

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

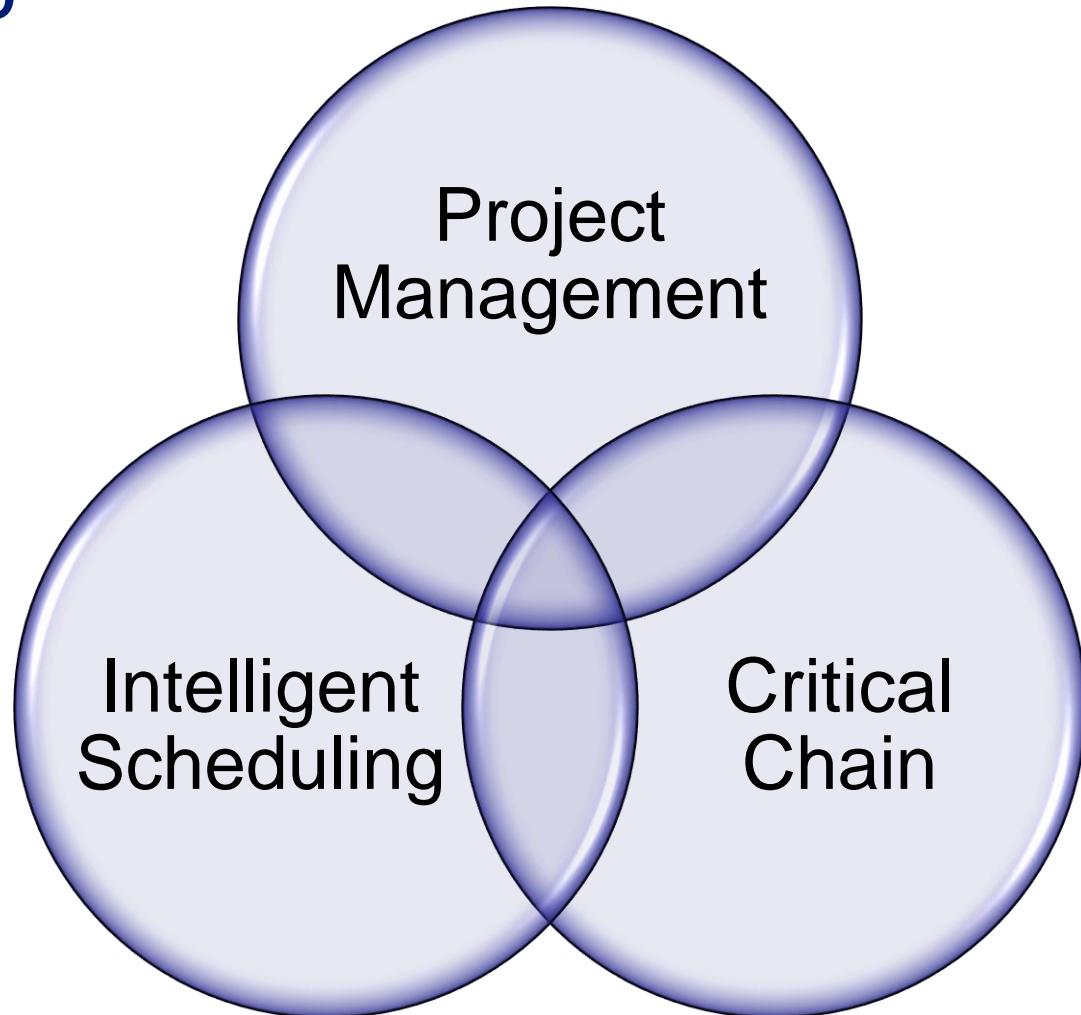
Rob Richards, Ph.D.
April 20, 2016

Stottler Henke
Smarter Software Solutions

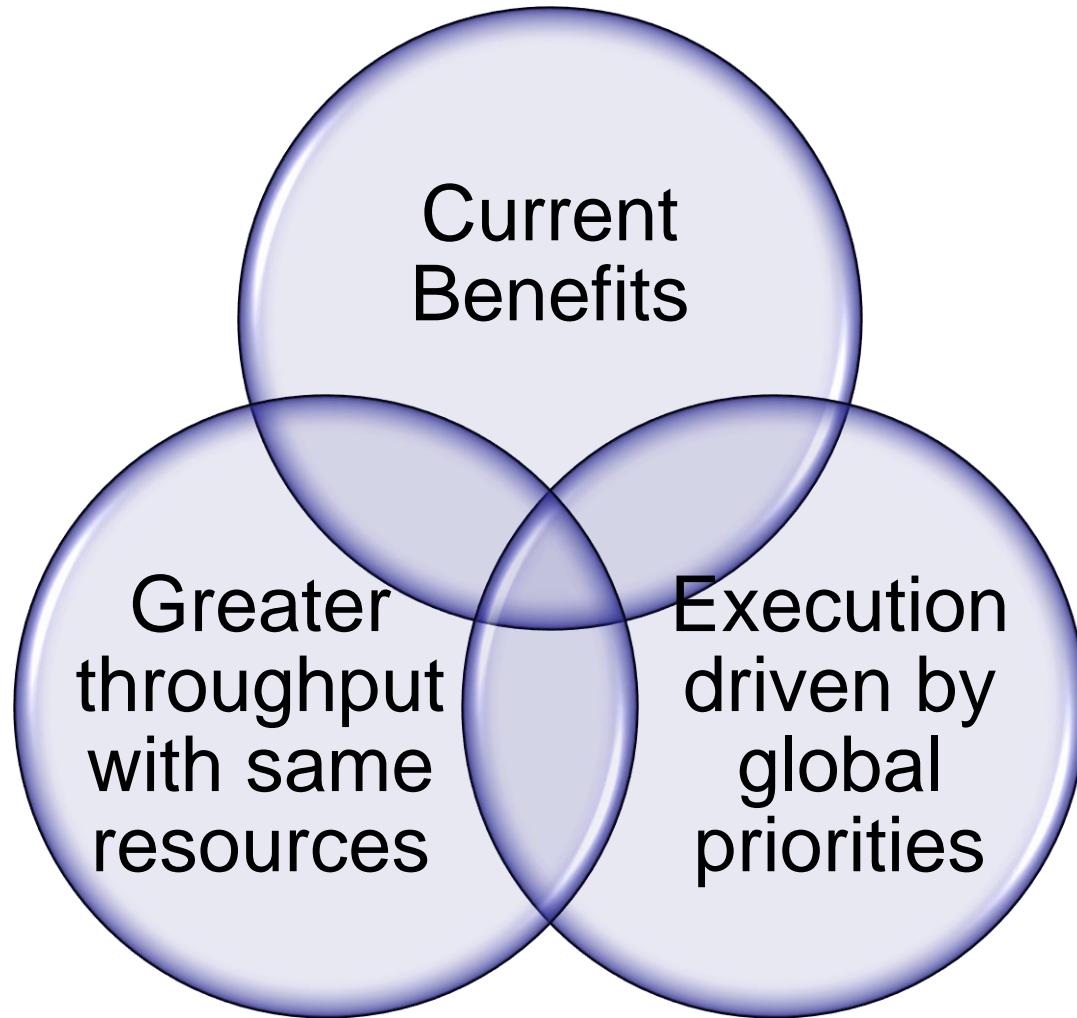
Planning, Production Processes &
Facilities Panel (PPP&F) Meeting
19-20 April, 2016
Portland, Oregon

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Enhancements to Traditional Project Management



Benefits



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

Primavera P6

Artemis

PS8 (by Sciforma)

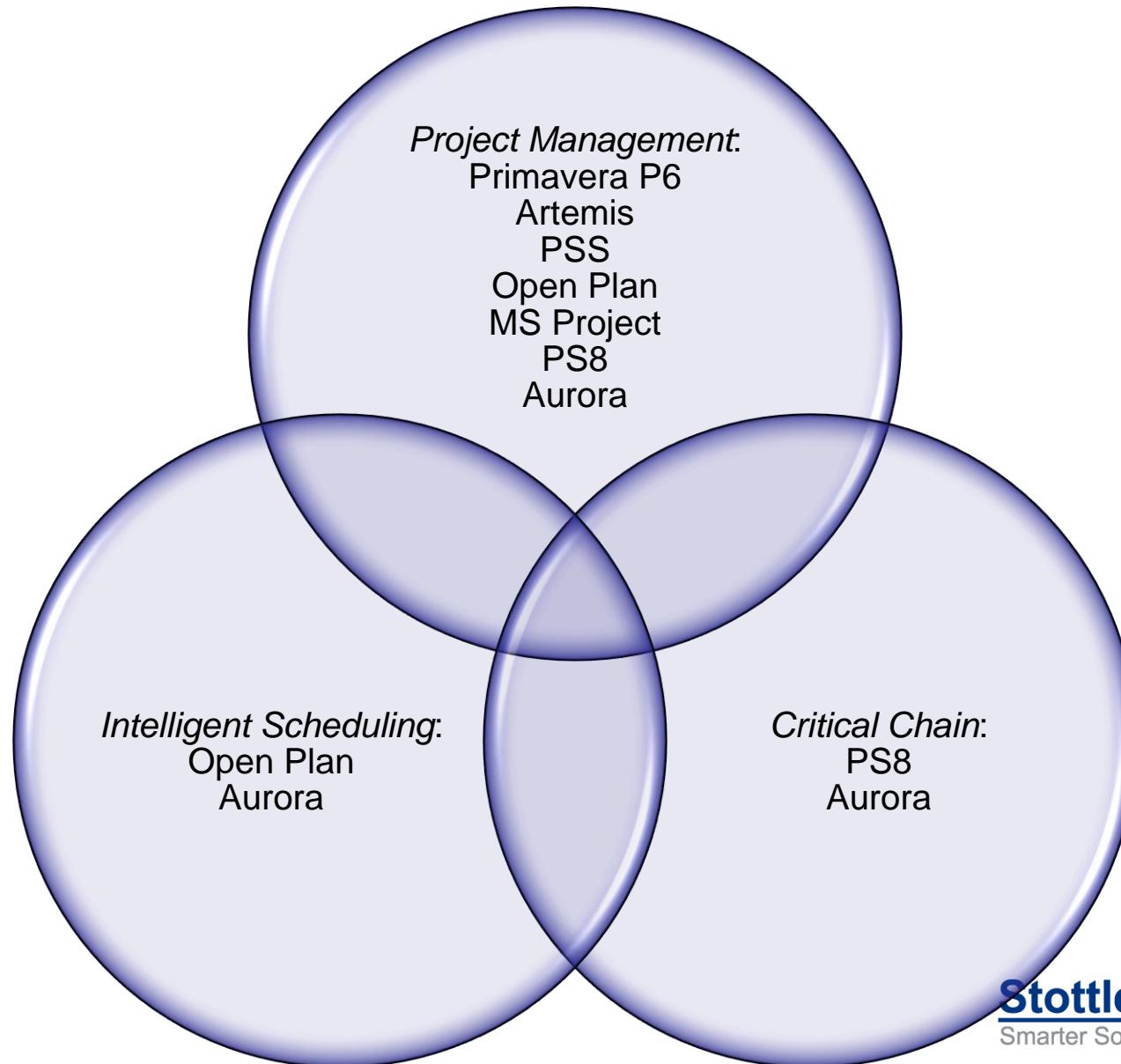
Open Plan (by Deltek)

