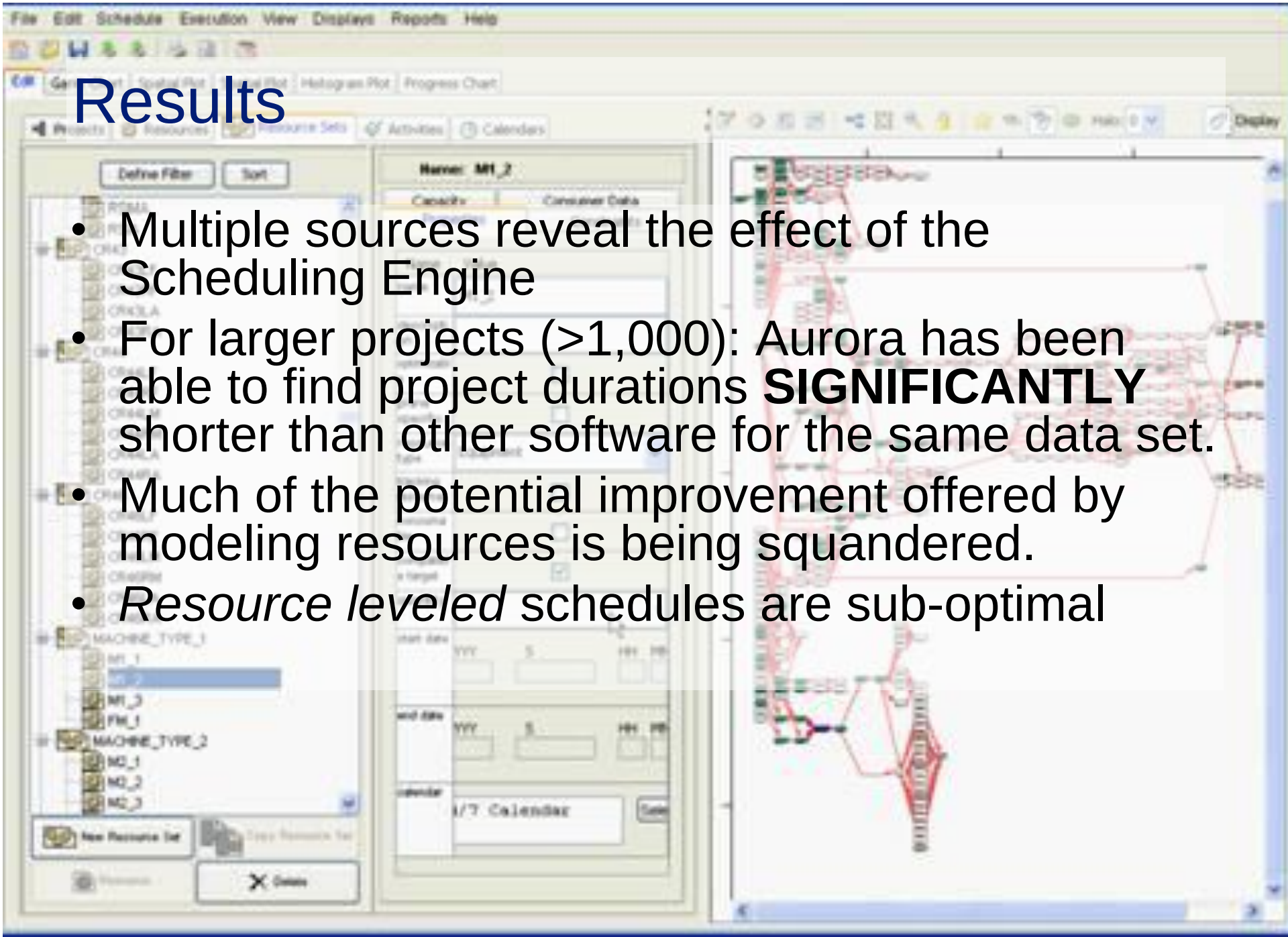
Scheduling is Fast

- 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

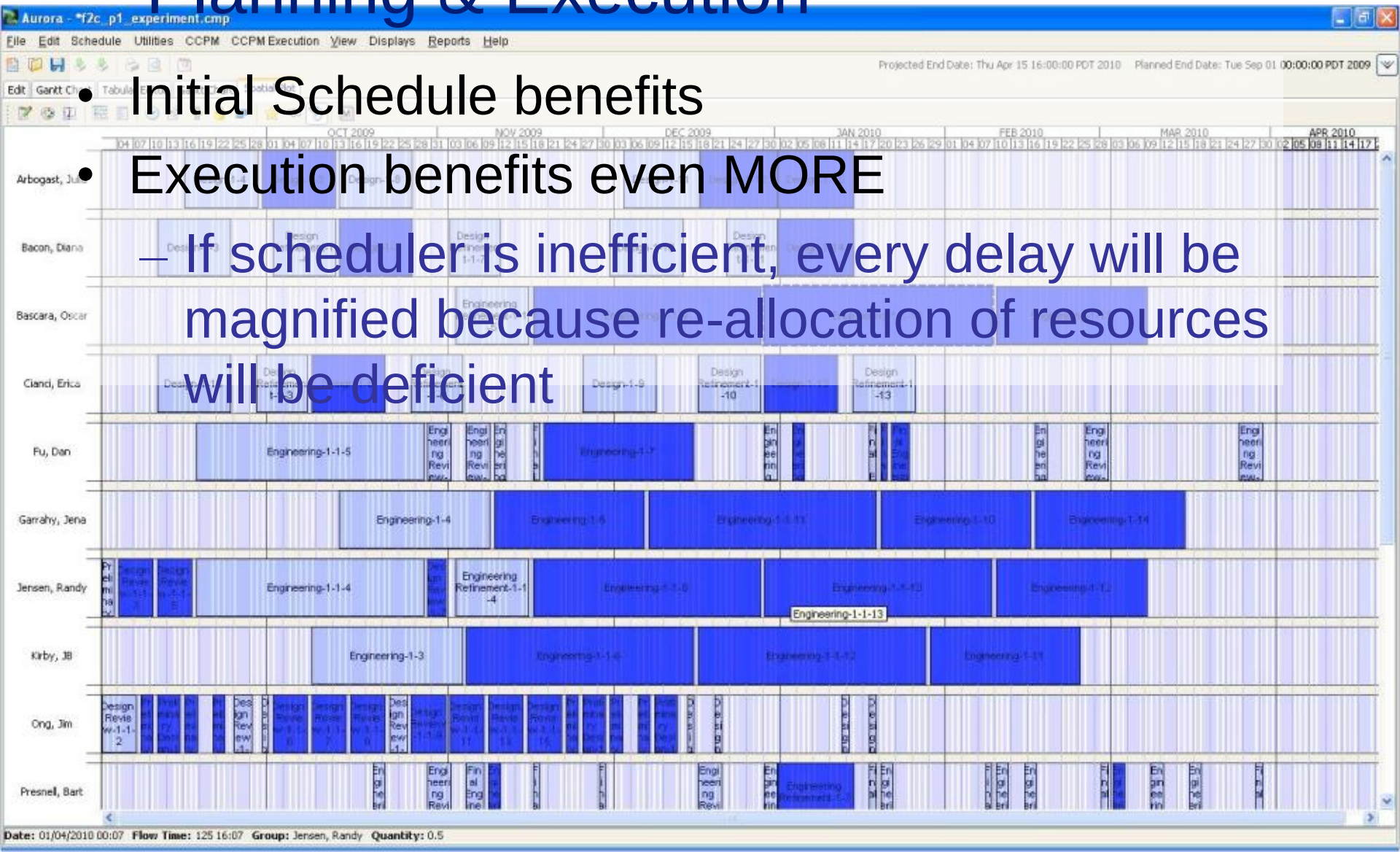
Results

- 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



Planning & Execution

- Initial Schedule benefits
- Execution benefits even MORE
  - If scheduler is inefficient, every delay will be magnified because re-allocation of resources will be deficient



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

Critical Resources

- Initial schedule usually has different critical resources via different schedulers
- Execution mode updates will also usually have different critical resources
  - Picking less than optimal resources if resource increases are used to make up slippage.
- Better to find more efficient schedule with intelligent scheduling, then increase critical resources if necessary.

Analogy: Chess

- Chess mathematically is similar to resource loaded scheduling.
  - Easy: Create basic rules to play
  - Hard: Win against other intelligent players
- Resource Leveling in most software is analogous to 'Easy' chess solution
- Each move analogous to execution mode update, challenge continues throughout game/execution of schedule