Aurora / Aurora-CCPM

Intelligent Scheduling and

Critical Chain Project Management

Stottler Henke

Smarter Software Solutions

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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

Background & Perspective

- Stottler Henke
- Artificial Intelligence Research & Development
  - Software Company
- Project Management Experience
  - Video: NASA SBIR Hallmark of Success Story

https://www.youtube.com/watch?v=uEt8NPDF-hI

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Planning and Scheduling

Given a list of tasks (or jobs or 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):

- 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**

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.

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

General Dynamics Electric Boat

Aurora is being leveraged by General Dynamics Electric Boat (EB) for the scheduling of various aspects of submarine construction.

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.

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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

Korea Aerospace Industries

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

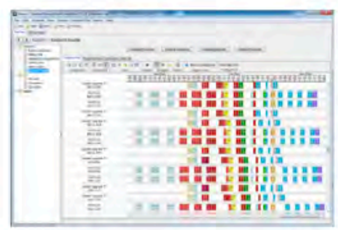
Learn More

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

Pilot Training



Pilot training involves a variety of specialized functionality and logic. The scheduling and logic enforcement was historically a slow and painstaking process, with a significant amount of manual cross-checking.

Learn More

Aurora History (1)

1990 1st Intelligent Scheduling Project – NASA's Kennedy Space Center (KSC)

1990's Several IS projects independent of each other (most at NASA)

1999 Aurora conceived to subsume all

2000 Aurora designed and prototyped

2001 – 2003 Main Aurora implementation

2002 1st Aurora application delivered

2005 Critical Chain enhancement: Boeing & others

- E.g., 2011: Critical Chain / Intelligent Scheduling for US Navy's submarine maintenance

Aurora History (2)

2009 Harvard Medical School / Mass General – Medical resident scheduling

2010 Air Force – Satellite downlink scheduling

2012 Pfizer – customization for pharmaceutical packaging scheduling

2012 Honda R&D – Vehicle testing scheduling

2014 TenA – Mortgage auditor scheduling

2014 Alaska Airlines – Pilot training scheduling

2017 General Dynamics EB – Submarine construction scheduling

2018 Spirit Aerosystems

Aurora-CCPM Summary

Enterprise-Level Critical Chain Project Management Software

Multi Project

Completely stand-alone

- Does NOT depend on any other product
- However, designed to interface with other project management software and exchange information with databases
  - E.g. Primavera

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

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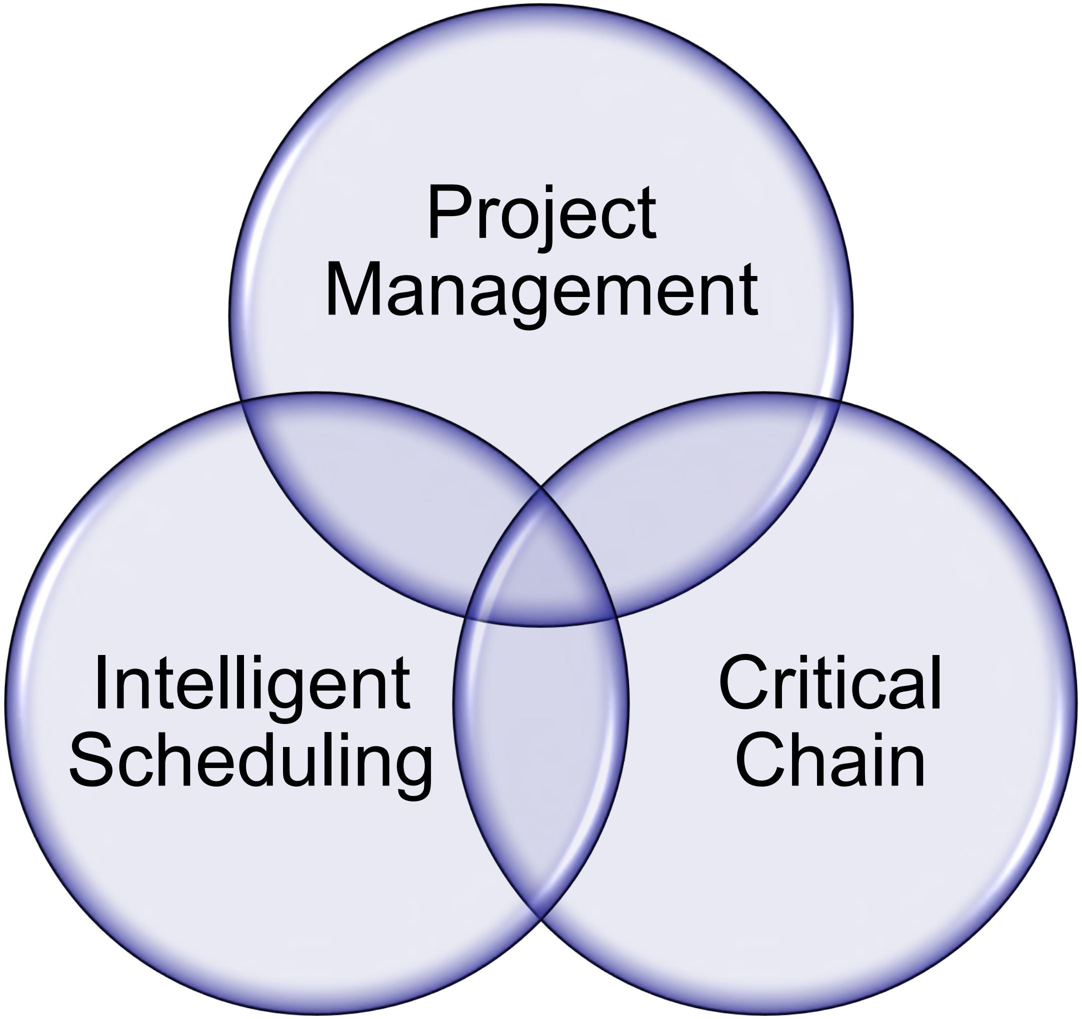
Value Proposition: Aurora

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.