Microsoft Project

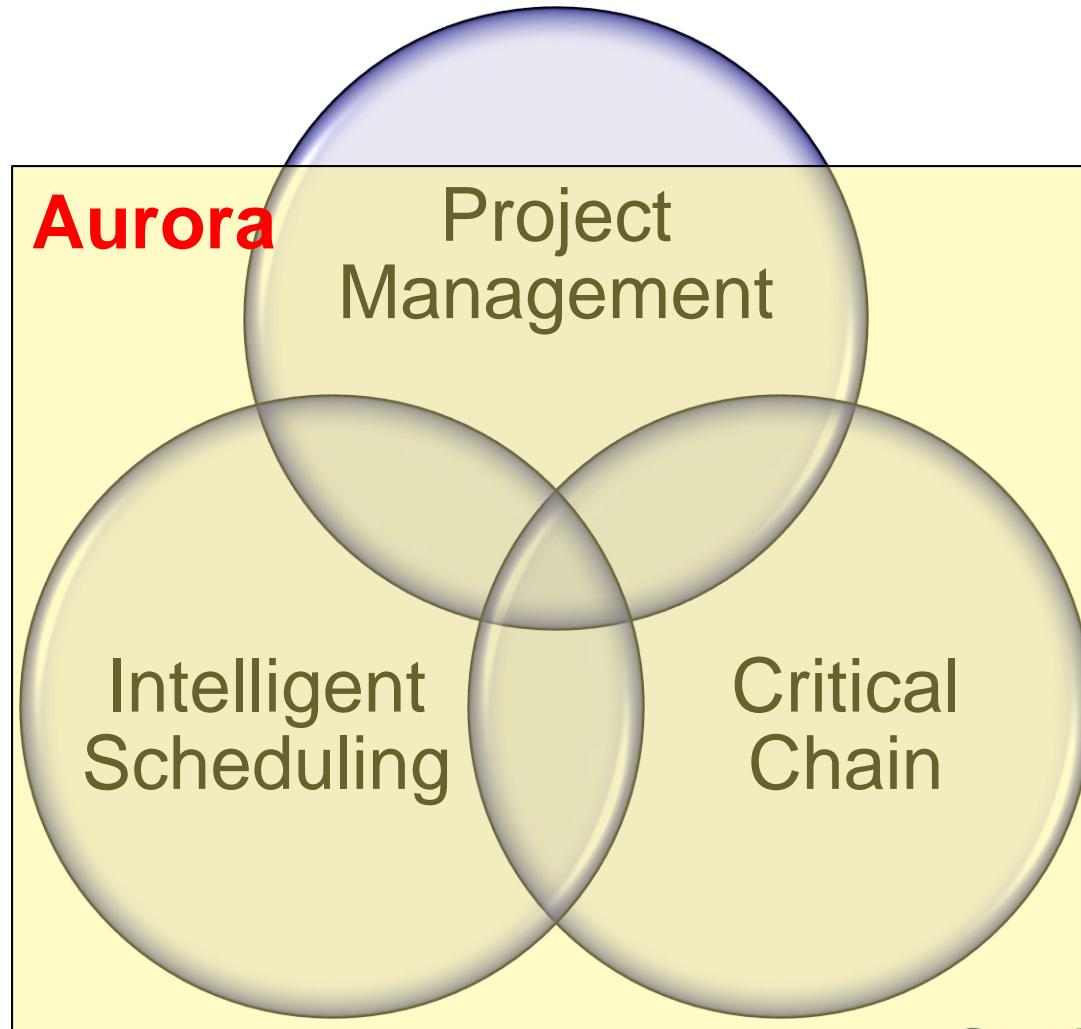
PSS

Databases / Non-traditional PM tools: e.g. SQL Server

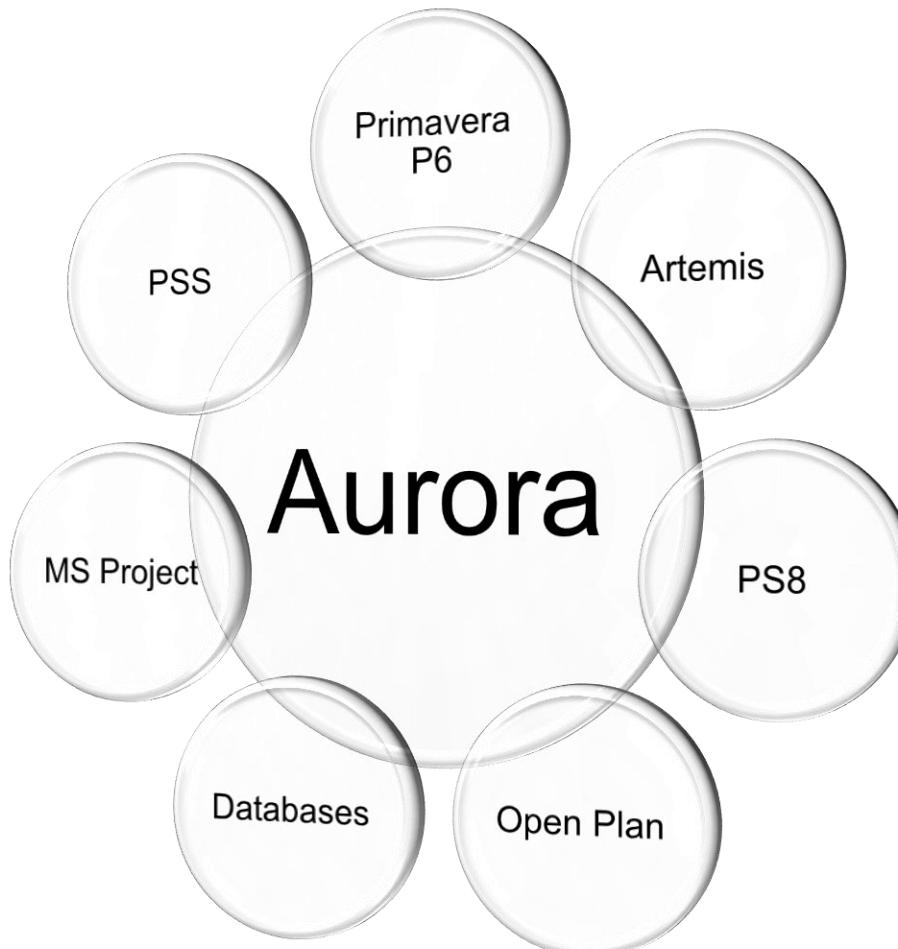
Navy & Contractor Tools



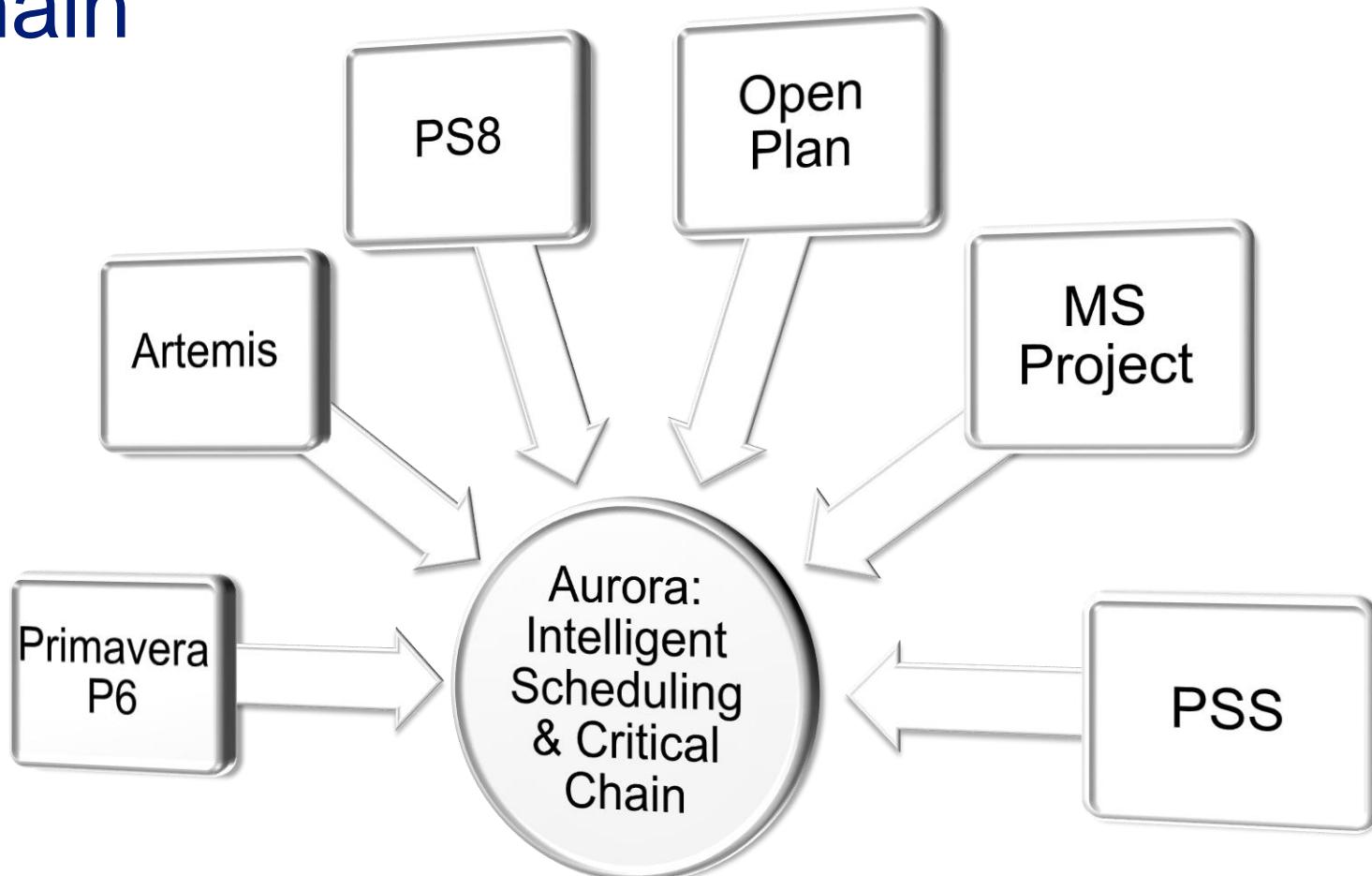
Aurora Functionality



Interfaces: Aurora can interface with all others



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

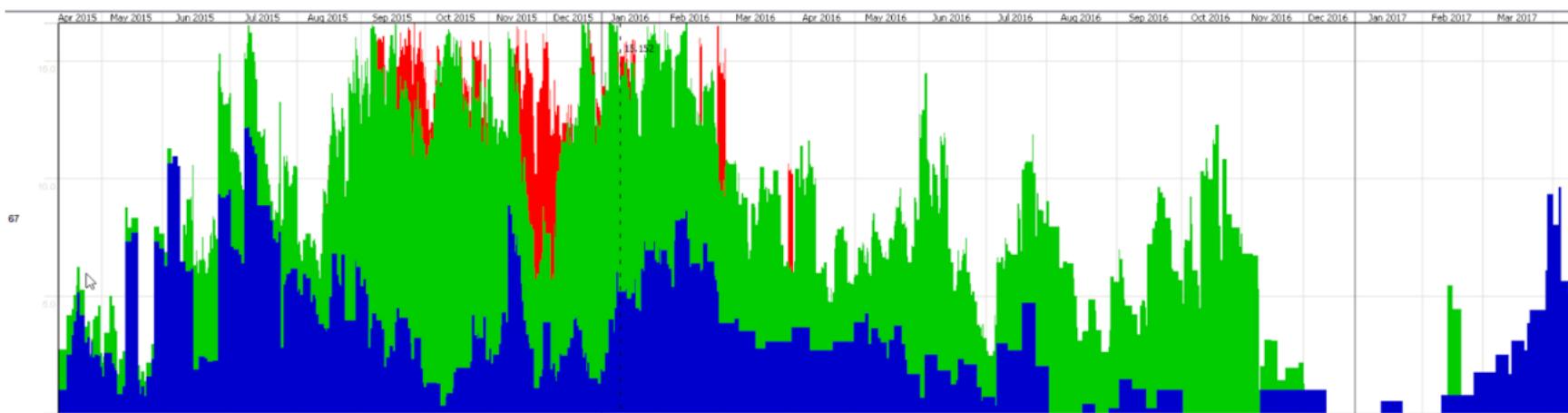


PSS Case Study (1)

- 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



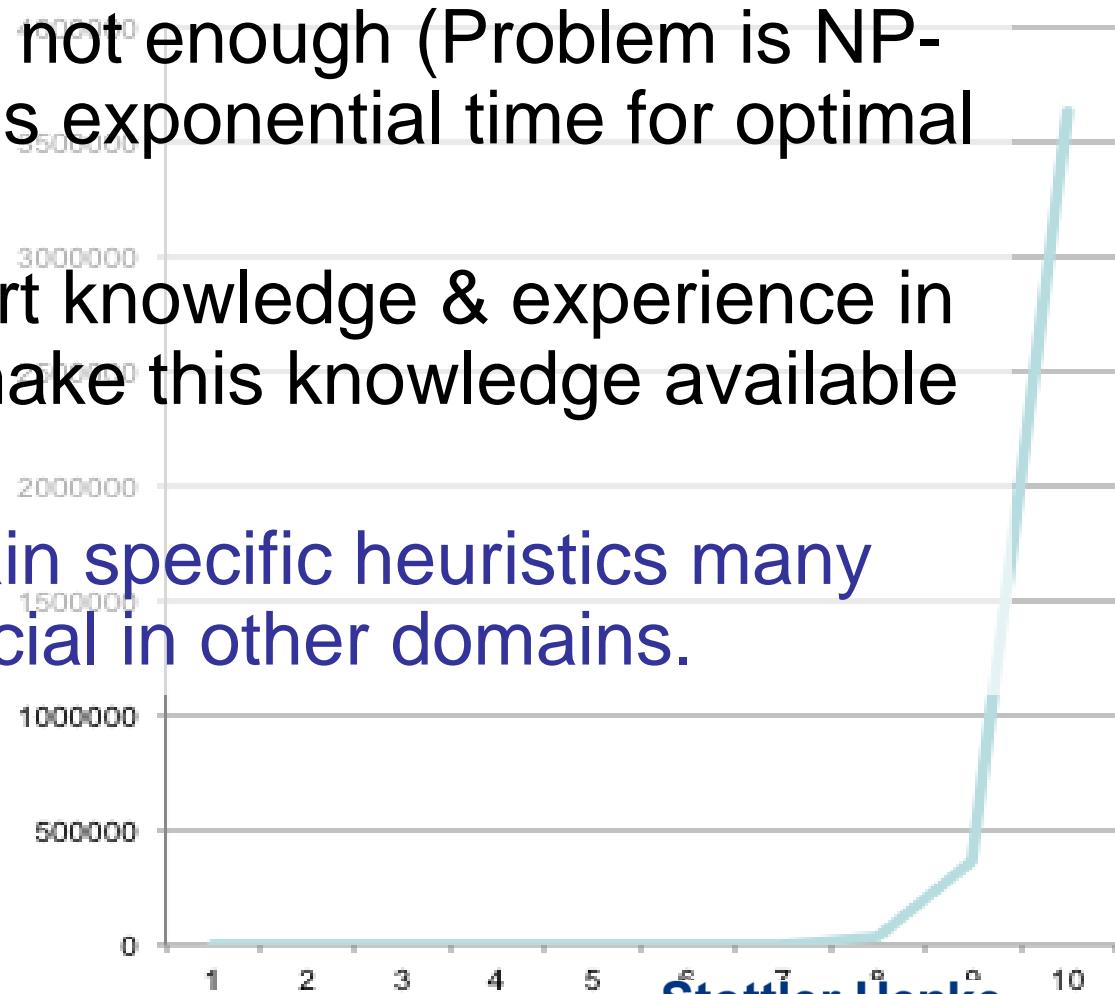
Projects Completed by

- **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



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 scheduled where it was scheduled
- 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](#)

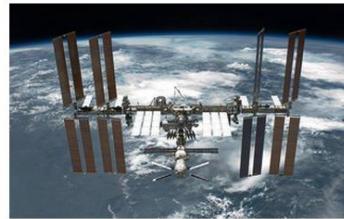
Mitsubishi Heavy Industries



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](#)

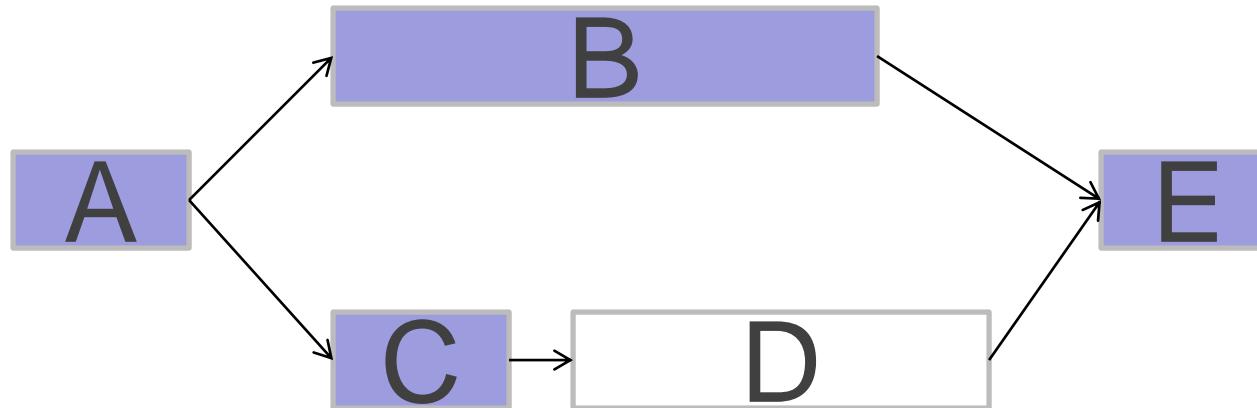
Value Proposition: Aurora

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

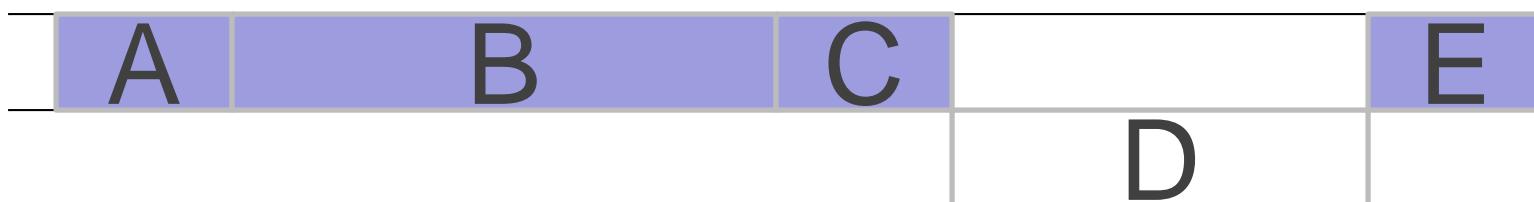
- That is, once the resource-loaded project model is developed, using Aurora will determine a shorter initial schedule, and then by using Aurora during the execution of the project Aurora will make more efficient decisions based on the reality on the ground so the execution results in a shorter project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

Why order matters?

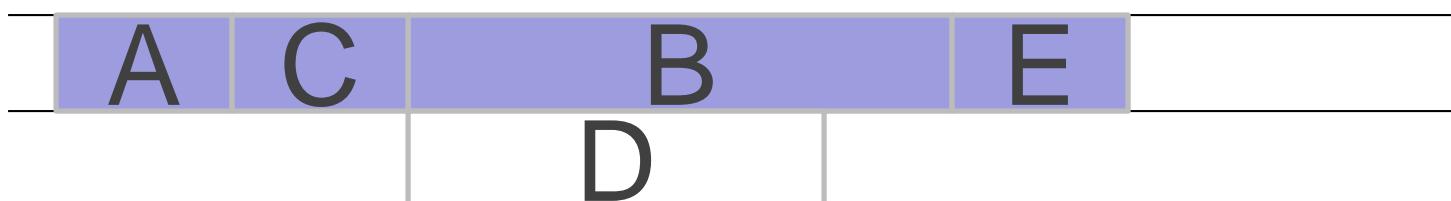
The example below involves jobs using two resources, purple and white



Schedule 1: B before C



Schedule 2: C before B



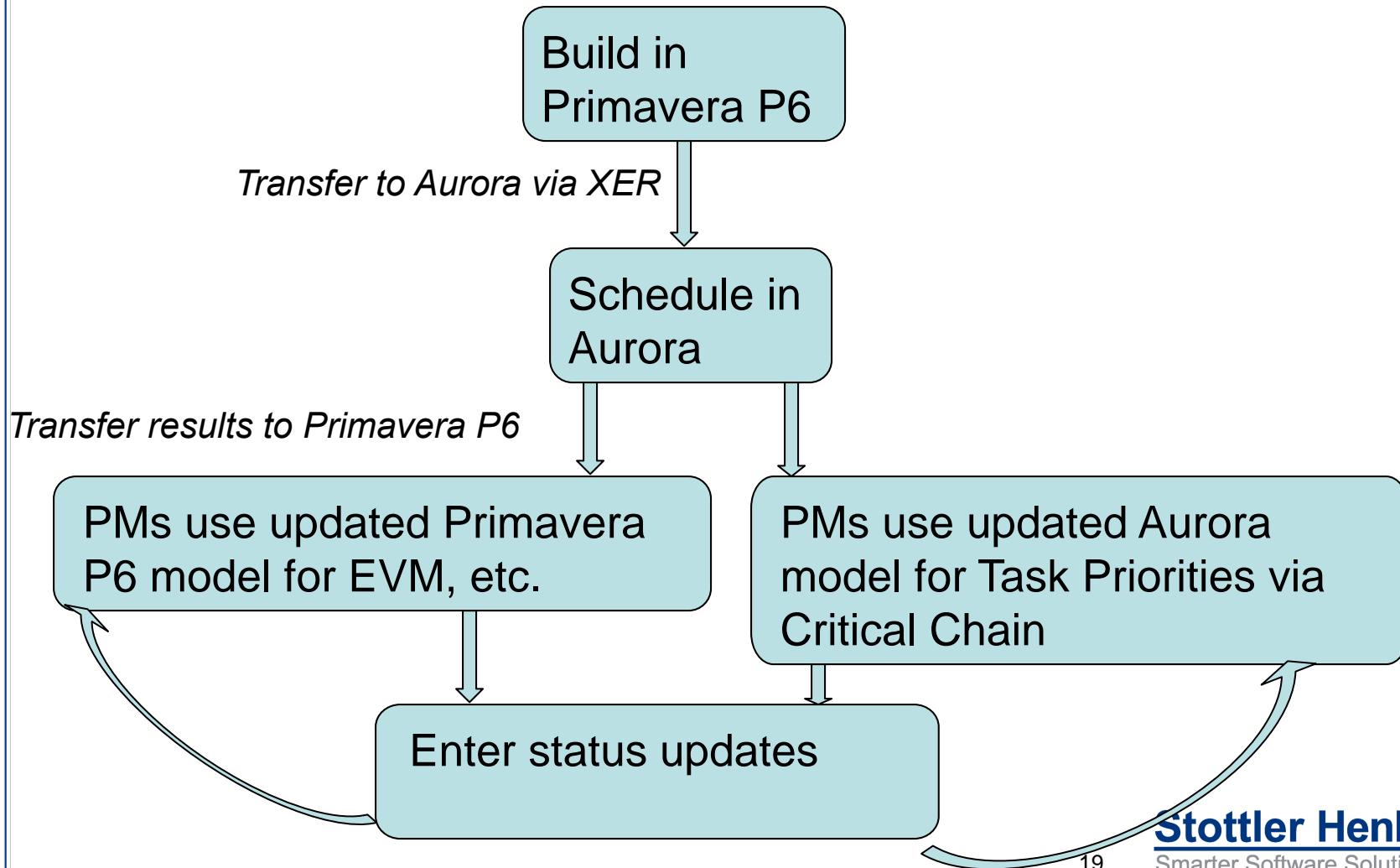
Aurora-CCPM Summary

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 scheduled 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