Enhancements to Traditional Project Management



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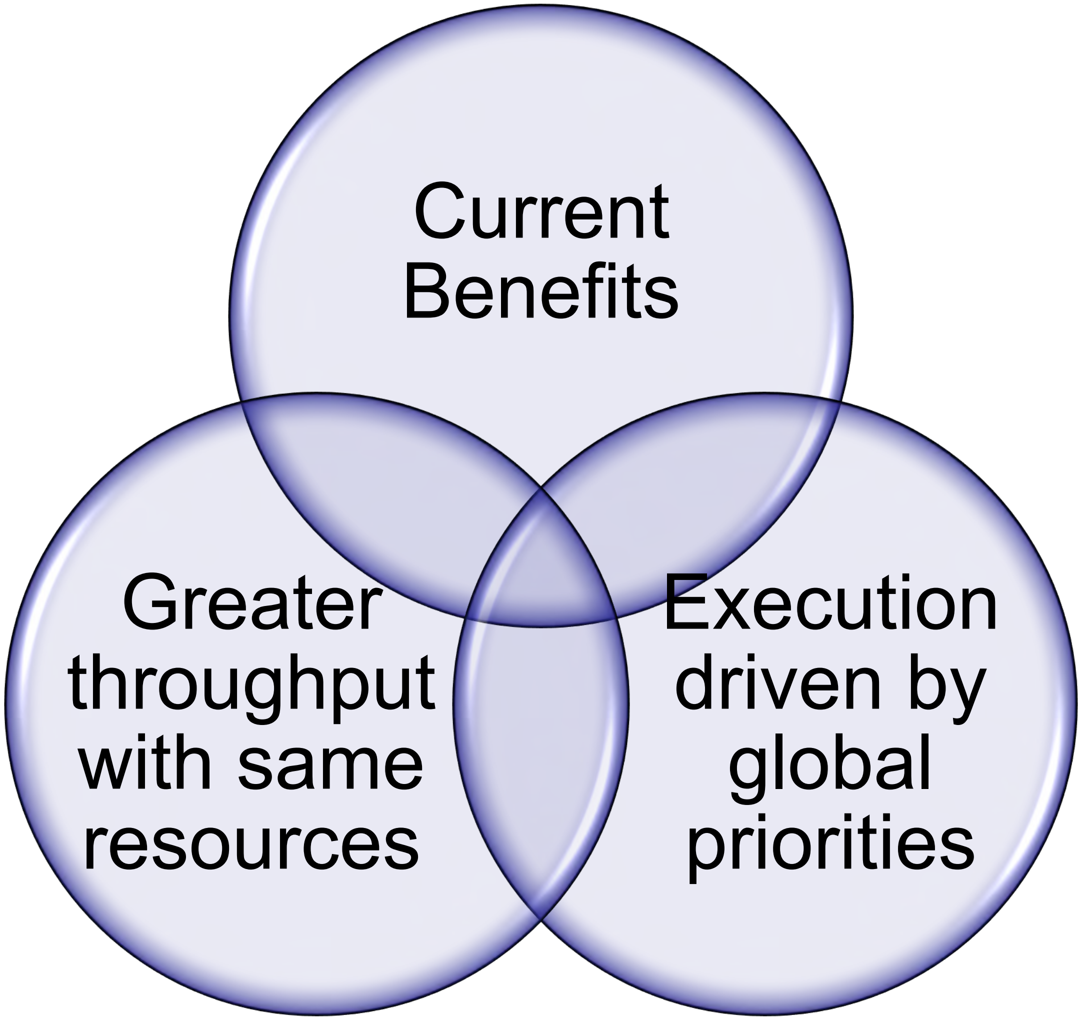
Benefits



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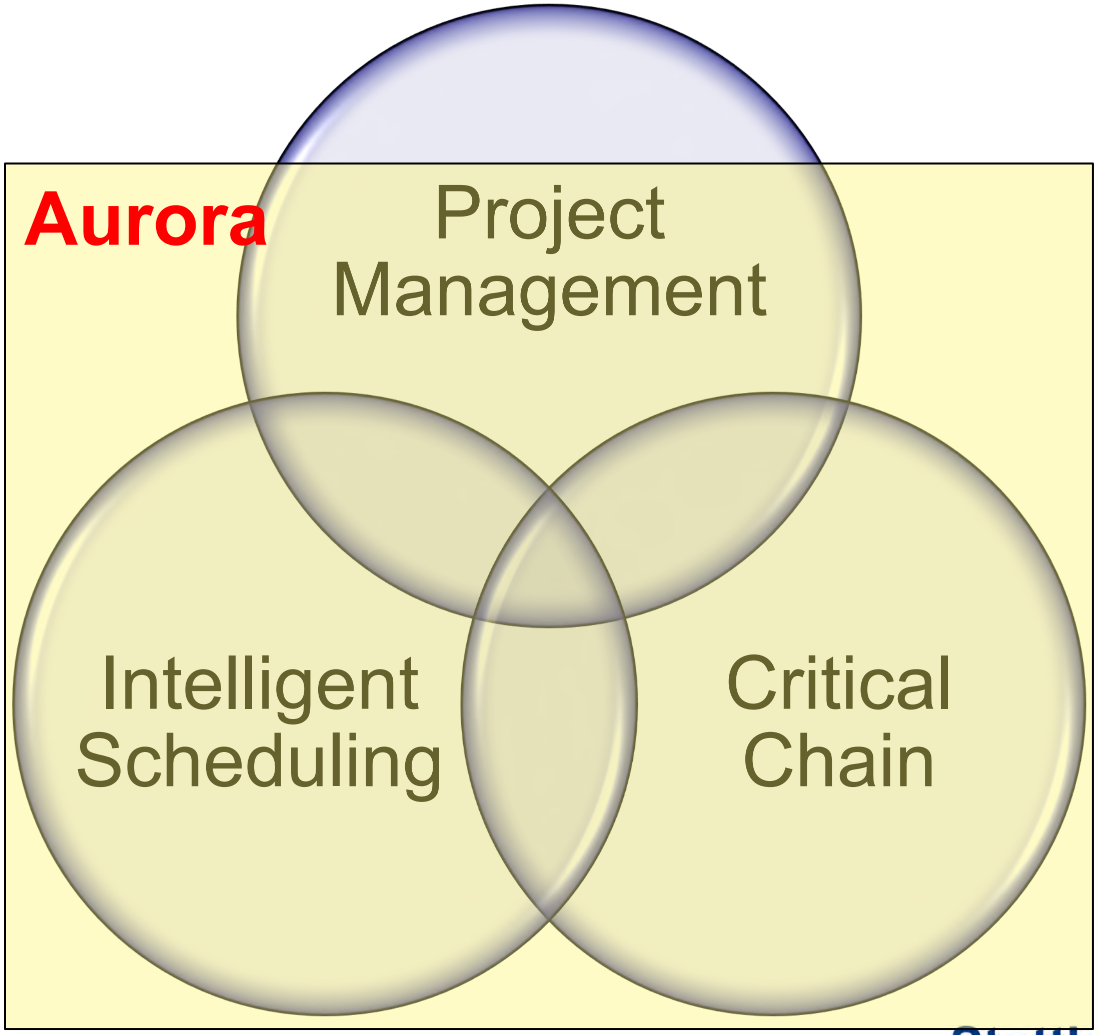
Aurora Functionality



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Critical Chain Models

Near Real Time Actionable Recovery and Prioritizations

Critical Chain Modeling Toolkit

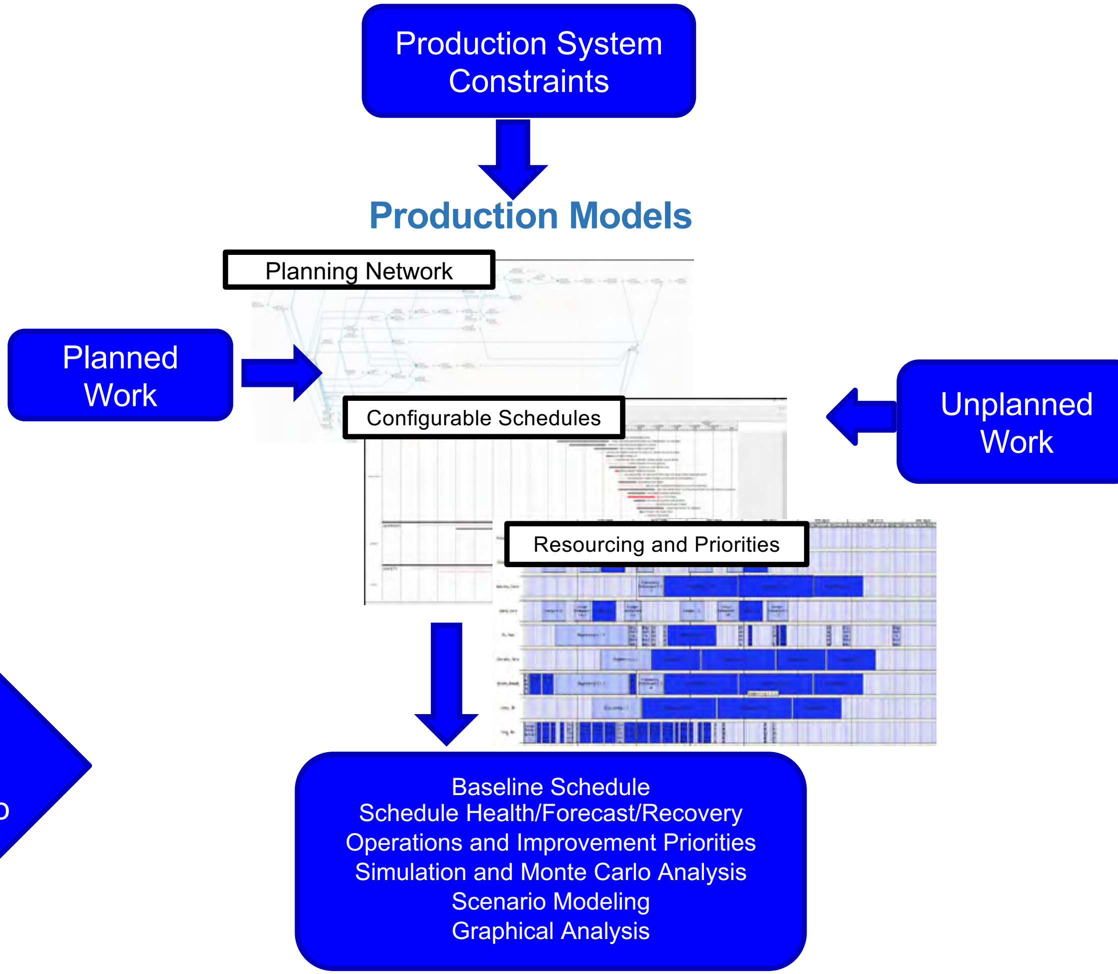
- Easily accesible bite sized trainings for production models
- Analytical Tools
- Metric Dashboards

Fast and Rigorous Solutions for

- Early Production System Design
- Avoiding & Managing Disruption
- Focused Operational Excellence

Results that Matter

- Clear, Actionable Priorities
- Fast Mitigation & Recovery
- Know What Matters and What to do About it.



A.I. Capabilities Power Critical Chain Models

Flexible Deployment

Completely stand-alone application on Windows, Linux & Mac

Standalone Aurora with Database access

Aurora Server version with Web access

Flexible deployments

- Windows XP to Windows Server
- Linux
- Mac
- 32 or 64-bit

Aurora Overview

Aurora provides ‘standard’ Project Management capabilities (e.g., MS Project, Primavera) plus incorporates many advanced features.

Aurora Philosophy

- No system will solve all problems well out of the box
  - Focus on easy customization
- Scheduling is NP-Complete -> must use heuristics
  - Focus on heuristic definition and substitution
- Scheduling problems have specific decision points
  - Modularize decision points to allow mix and match configuration

Aurora Unique Capabilities

Multiple-pass intelligent resource-constrained scheduling

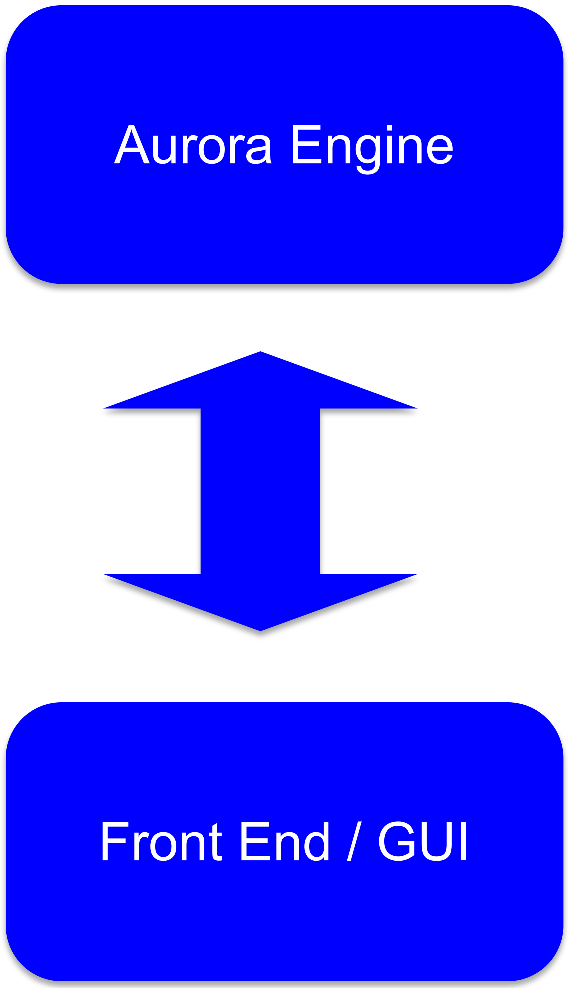
Mixed-mode scheduling providing both forward and backward scheduling, available on a task-by-task basis.

Schedule Rationale – Aurora includes the rationale for each task on why it was schedule where it was schedule.