Aurora - *f2c_p1_experiment.cmp

File Edit Schedule Utilities CCPM CCPM Execution View Displays Reports Help

Projected End Date: Thu Apr 15 16:00:00 PDT 2010 Planned End Date: Tue Sep 01 00:00:00 PDT 2009

Edit Gantt Chart Tabular Editor Gantt Chart Spatial Plot

Projects Resources Resource Sets Activities Calendars

Define Filter Sort

IP Number: Engineering-1-9
Name: Engineering-1-9

Actuals Requirements Constraints CCPM Flags

Properties Schedule Results Schedule Attributes

Name Value

explanation	cted by Design Refinement-1-9 , which set it to 2009:12:24:16:00. Restricted by ForwardSchedule, restricted by availability of Zin, Anthony . Restricted by ForwardSchedule, based on duration and start time, which is restricted by ForwardSchedule, based on the active work calendar, which is restricted by ForwardSchedule.		
early start date	09/01/2009 00:00		
start date	01/18/2010 08:00		
end date	02/12/2010 16:00		
late end date	+ infinity		
flow start	140 08:00		
flow end	165 16:00		
resource assignments	Theroff, David		
critical path element	<input checked="" type="checkbox"/>		
restricting resource	Zin, Anthony		
start time drivers	Engineering Refinement-1-8	Select	Clear
end time drivers		Select	Clear
baseline start date			
baseline end date			

New Project New Instance Add Job Delete Copy

Flowchart Diagram:

```
graph LR; A[Preliminary Design-1-9] --> B[Design-1-9]; B --> C[Design Review-1-9]; C --> D[Design Refinement-1-9]; D --> E[Engineering-1-9];
```

Engineering-1-9

Schedule Results: Explanation

Name: Post-Operations for Hyper Servicing	
Property Search: <input type="text"/>	
Properties Details Geometry Duration Info Schedule Attributes Schedule Results CCPM Analysis Actuals Integrations Flags Constraints Requirements	
scheduled order	42
explanation	<p>The end date was affected by the maximum flow time of 7300.00 days, which set it to 12/27/2033 00:00</p> <p>The start date was affected by Hyperqol Servicing for Booster Aft Skirt(s), which set it to 01/03/2014 00:00</p> <p>The end date was affected by Establish Hazardous Control Area for Ordnance Ops, which set it to 12/25/2033 10:49</p> <p>The start date was affected by Hyperqol Servicing for Booster Aft Skirt(s), which set it to 01/04/2014 22:00</p> <p>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 00:00</p> <p>The end date was affected by ForwardSchedule, based on duration and start time, which set it to 01/05/2014 15:00</p>

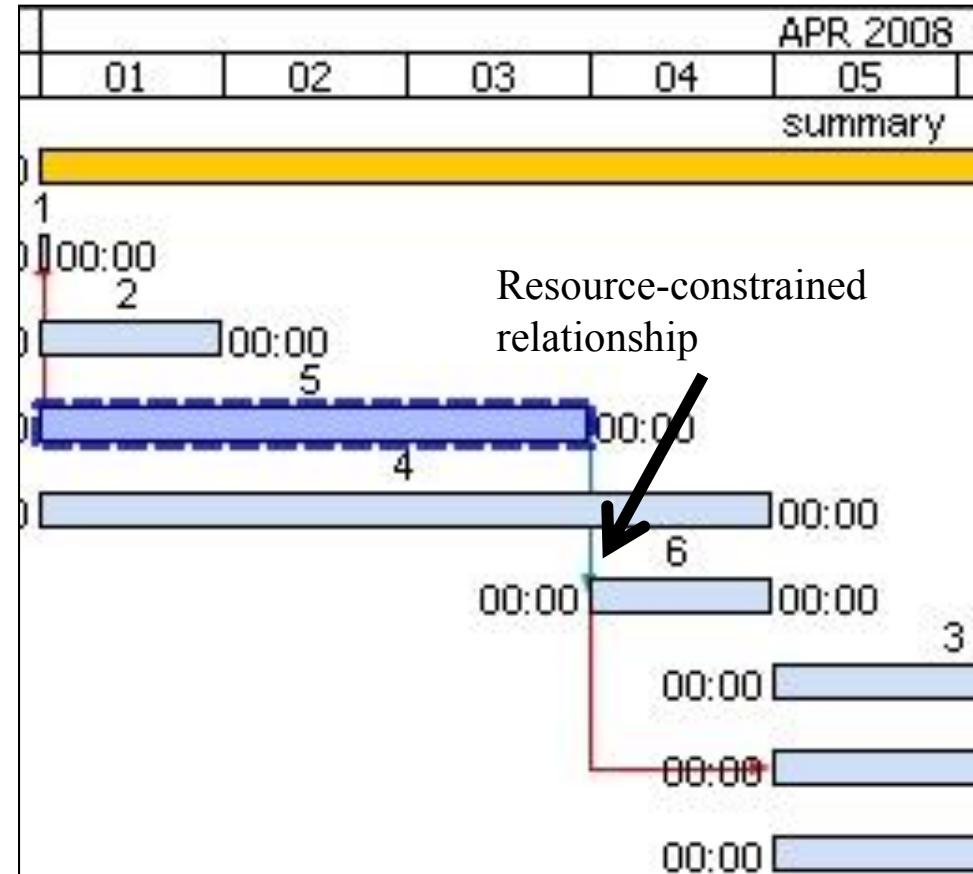
Resource Contention: Visual

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.

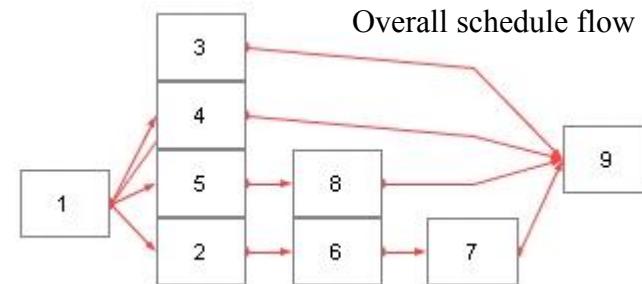
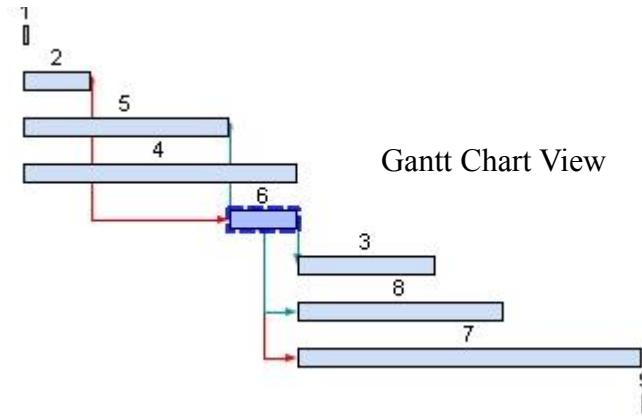
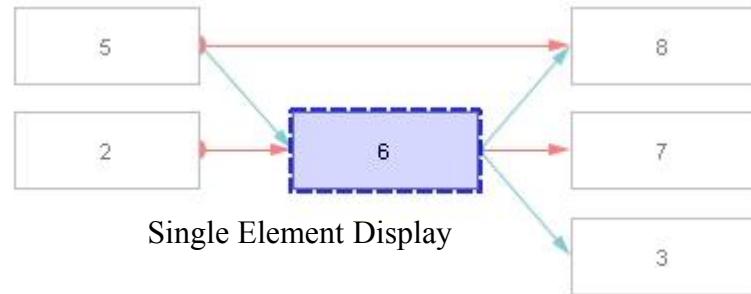
Resource Contention: Task 6

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

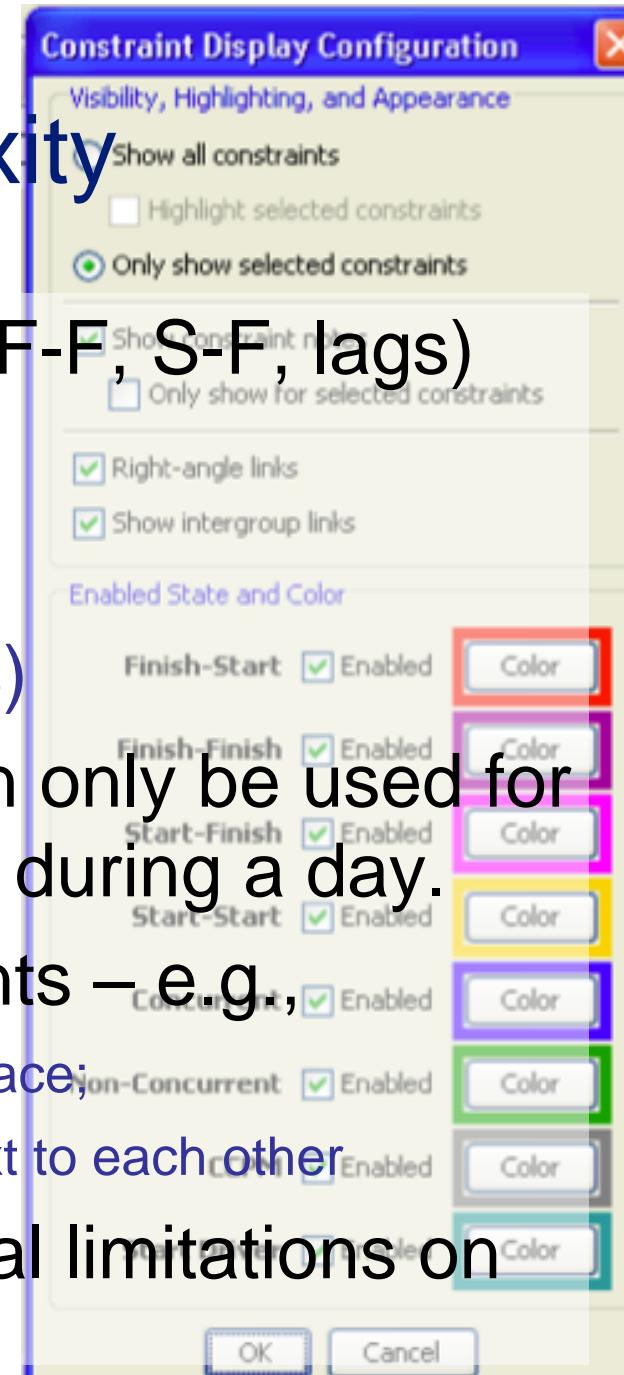
Referring to the three diagrams to the right:

- 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)



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

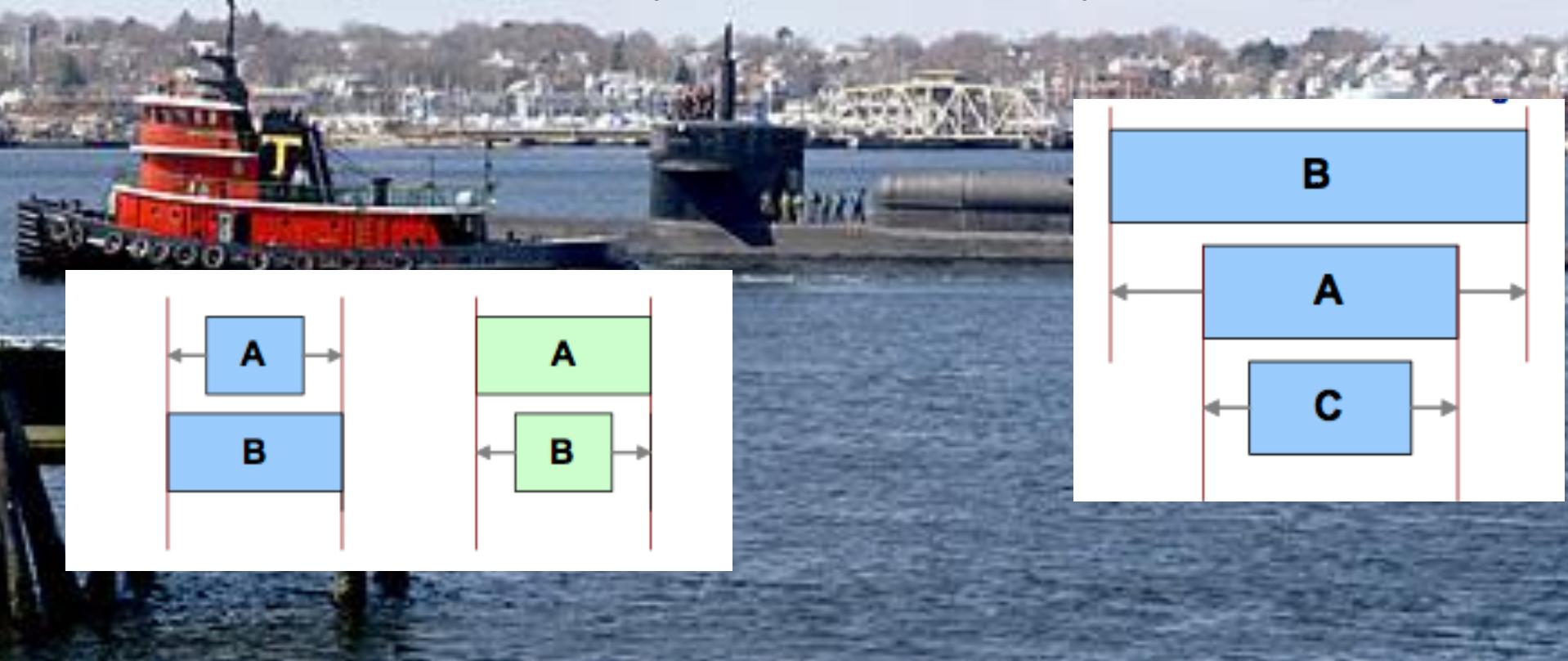
- Aurora is used at Naval Submarine Support Facility (NSSF) at the Naval Submarine Base New London
- Interfaces with Microsoft SQL Server