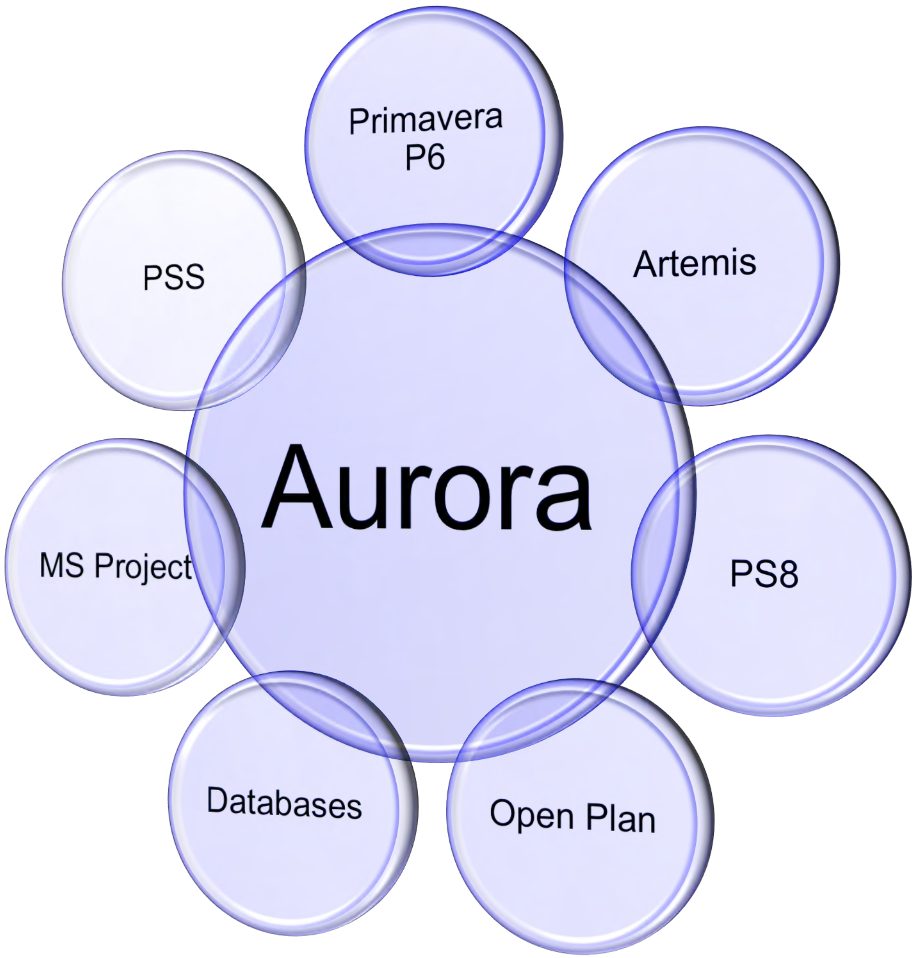
Critical Chain

Designed to interface with other tools

Aurora Engine & Front End



Interfaces: Aurora can interface with all others



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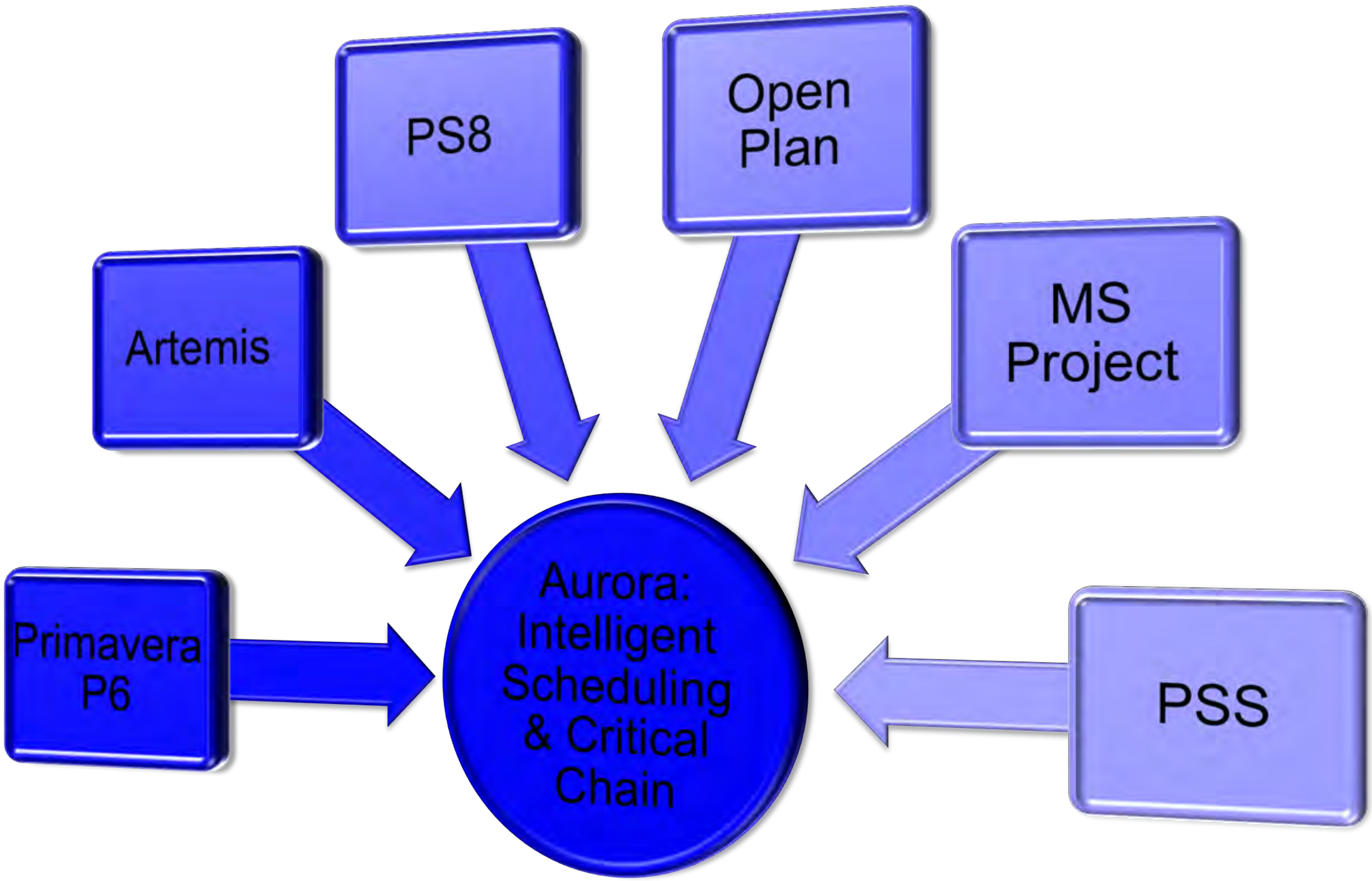
Build in current tool: Benefit from Intelligent Scheduling &/or Critical Chain



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Potential Workflow with MS Project

Develop network diagram in MS Project

- task names, predecessors/successors, resource pool, resource allocations, durations, etc.

Export MS Project → XML → Import into Aurora

Perform Critical Chain analysis

Export Aurora → XML → Import MS Project

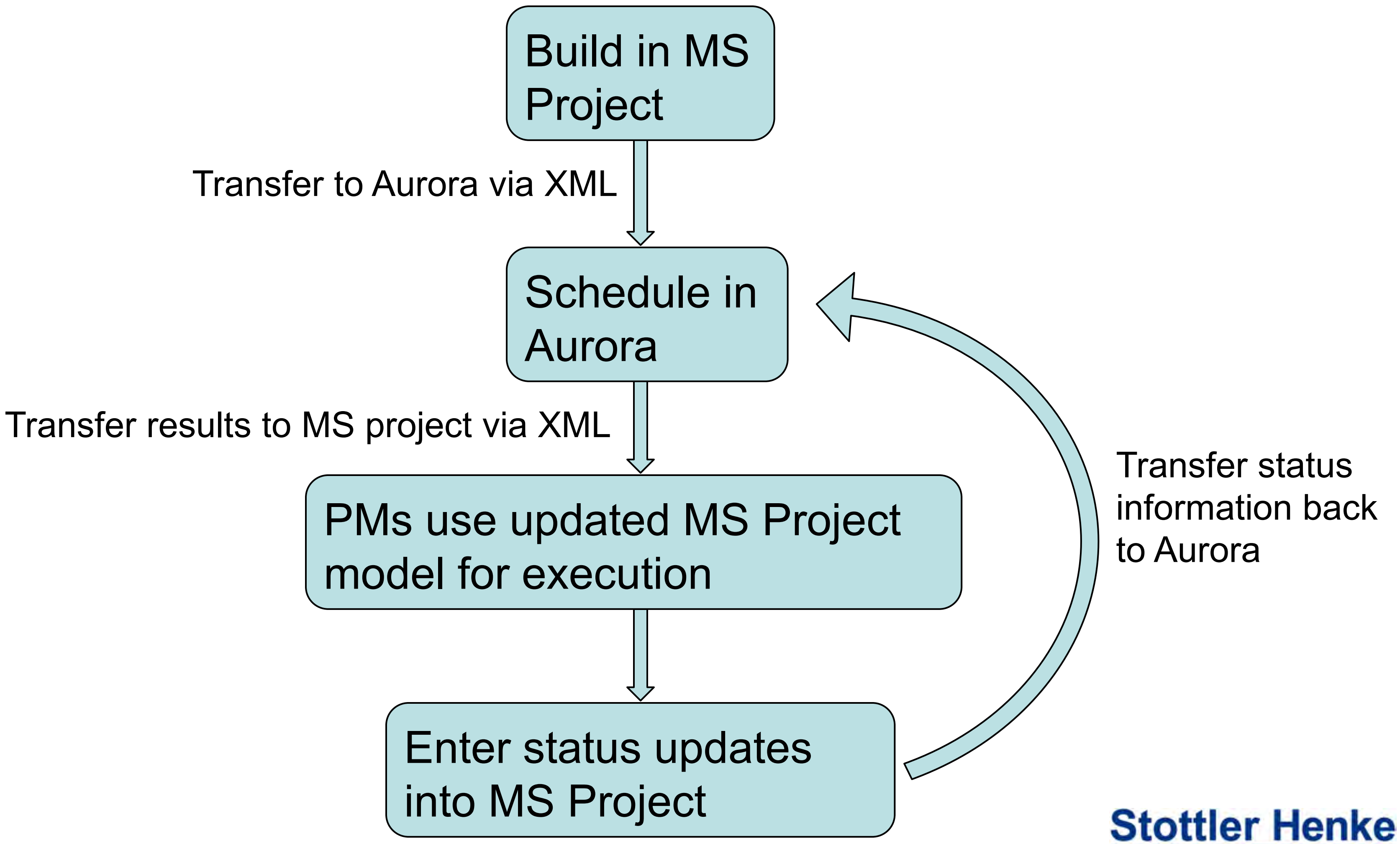
Potential Workflow with MS Project (2)

Program Managers use MS Project model to manage their programs until (weekly) status update.

Status updates entered into MS Project

- Export updated MSP file → XML → Aurora
- Aurora updates schedule
- Export Aurora → XML → MS Project

Potential Workflow with MS Project: Flowchart



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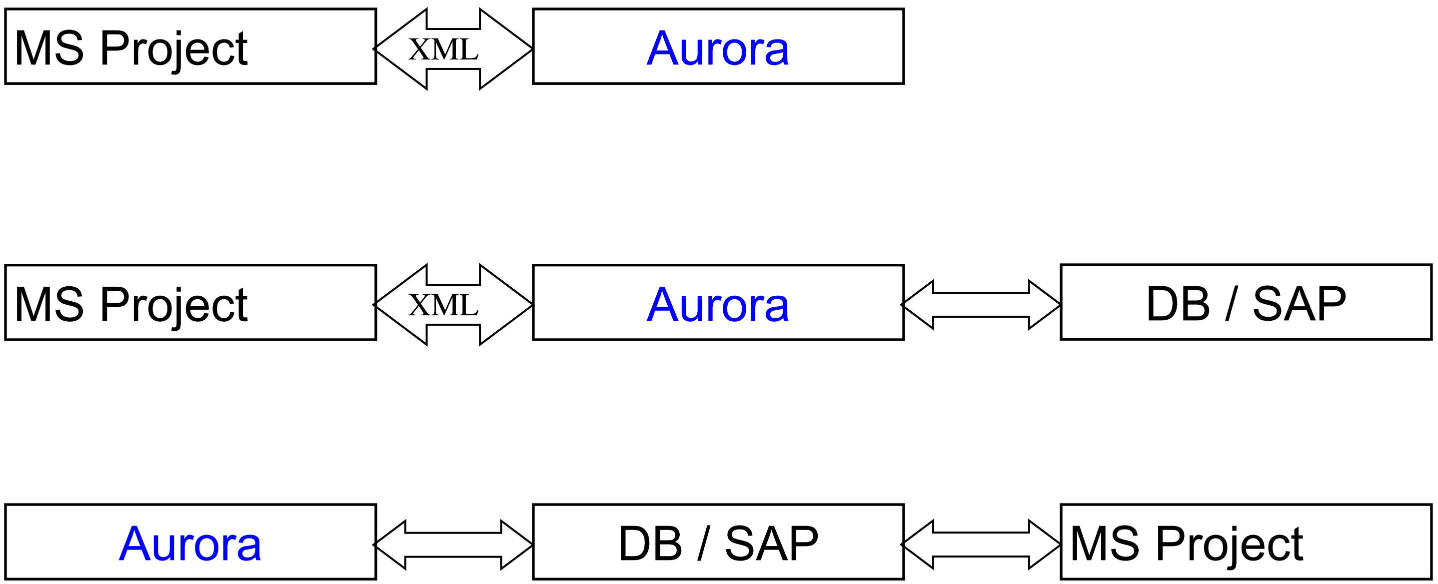
Aurora 3rd Party Interface Options: MS Project



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Potential Workflow with Primavera P6

Develop network diagram to Primavera P6

- task names, predecessors/successors, resource pool, resource allocations, durations, etc.

Save Primavera P6 as XER → Import into Aurora

Perform Intelligent Scheduling / Critical Chain analysis

Export Aurora → XML → Import Primavera P6

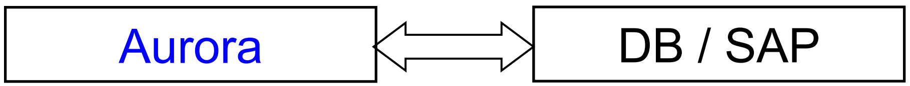
Potential Workflow with Primavera P6 (2)

Program Managers use Primavera P6 model to manage their programs until status update.