NSSF: Submarine Maintenance

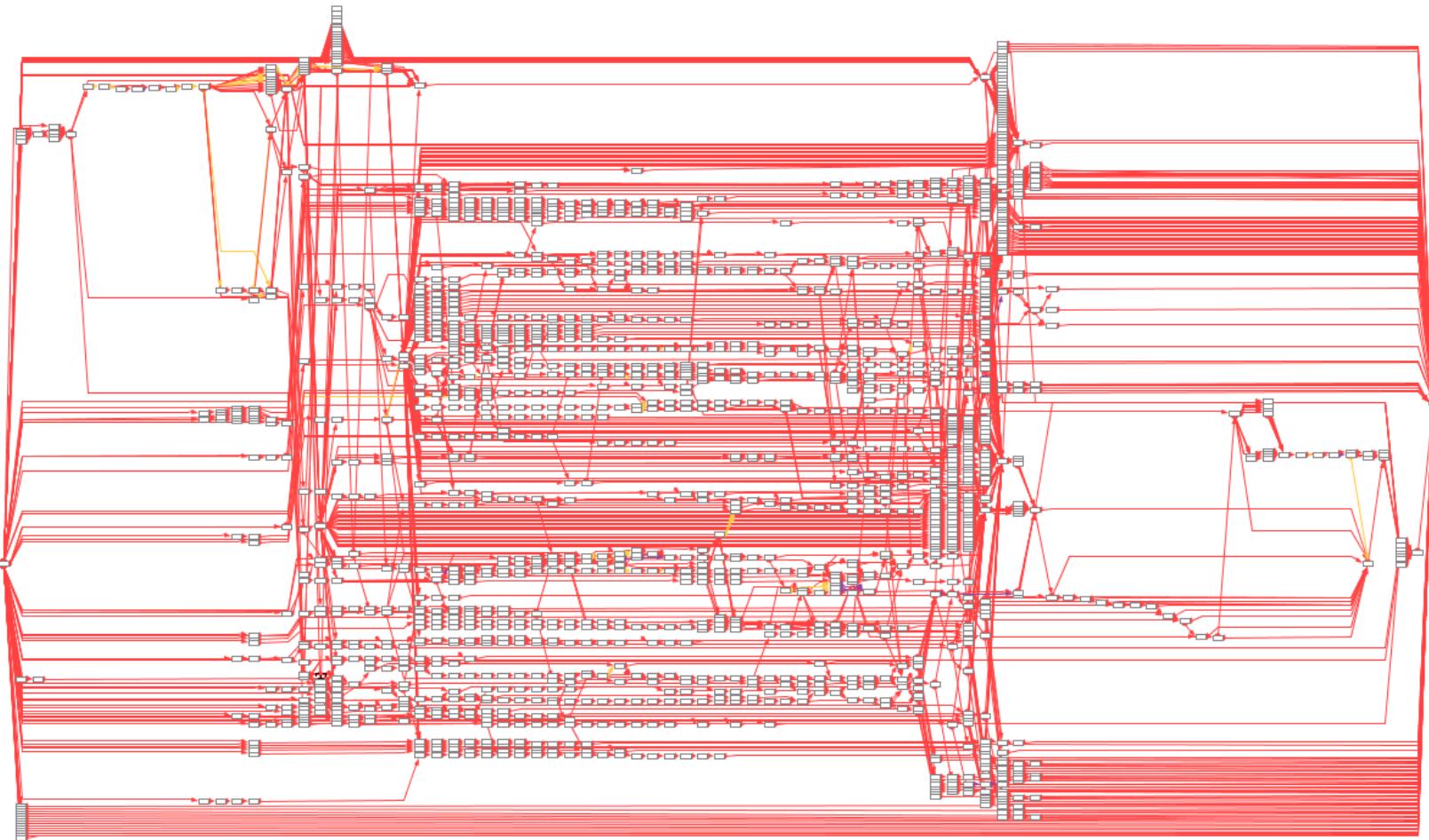
- Each dock is different
- Different work rules if another submarine on other side of pier
- Each crane is different & there is a waterborne crane
- Multiple occupations with skills/certifications
 - Task may require occupations with skills/certs
 - Skill/certs combination needed per task may be by worker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

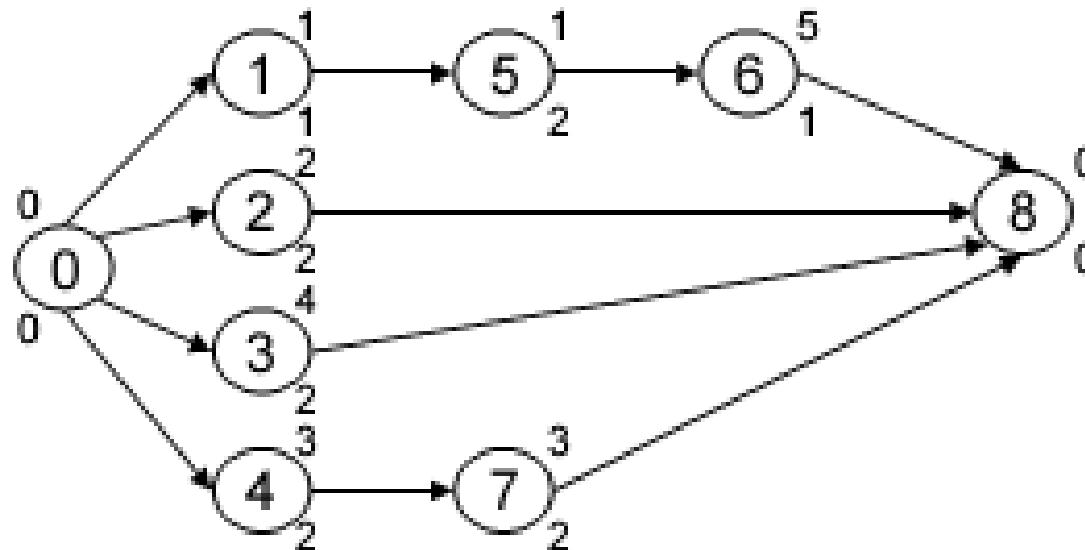


Results: 2,500+ Turnaround

- 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%**

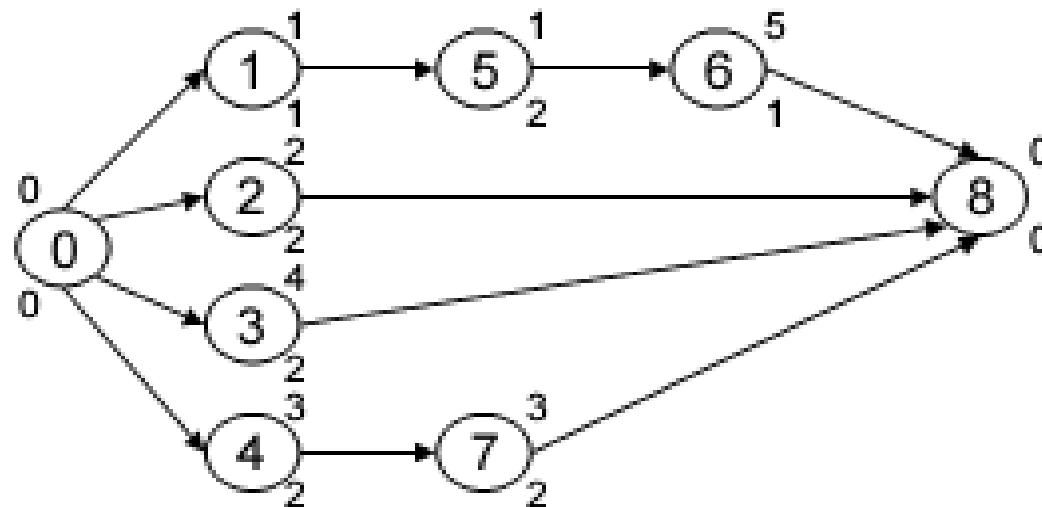
Maybe Only for ‘Big’ Problems?

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



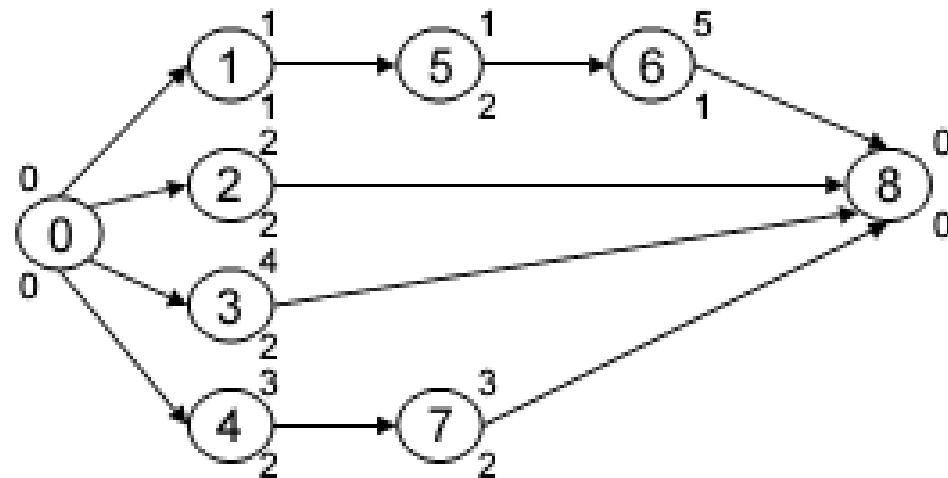
‘Simple’ Network details

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



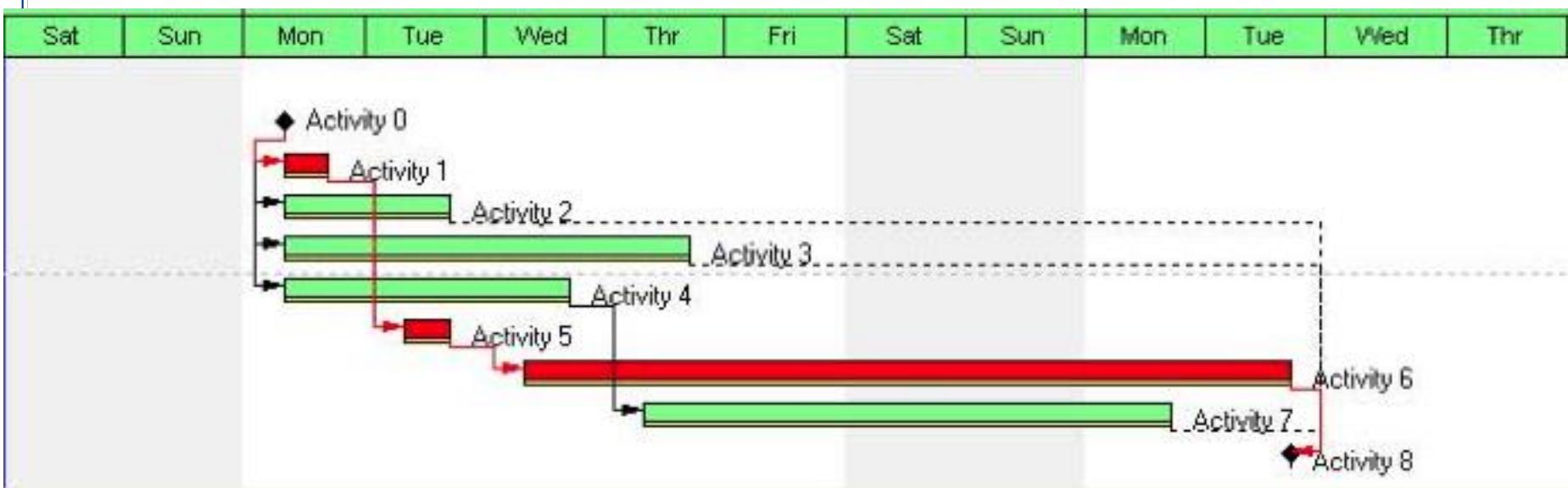
Critical Path of Network

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



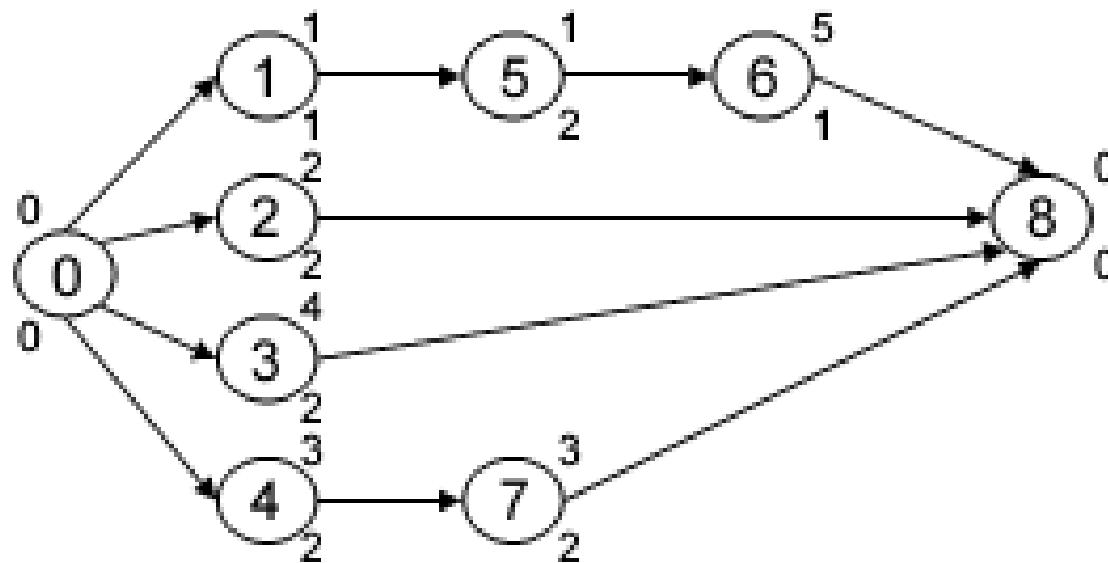
Gantt Chart of Critical Path

- Note: Sat/Sun are not workdays



Set Resource Pool to 5

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



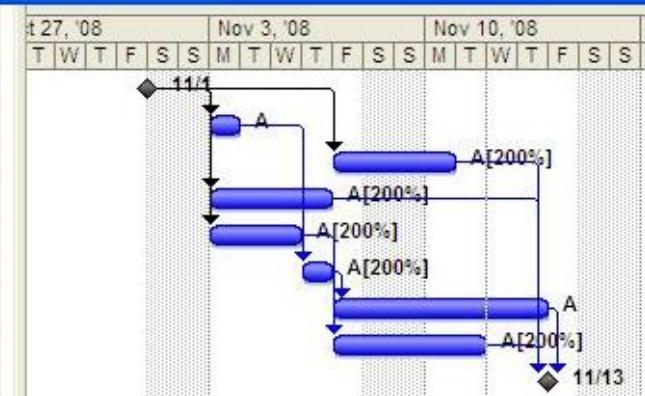
Gantt Chart Showing the Critical Path & Histogram

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

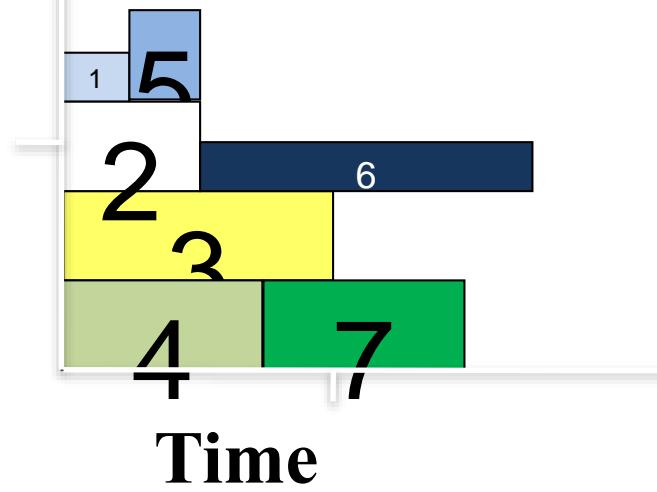


Resource-Leveled in MS Project = 9 days

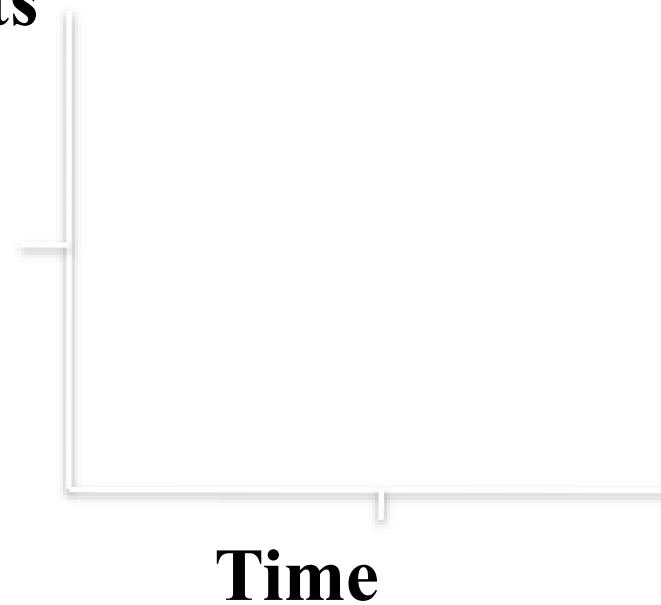
		Task Name	Duration	Start	Finish	Predecessors	Resource Names
1		T0	0 hrs	Sat 11/1/08 12:00 AM	Sat 11/1/08 12:00 AM		
2		T1	8 hrs	Mon 11/3/08 8:00 AM	Mon 11/3/08 5:00 PM	1	A
3		T2	16 hrs	Fri 11/7/08 8:00 AM	Mon 11/10/08 5:00 PM	1	A[200%]
4		T3	32 hrs	Mon 11/3/08 8:00 AM	Thu 11/6/08 5:00 PM	1	A[200%]
5		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	



Resource Units

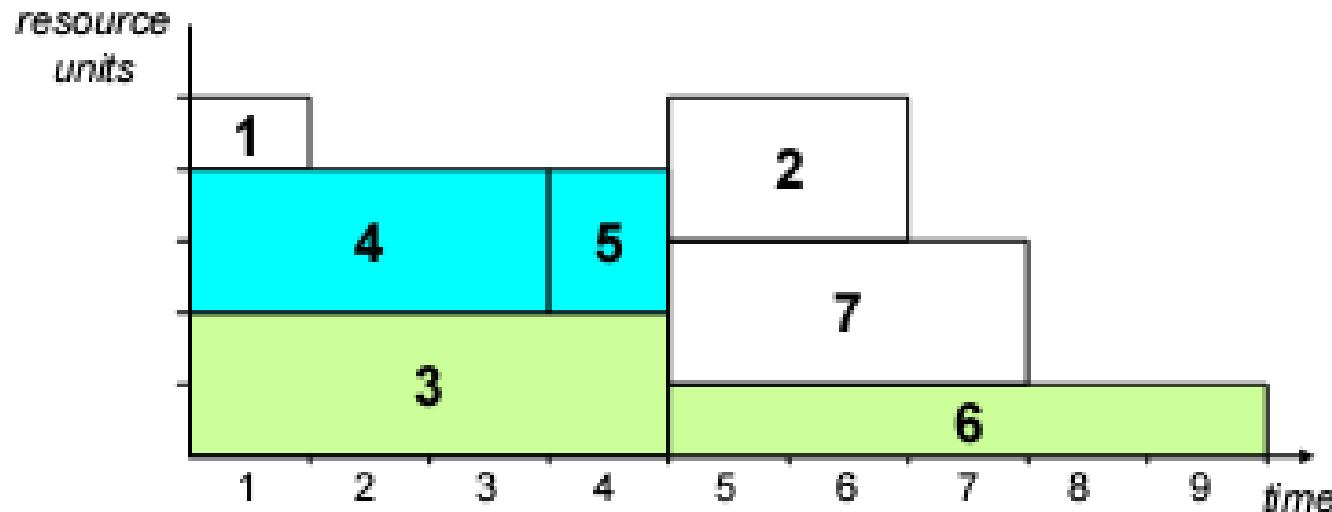


Resource Units



Simple Enough, Right?