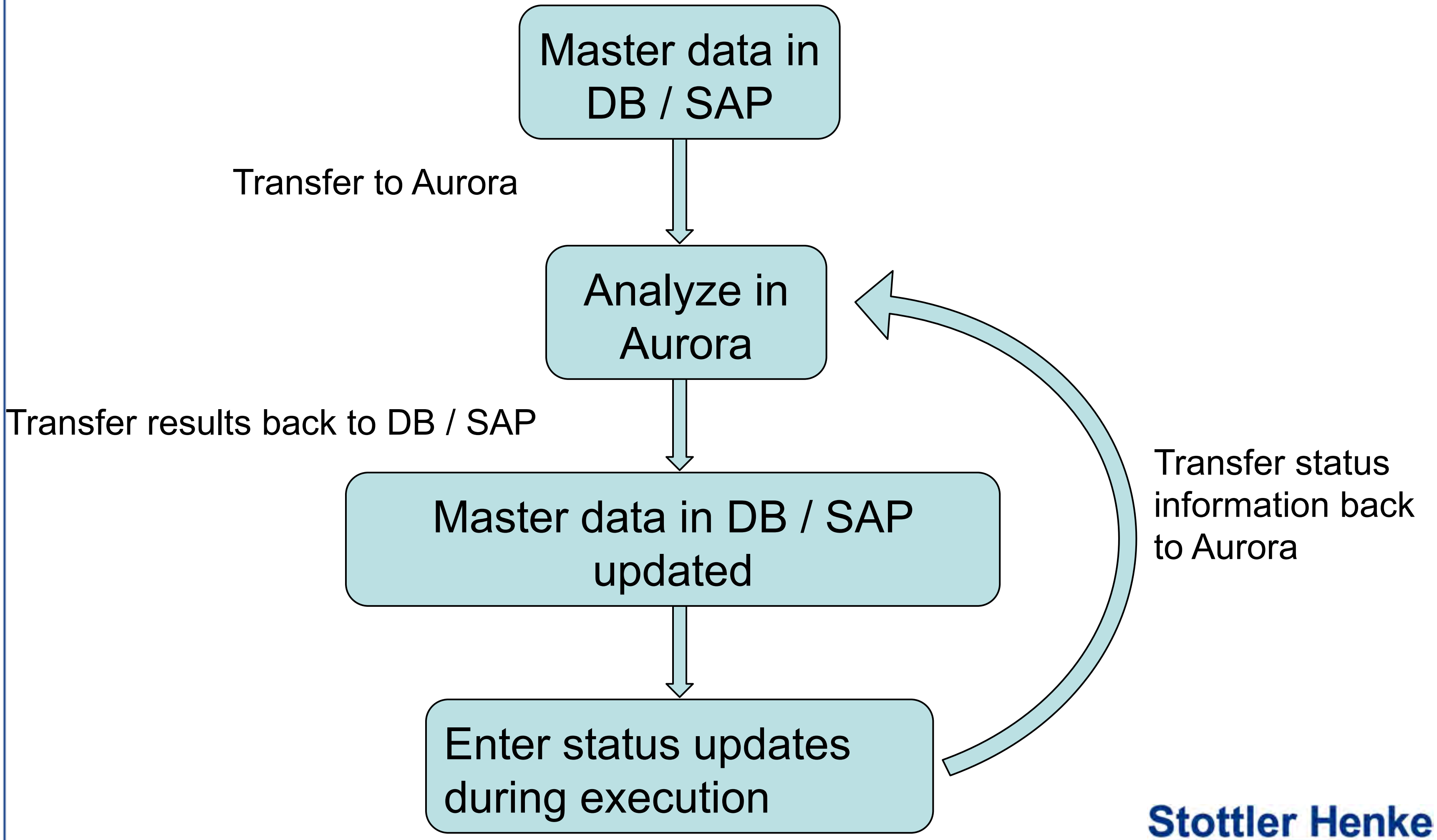
Status updates entered into Primavera P6

- Save Primavera P6 as XER → Import into Aurora
- Aurora updates schedule
- Export Aurora → XML → Primavera P6

Aurora 3rd Party Interface Options: Enterprise DB / SAP



Potential Workflow with DB / SAP



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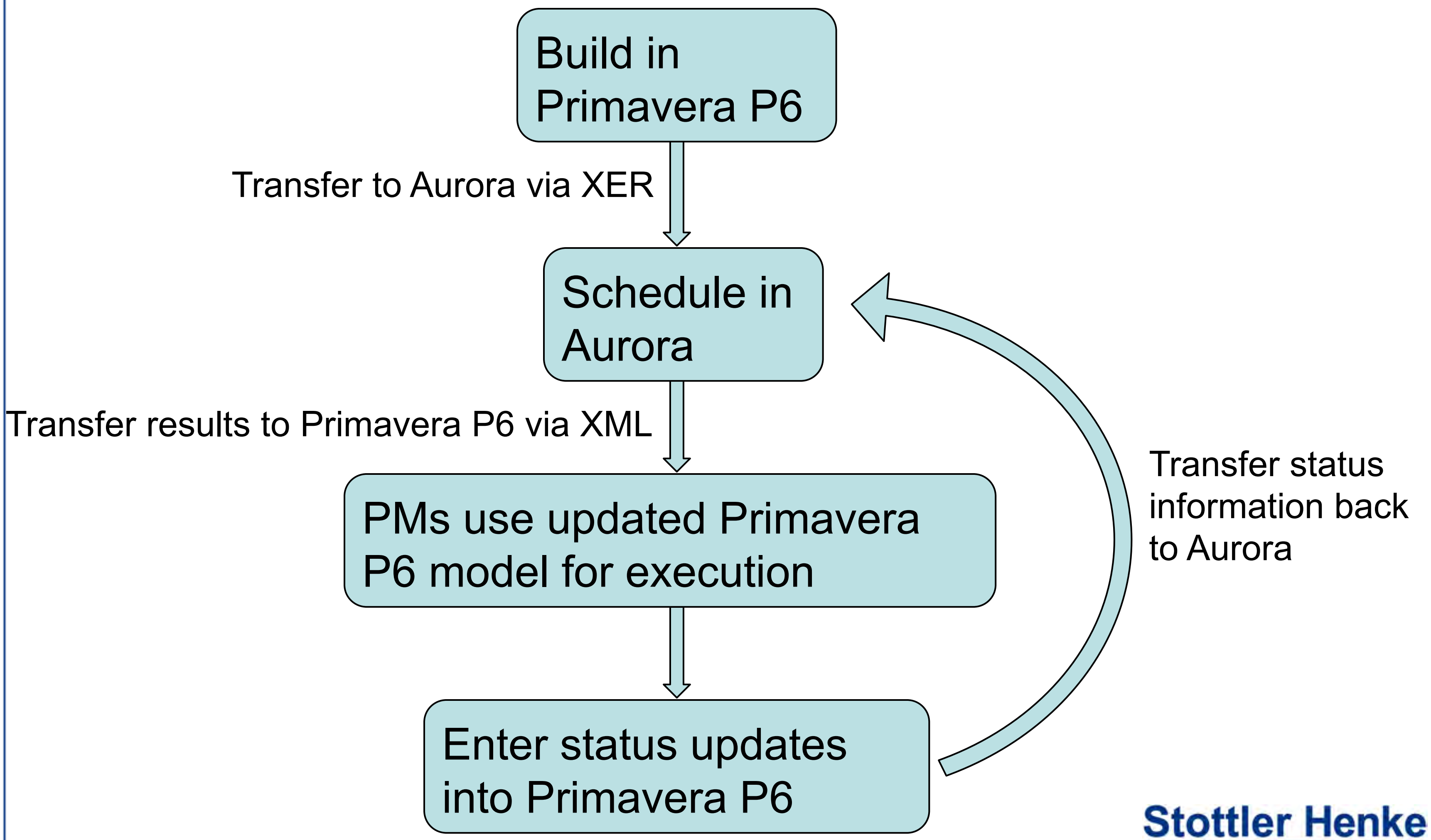
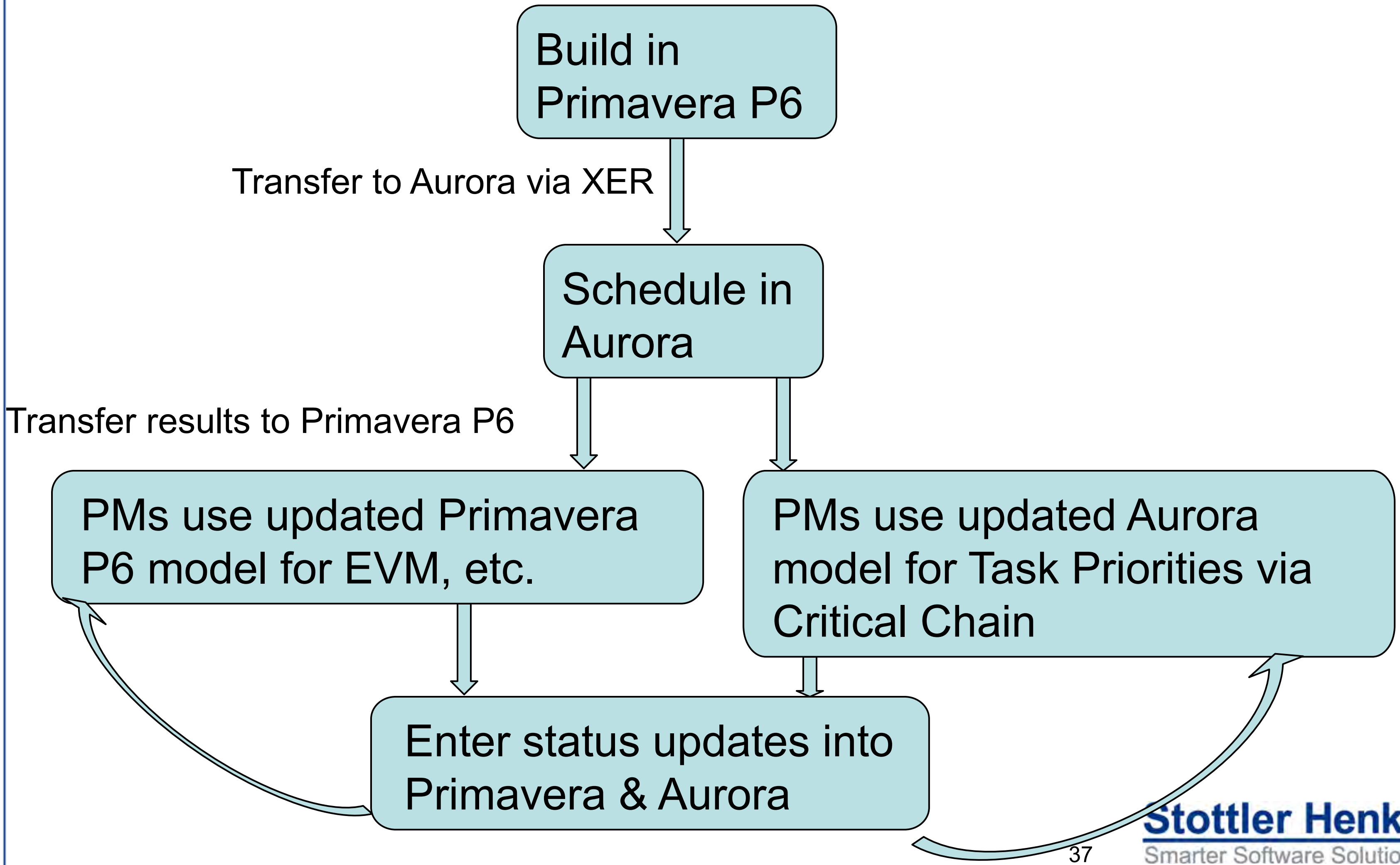
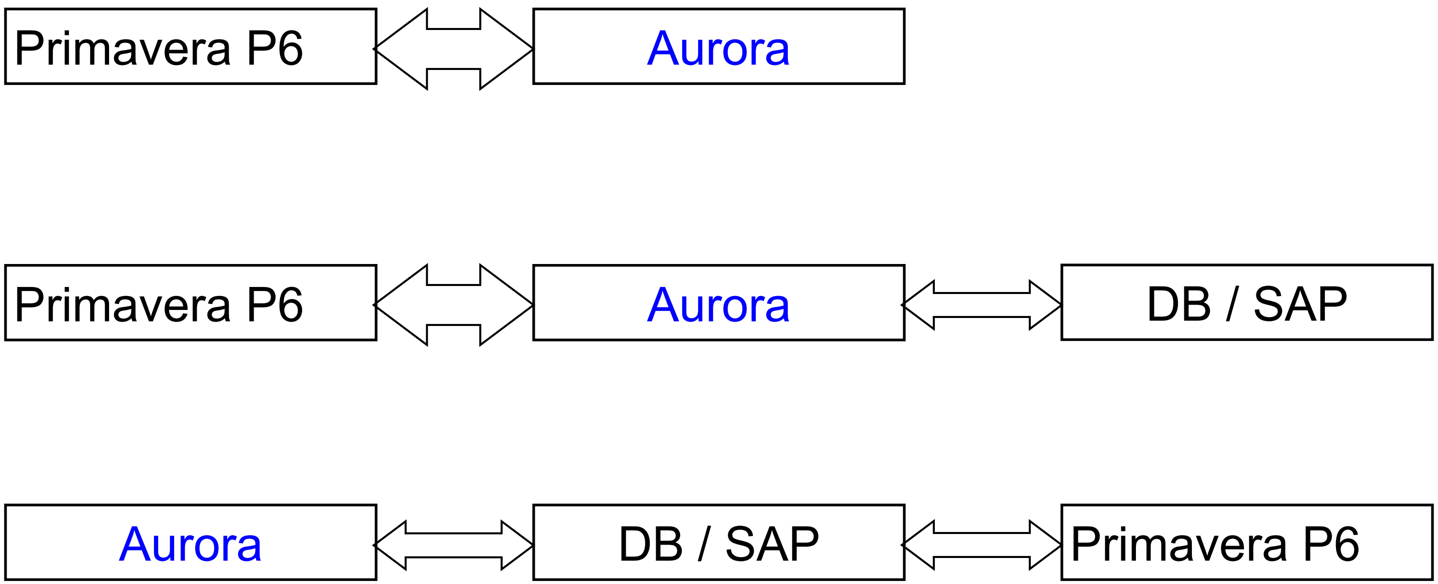
Potential Workflow with Primavera P6: Flowchart



P6:
Flowchart for Critical Chain



Aurora 3rd Party Interface Options: Primavera P6



IT Configuration Options

- Simple Single Aurora Instance
- Standalone Aurora with Database access
- Aurora Server version with Web access

Simple Single Aurora Instance

Windows Server 20xx

- Microsoft Project
- Aurora

Standalone Aurora with Database Access

Windows Server 20xx

- Microsoft Project
- Aurora DB
- Aurora
- SAP Interface (optional)