- Another view of the solution

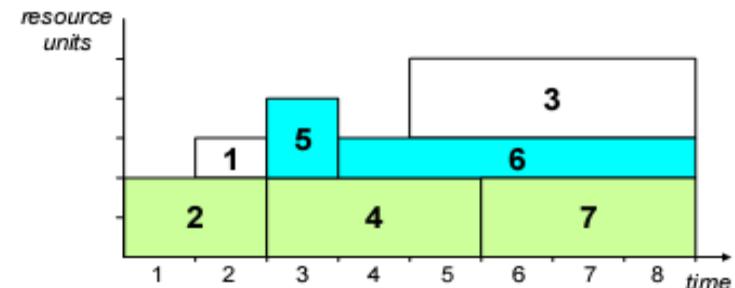
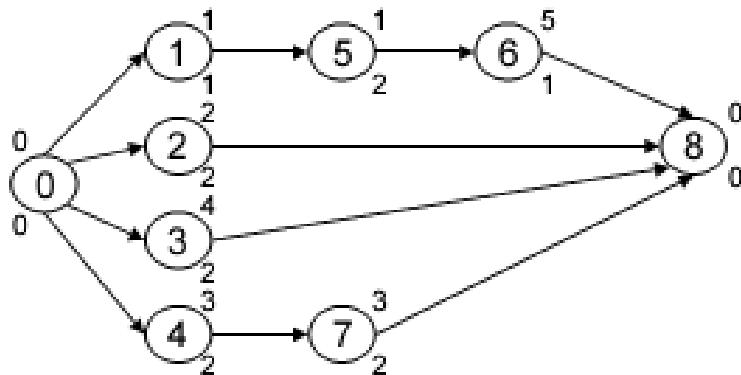


But there is a better solution ...

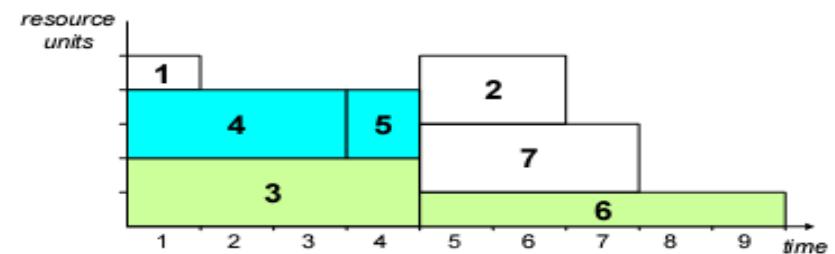
P6 Model: Resource Leveled = 8 days



Simple?

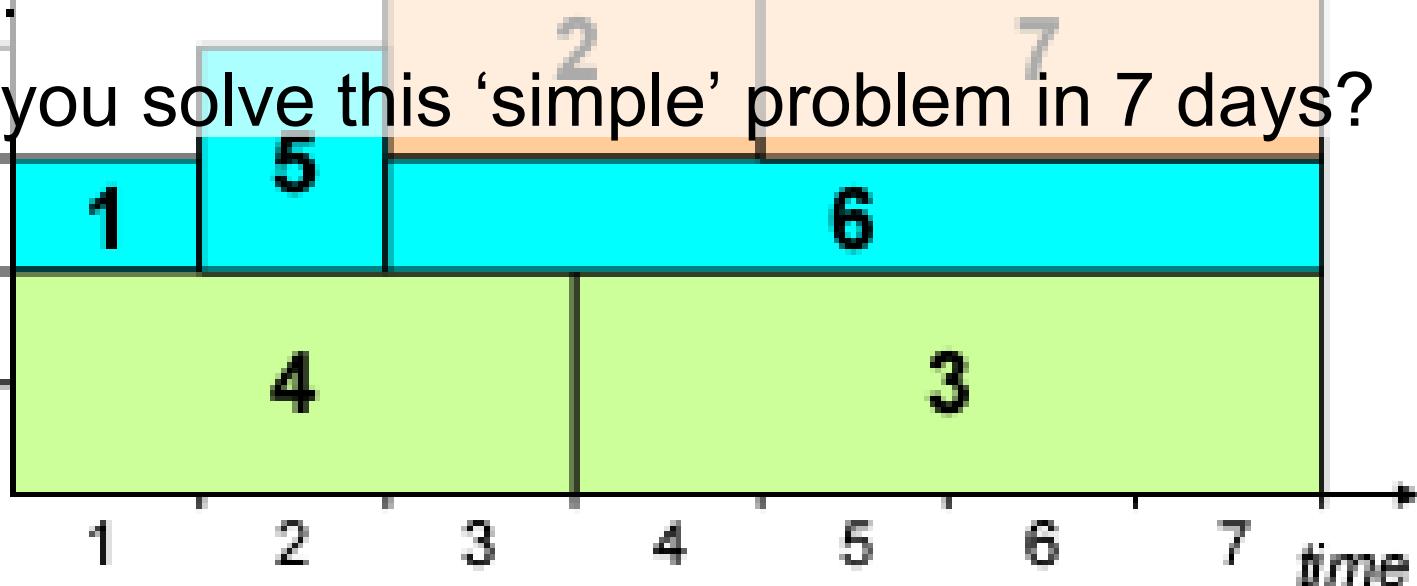


- Critical Path =
 $1 + 1 + 5 = 7$
- 1 resource
5 total units



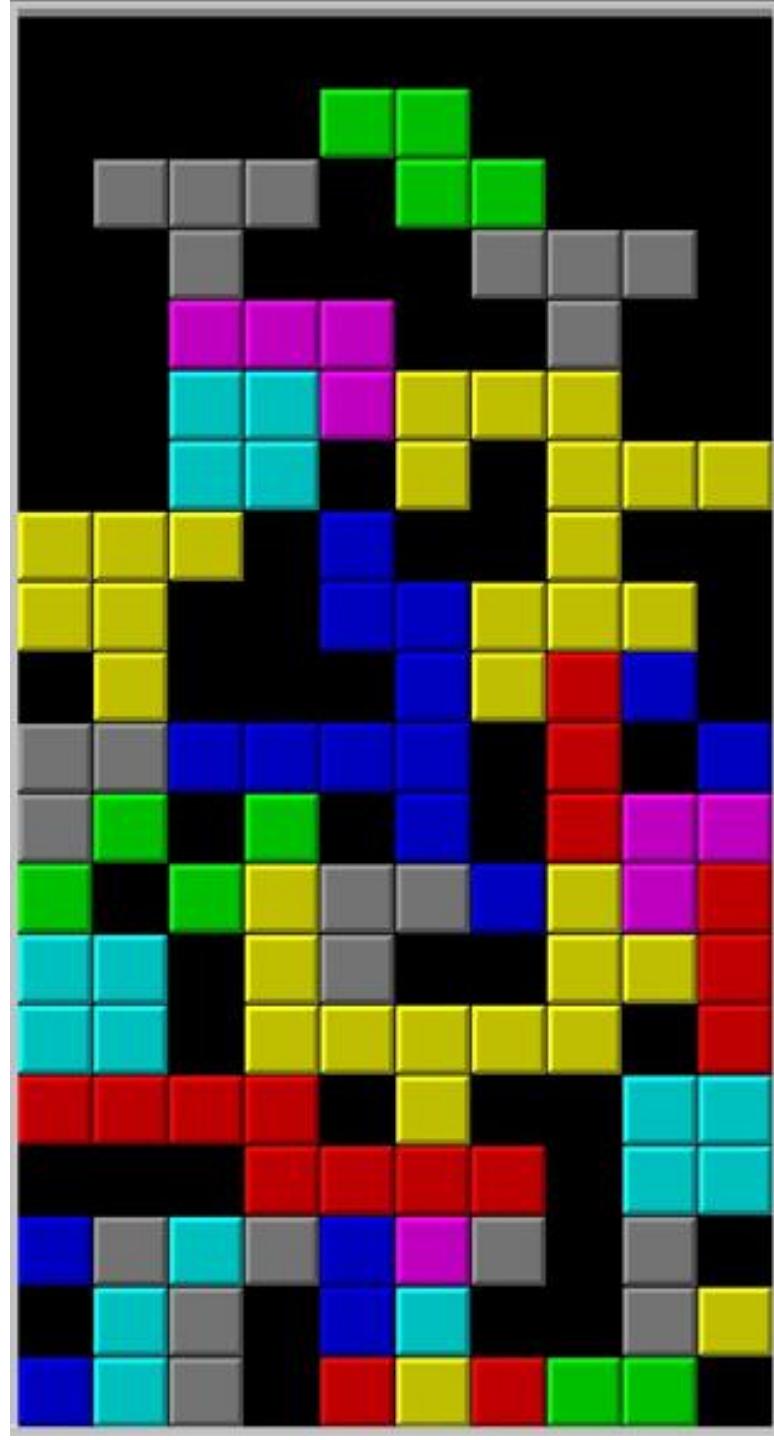
End of Story... Not quite

- 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?

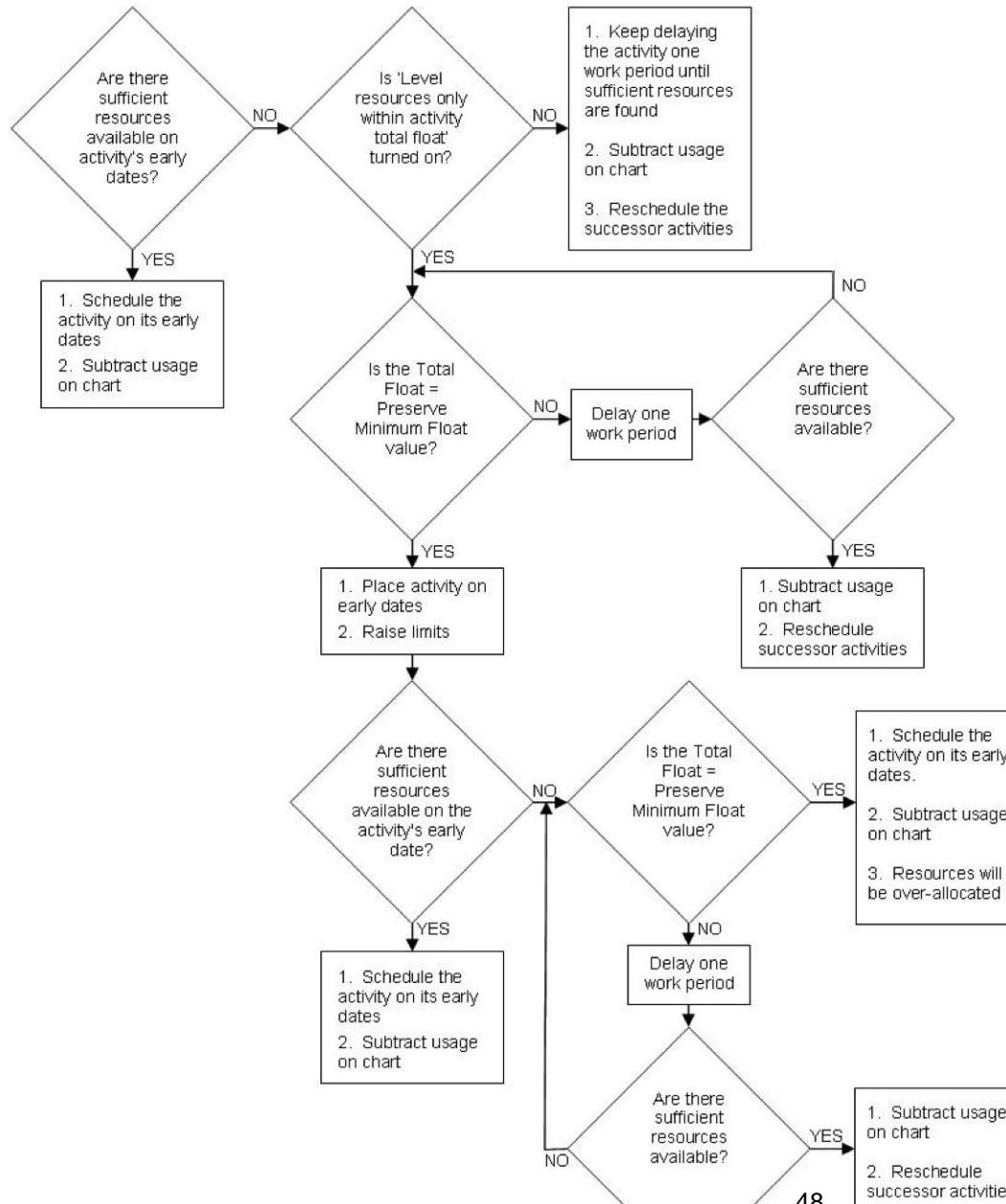


Tetris

- 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

Task Name

Duration

Start

Finish

7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

Wed May 30

Thu May 31

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Projects Resources Resource Sets Activities Calendars

Define Filter

IP Number: 8 Name:

Properties Schedule Attributes Schedule Results CCPM

Actuals Constraints Requirements

Options: 1. PLANE set, RFR set, RFTE set...

PLANE set: 1 use full set

RFR set: 1 use full set

RFTE set: 1 use full set

RFL set: 1 use full set

LFR set: 1 use full set

LFTE set: 1 use full set

LFLE set: 1 use full set

LFDE set: 1 use full set

MECH set: 1 use full set

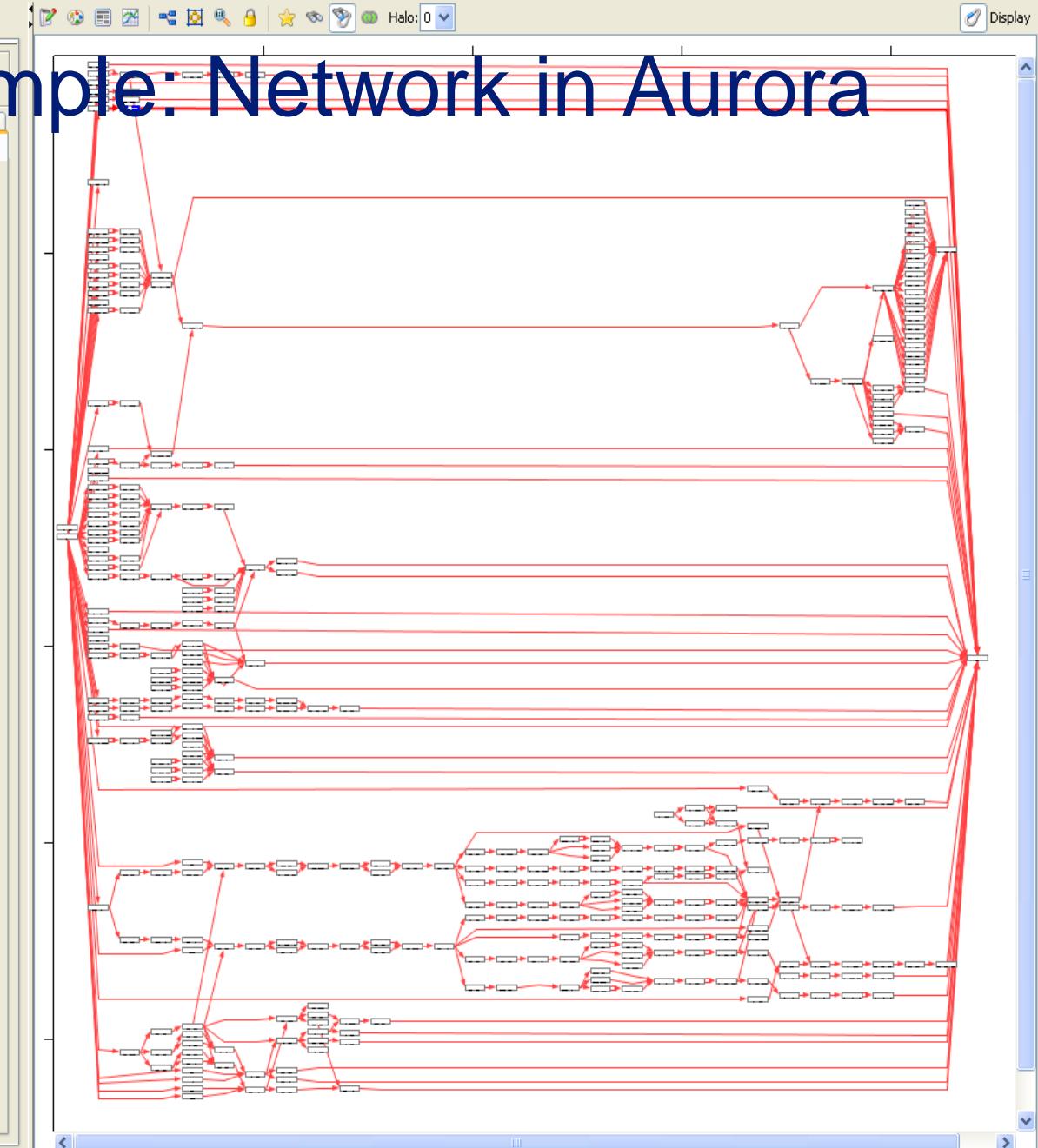
300 selected

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44

New Project New Instance

Add Activity Delete

Copy



Results: 300 Task Example

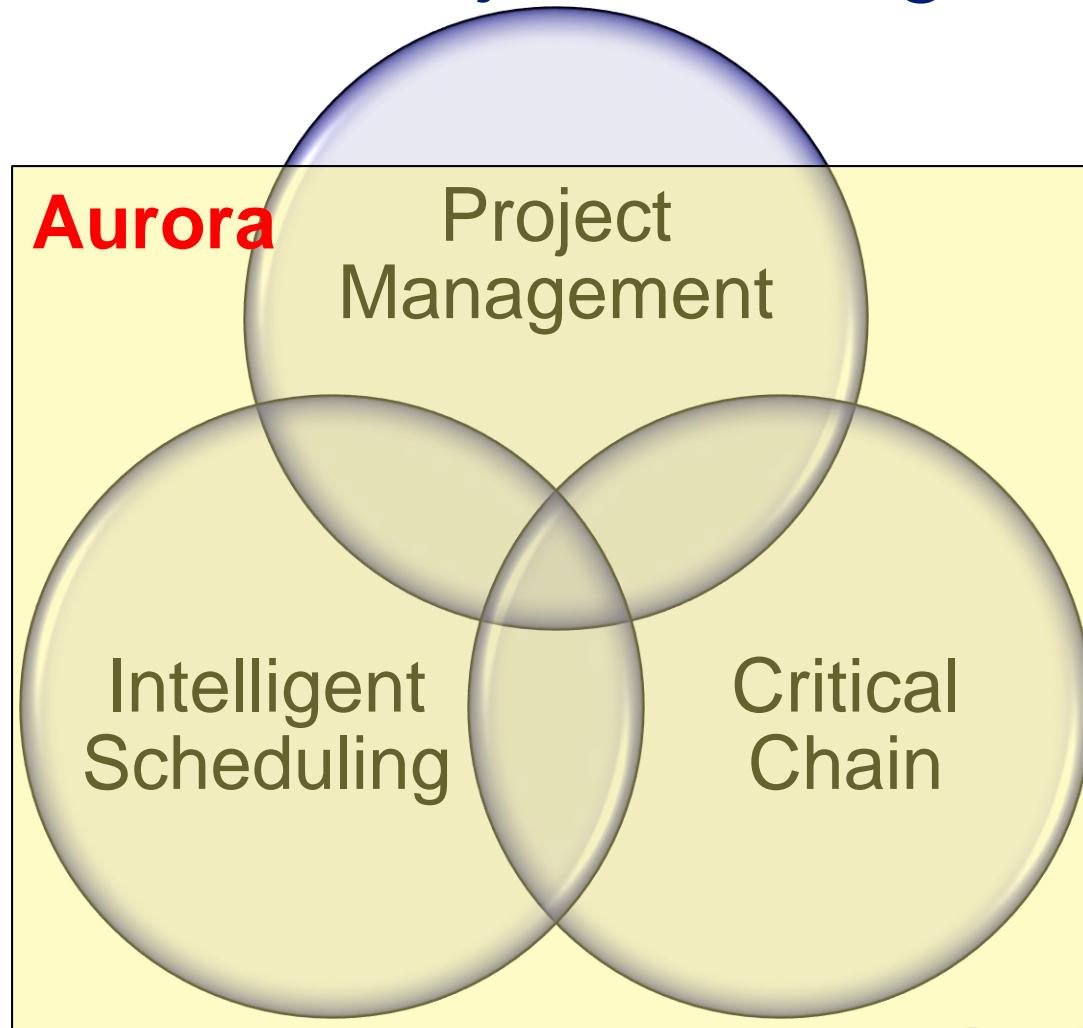
- MS Project 2003 **145.6** days
- MS Project 2007 **145.6** days
- Primavera P6 **115** days
 - Performed by 3rd party
- Deltek Open Plan **110** days
 - Performed by Deltek
- Aurora **102.5** days



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



The world's most advanced scheduling software?



The world's most advanced scheduling software?

Well, you decide. Boeing uses *Aurora™* to build their new 787 Dreamliner. *Aurora* has a proven track record of reducing schedules by up to 33%. This could translate into millions of dollars worth of additional productivity within your organization. *Aurora* works with most popular project management tools including *Primavera™* and *Microsoft Project*.

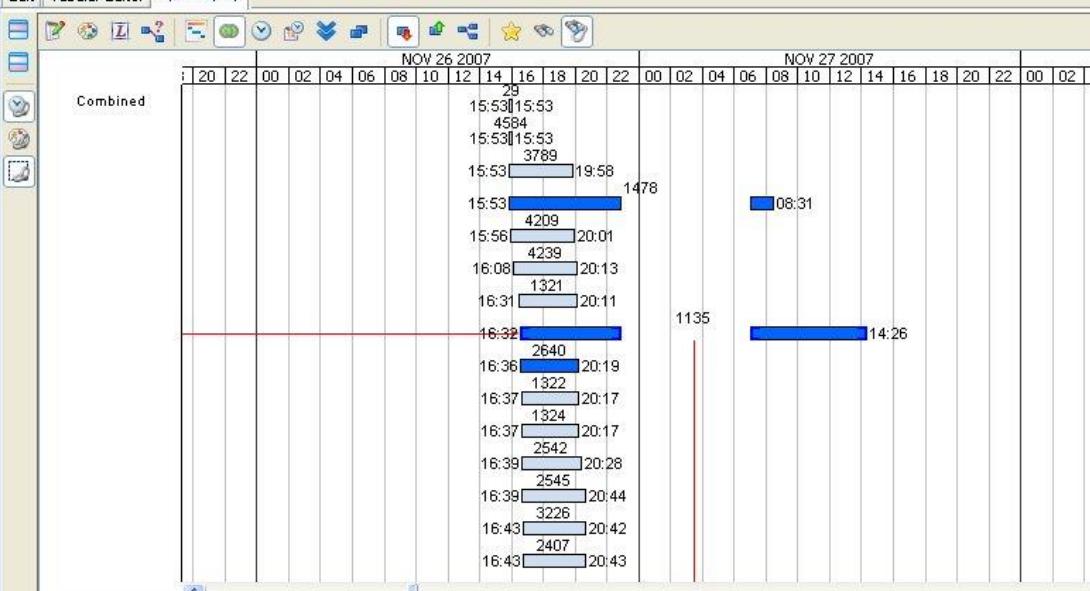
With *Aurora*, is the sky the limit?

Well, no actually. *Aurora* has been used to send missions to outer space. NASA uses *Aurora* to solve some of their most challenging scheduling problems. *Aurora* is currently in use for the Space Shuttle, Space Station, and several more NASA projects. *Aurora* has also been chosen by the United Space Alliance for the next generation Crew Exploration Vehicle.

Submit your schedule to Aurora@StottlerHenke.com
We'll analyze it and send you the results FREE!

Web: www.stottlerhenke.com Tel: (650) 931-2715

Stottler Henke
Smarter Software Solutions



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, which
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 DD MMM YYYY S HH MM +∞ -∞
26 NOV 2007 shift 1 16 32

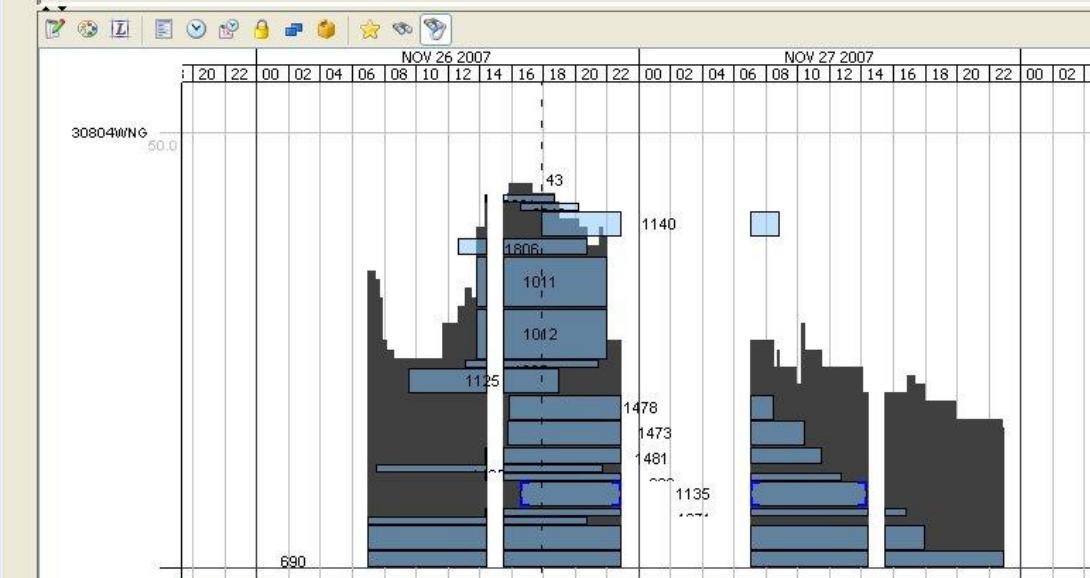
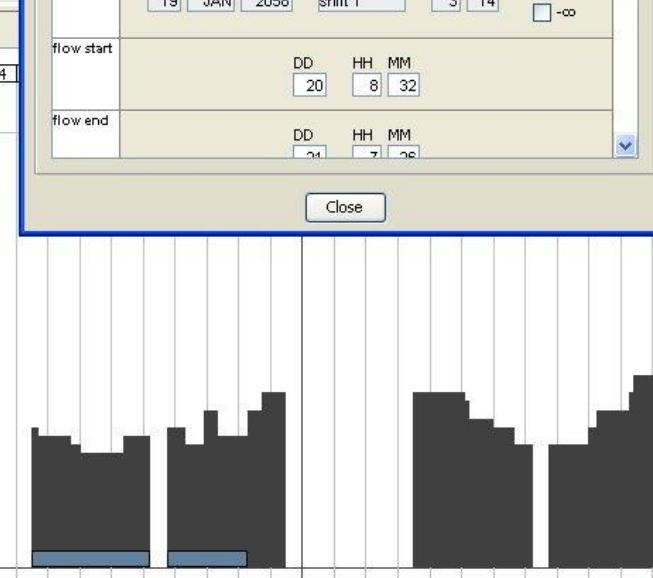
end date DD MMM YYYY S HH MM +∞ -∞
27 NOV 2007 shift 1 14 26

late end date DD MMM YYYY S HH MM +∞ -∞
19 JAN 2058 shift 1 3 14

flow start DD HH MM
20 8 32

flow end DD HH MM
21 7 30

Close



Date: 11/27/2007 16:56 Flow Time: 30 16:56 Group: 30804WNG Quantity: 7.8 Relative: 23 Hours



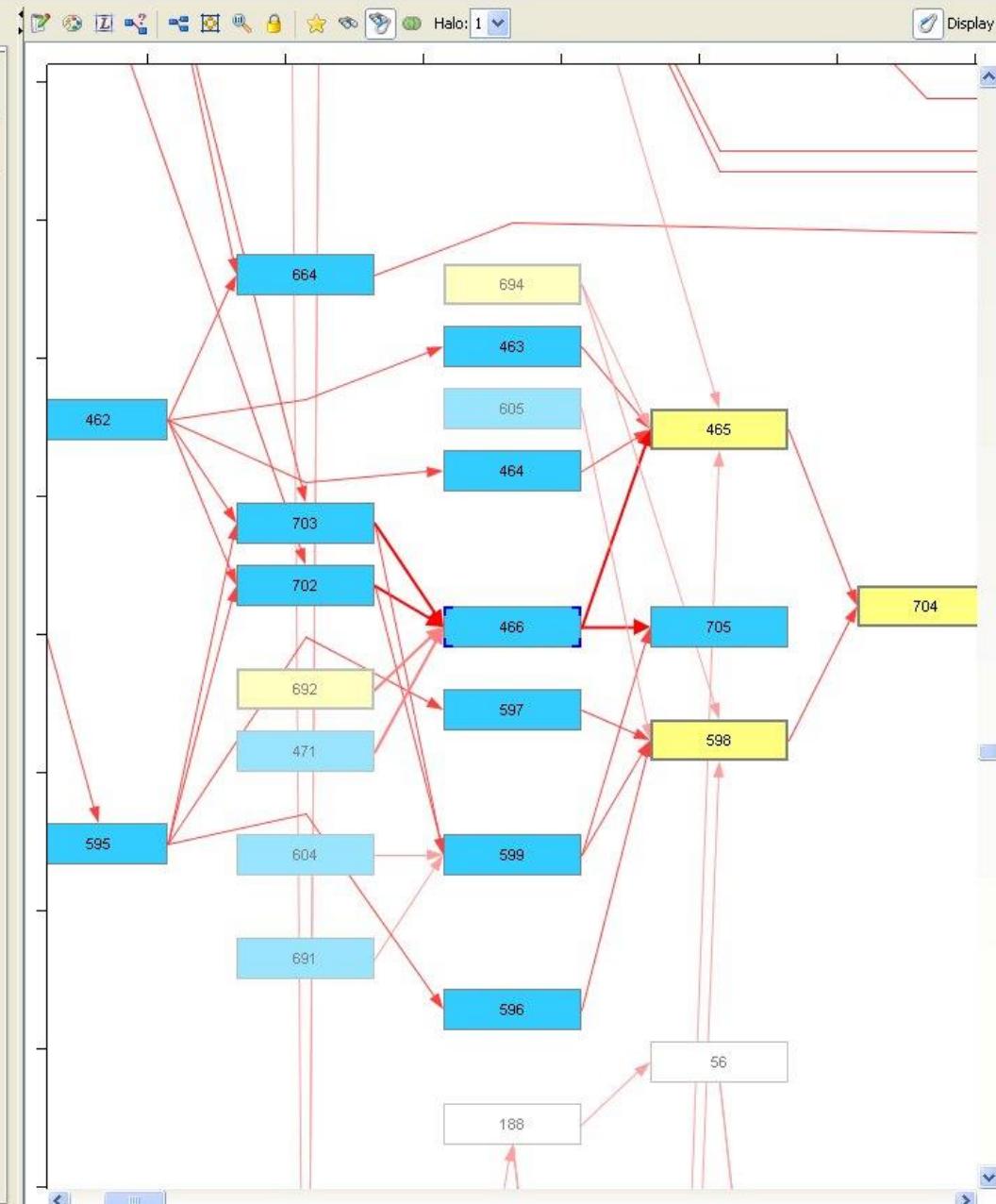
Projects Resources Resource Sets Activities Calendars

Define Filter Sort

IP Number: 466
Name: Initialize Large Scale Mapping & Alignment ...

Actuals	Flags	Constraints	Requirements																												
Properties	Schedule Attributes	Schedule Results	CCPM																												
<table border="1"> <thead> <tr> <th>Name</th> <th>Value</th> </tr> </thead> <tbody> <tr> <td>calendar</td> <td>Default Calendar <input type="button" value="Select"/></td> </tr> <tr> <td>schedule method</td> <td>Forward schedule</td> </tr> <tr> <td>active duration</td> <td>67 minutes = 1:07 hours <input type="checkbox"/> Unknown Duration</td> </tr> <tr> <td>safe duration</td> <td>67 minutes = 1:07 hours</td> </tr> <tr> <td>aggressive duration</td> <td>45 minutes</td> </tr> <tr> <td>duration standard</td> <td>10 minutes</td> </tr> <tr> <td>risk</td> <td>0</td> </tr> <tr> <td>can break across days</td> <td><input checked="" type="checkbox"/></td> </tr> <tr> <td>can break across</td> <td><input checked="" type="checkbox"/></td> </tr> <tr> <td>shift end offset (minutes)</td> <td>minutes</td> </tr> <tr> <td>interruptible</td> <td><input type="checkbox"/></td> </tr> <tr> <td>compatible activities</td> <td><input type="button" value="Select"/> <input type="button" value="Clear"/></td> </tr> <tr> <td>exclusivity</td> <td></td> </tr> </tbody> </table>				Name	Value	calendar	Default Calendar <input type="button" value="Select"/>	schedule method	Forward schedule	active duration	67 minutes = 1:07 hours <input type="checkbox"/> Unknown Duration	safe duration	67 minutes = 1:07 hours	aggressive duration	45 minutes	duration standard	10 minutes	risk	0	can break across days	<input checked="" type="checkbox"/>	can break across	<input checked="" type="checkbox"/>	shift end offset (minutes)	minutes	interruptible	<input type="checkbox"/>	compatible activities	<input type="button" value="Select"/> <input type="button" value="Clear"/>	exclusivity	
Name	Value																														
calendar	Default Calendar <input type="button" value="Select"/>																														
schedule method	Forward schedule																														
active duration	67 minutes = 1:07 hours <input type="checkbox"/> Unknown Duration																														
safe duration	67 minutes = 1:07 hours																														
aggressive duration	45 minutes																														
duration standard	10 minutes																														
risk	0																														
can break across days	<input checked="" type="checkbox"/>																														
can break across	<input checked="" type="checkbox"/>																														
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interruptible	<input type="checkbox"/>																														
compatible activities	<input type="button" value="Select"/> <input type="button" value="Clear"/>																														
exclusivity																															
<input type="button" value="Add"/> <input type="button" value="Remove"/>																															
<p>early start date: MM YYYY S HH MM</p> <p>10V 2007 shift 1 0 00</p>																															

Add Activity





Projects Resources Resource Sets Activities Calendars

Define Filter Sort

IP Number: 466
Name: Initialize Large Scale Mapping & Alignment ...

Actuals Flags Constraints Requirements Properties Schedule Attributes Schedule Results CCPM

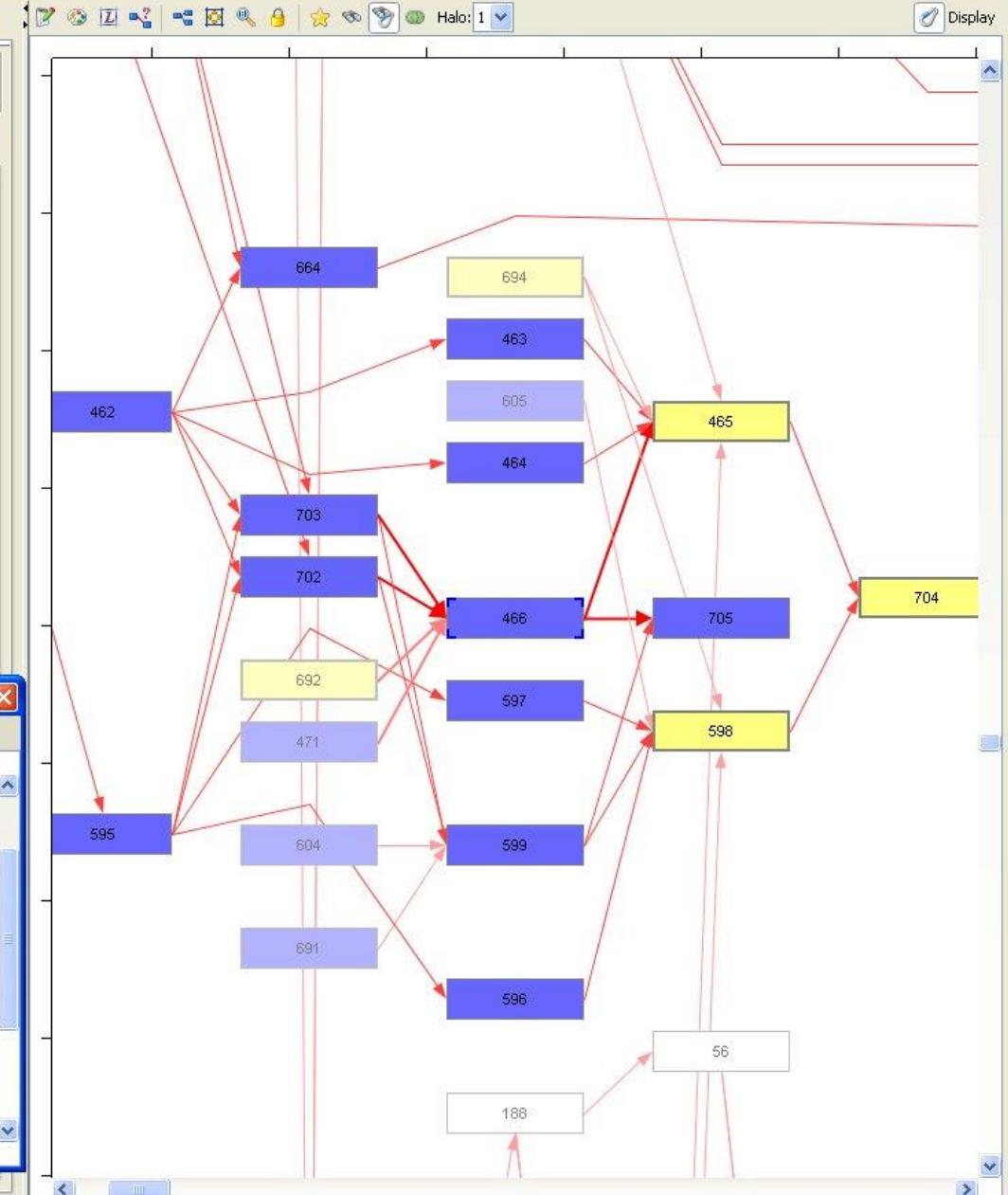
Name	Value
calendar	Default Calendar <input type="button" value="Select"/>
schedule method	forward schedule
active duration	67 minutes = 1:07 hours <input type="checkbox"/> Unknown Duration
safe duration	67 minutes = 1:07 hours
aggressive duration	45 minutes
duration standard	10 minutes
risk	0
can break across days	<input checked="" type="checkbox"/>

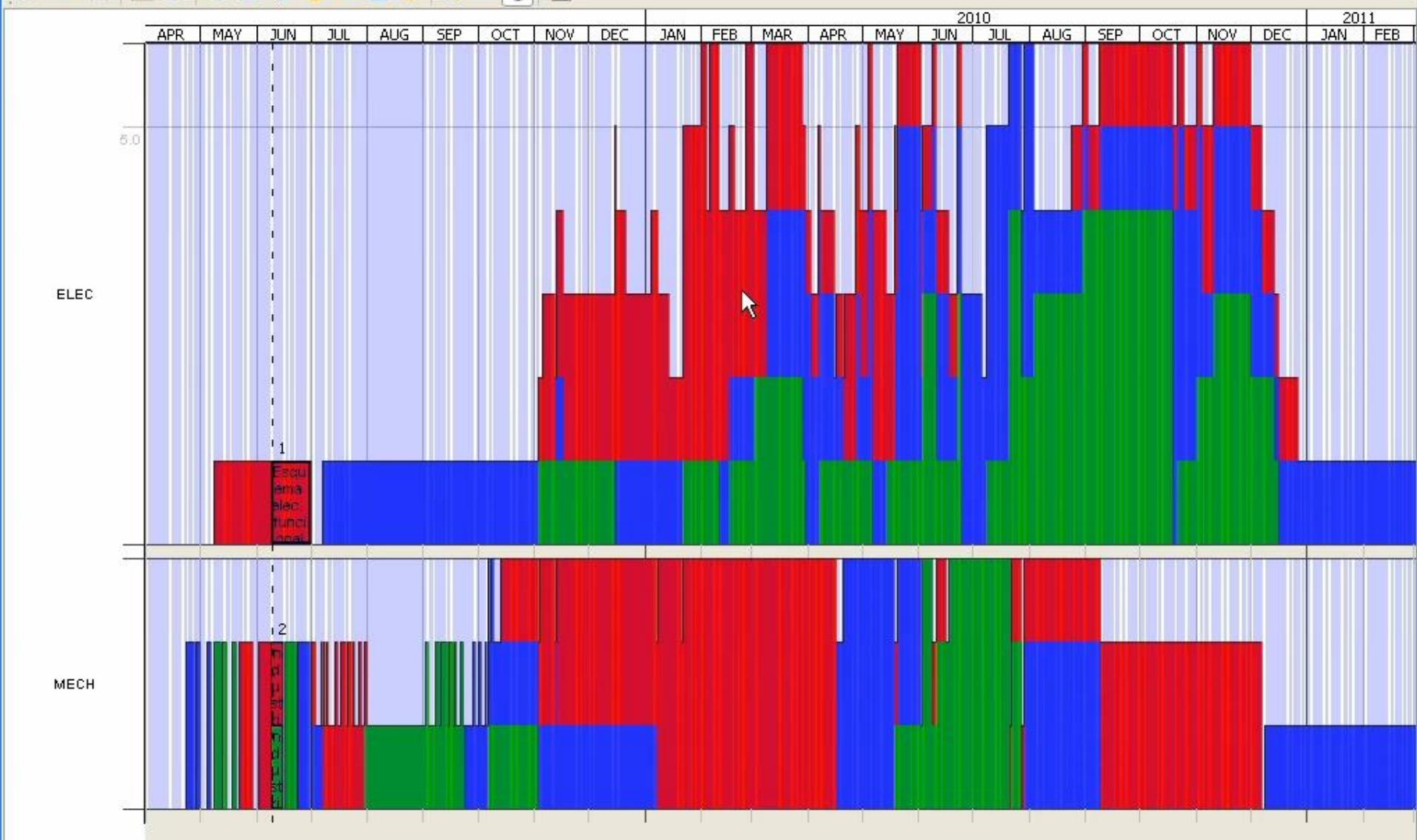
Single Element Display

Actuals Flags Constraints Requirements Properties Schedule Attributes Schedule Results CCPM

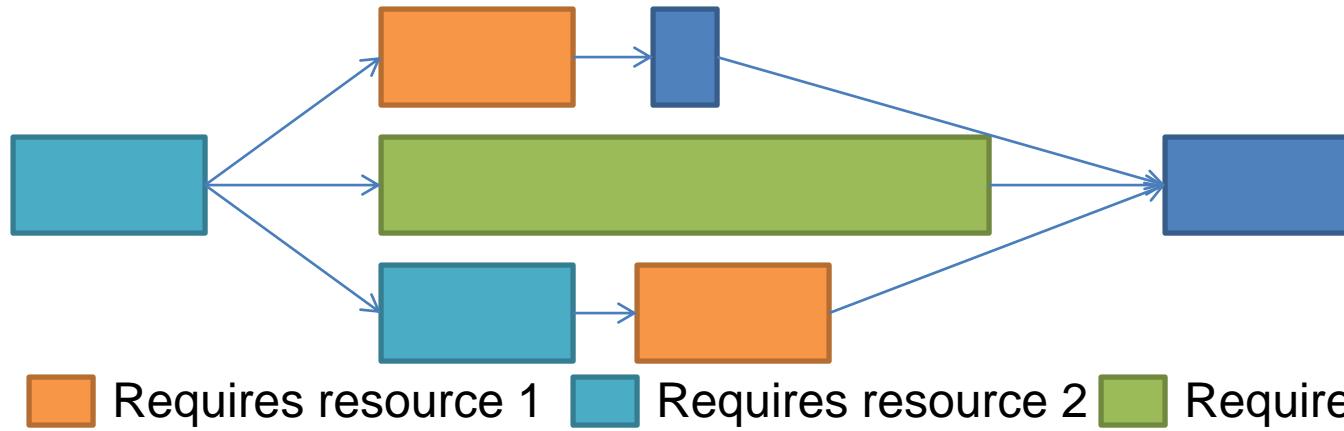
```

graph LR
    702 --- 692
    702 --- 466
    692 --- 466
    703 --- 466
    471 --- 466
    466 --> 465
    466 --> 705
    595 --- 466
  
```

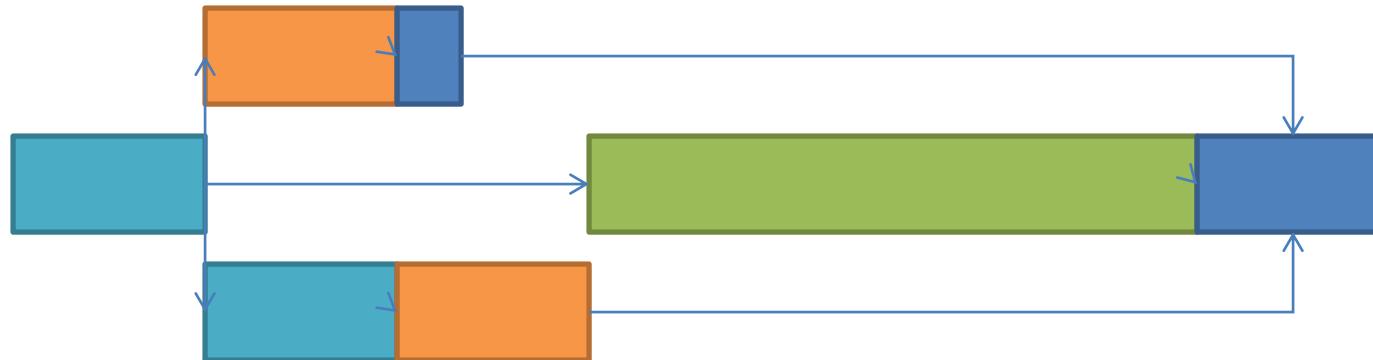




Critical Chain – Example 3



As scheduled:



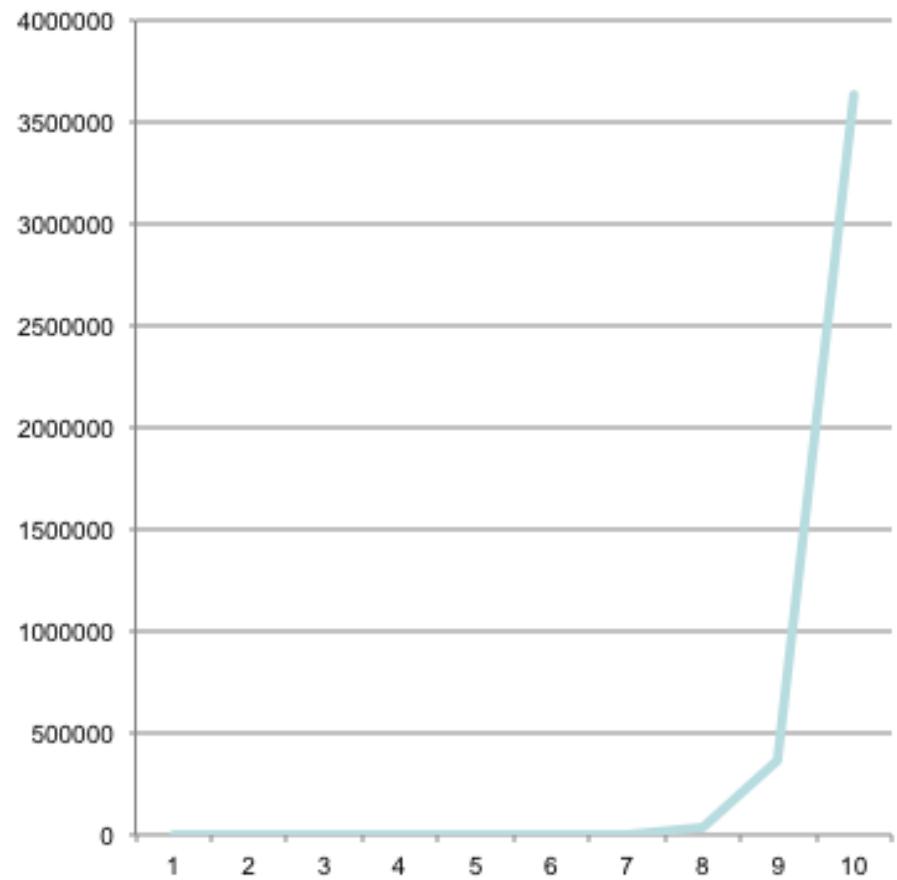
Critical chain:



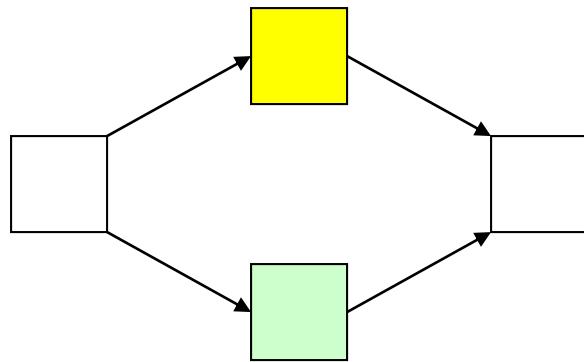
Why can't you search for the best order?

- Ordering options scale as $N!$

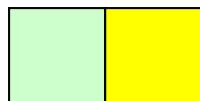
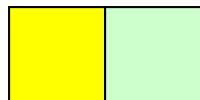
1	1
2	2
3	6
4	24
5	120
6	720
7	5040
8	40320
9	362880
10	3628800



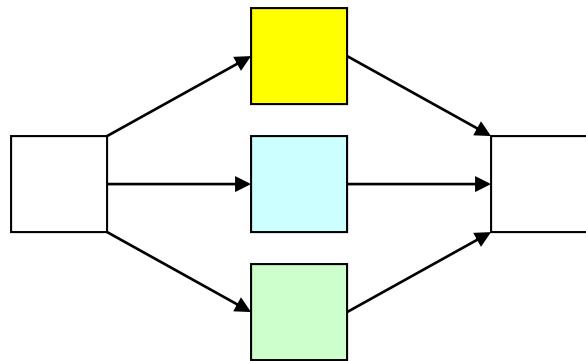
Two tasks that can occur in either order (one at a time)



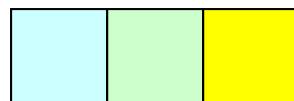
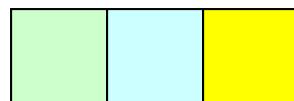
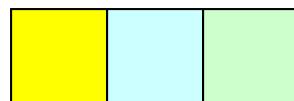
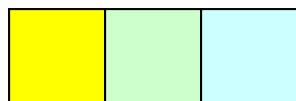
results in two options



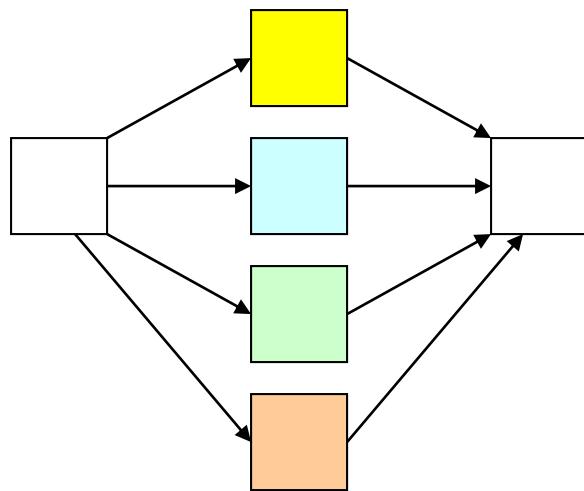
Three tasks that can occur in any order (one at a time)



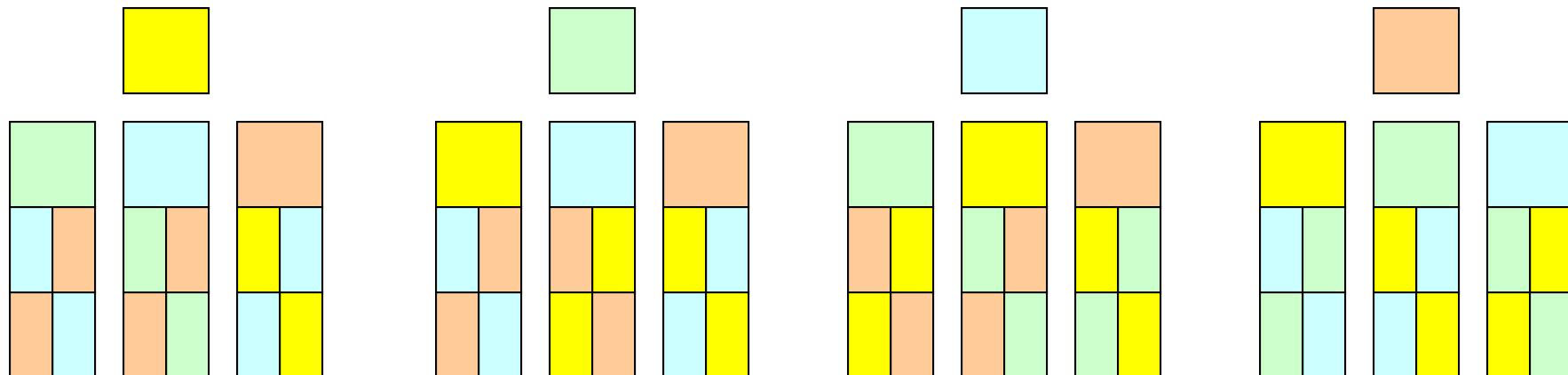
results in six options



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

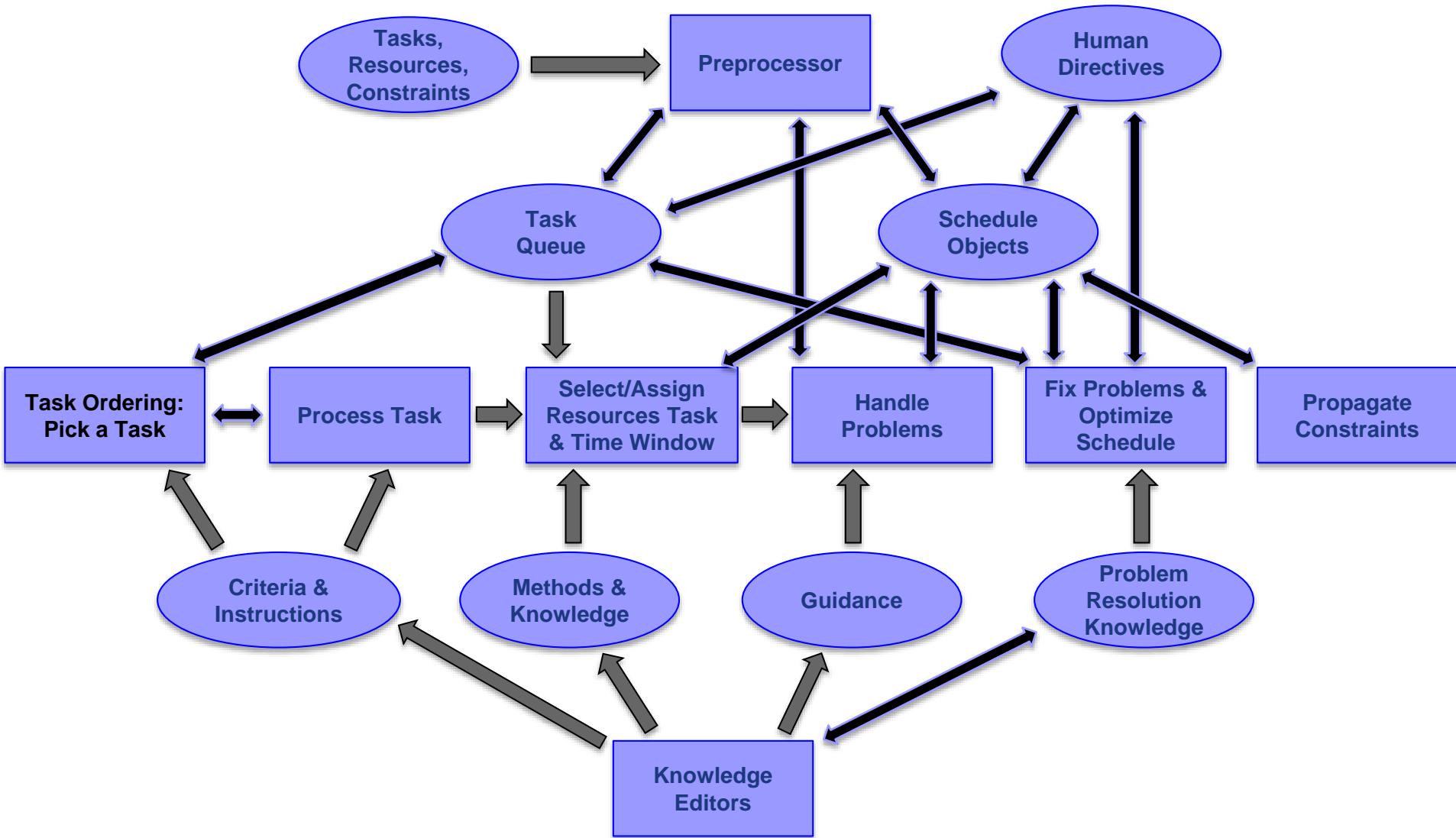
- Whole field of Operations Research

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).

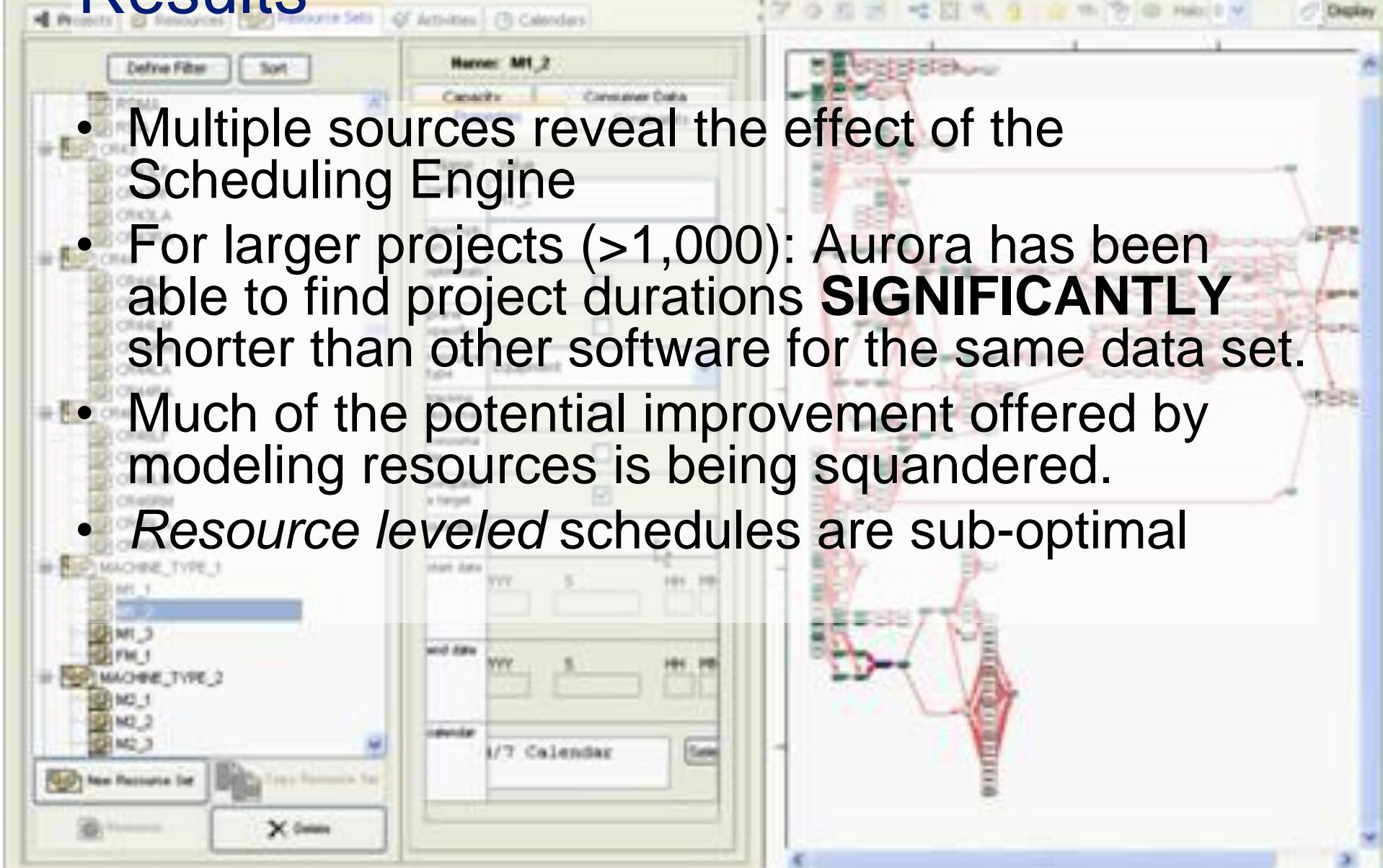


Scheduling is Fast

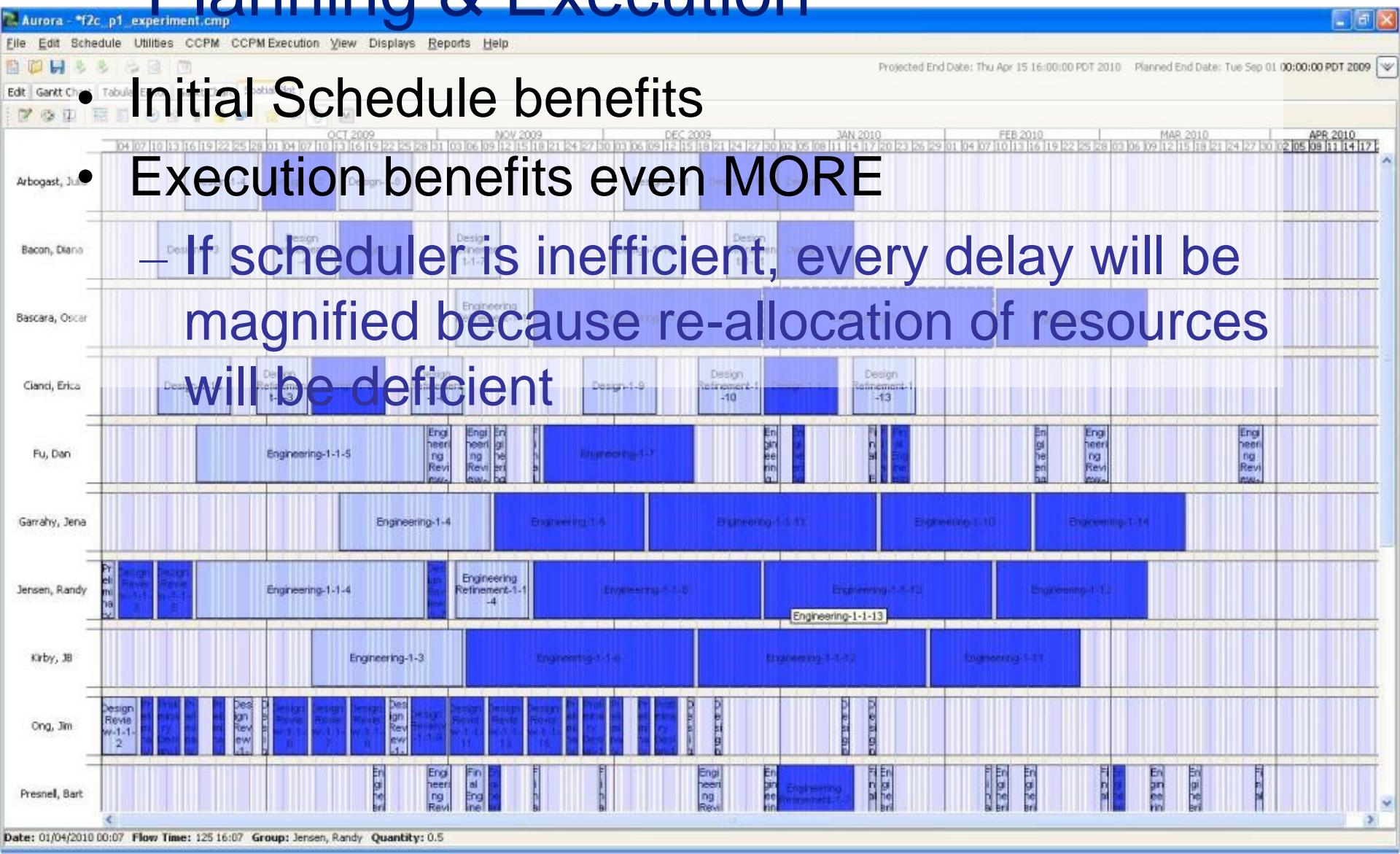
The screenshot shows a scheduling software interface with a toolbar at the top, a navigation bar with tabs like 'Home', 'Tasks', 'Resources', 'Resource Sets', 'Activities', and 'Calendars', and a main area with a Gantt chart and a resource list.

Tasks	Time
• 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



Planning & Execution



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