Client Machines

- Aurora
  - Local file
  - DB Access

Aurora Server Version with Web Access

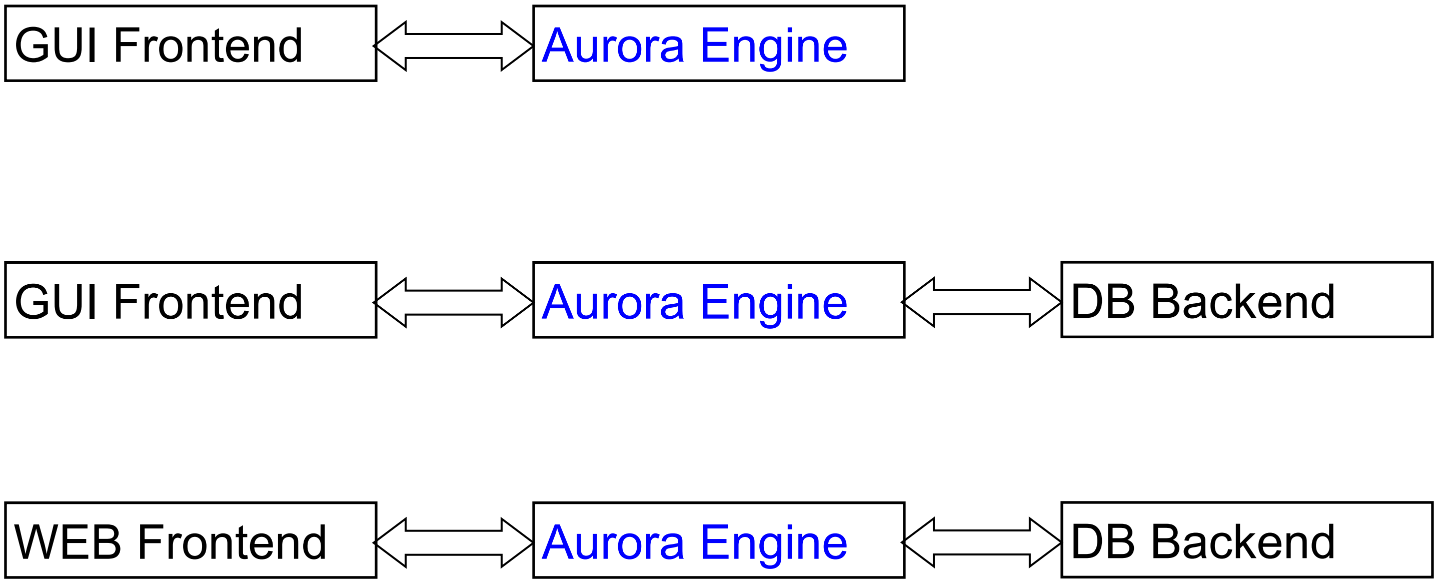
Windows Server 20xx

- Microsoft Project
- Aurora DB
- Aurora Server
- Apache/Tomcat Server
- SAP Interface (optional)

Client Machines

- Aurora Standalone (optional)
- Web Browser

Aurora Interface Options



Aurora Customization

Pluggable decision methods
Combines temporal and resource-oriented approaches
Fuses good defaults and extensive expert access
Mix of general and specific methods
Build up library, menu approach
Produces schedules for easy comprehension
Provides extensive interactive displays supporting analysis
Separate UI Application (vocab., mapping)
Customizable graphical displays
Customizable external system interfaces

Aurora Critical Chain Summary

Enterprise Level Critical Chain Project Management Software

Multi Project

Aurora-CCPM: Unique Benefits

World's Most Powerful Critical Chain Software

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Aurora-CCPM 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 software *only* provides ALAP scheduling

Aurora-CCPM Unique Capabilities & Benefits (2)

Primavera P6 Integration

- Only software that works 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-CCPM 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-CCPM 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

Critical Chain Market

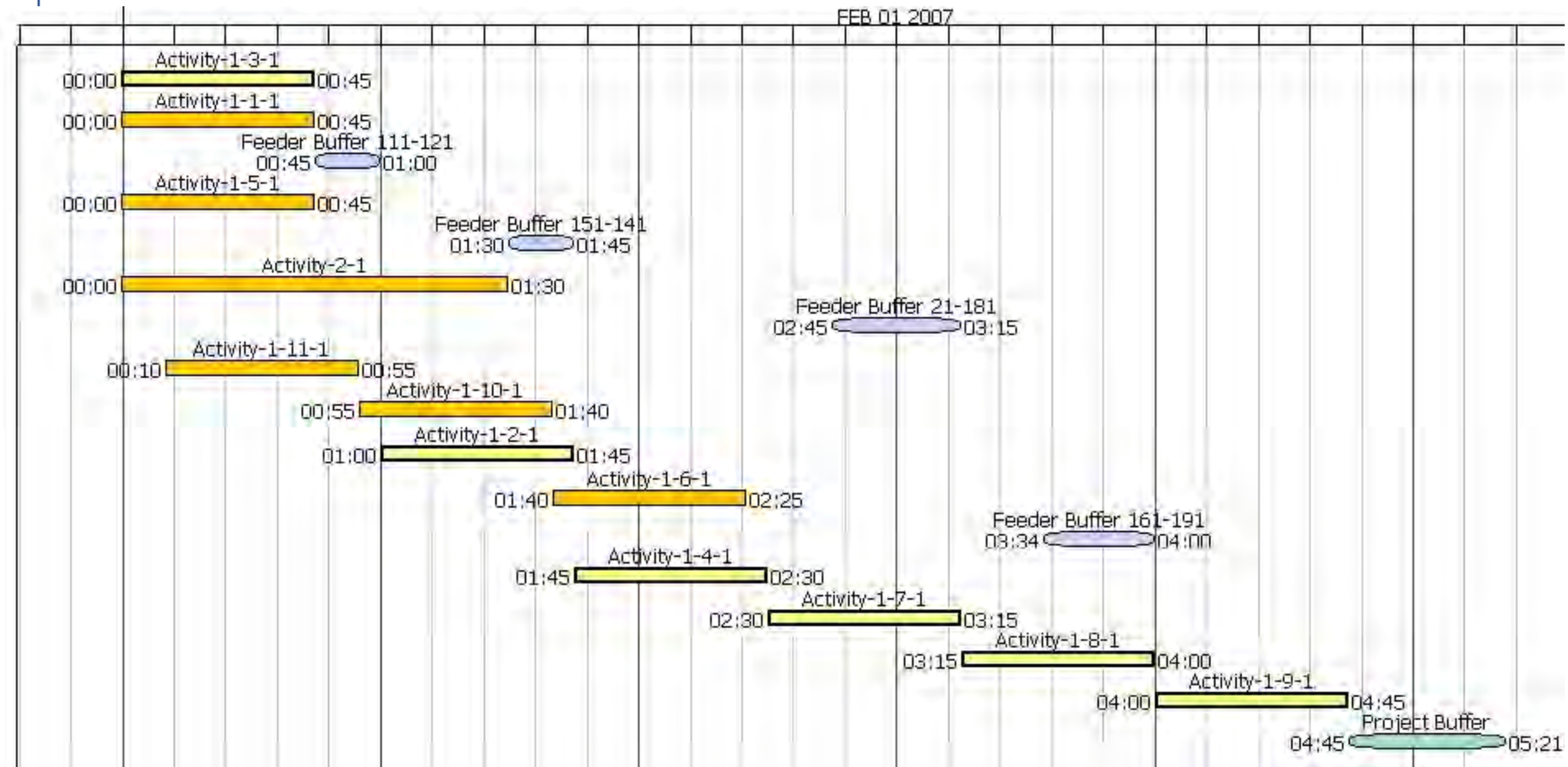
Japan's Ministry of Land Infrastructure and Transportation has mandated that all contractors must use Critical Chain

Many Critical Chain solutions built on-top of Microsoft Project

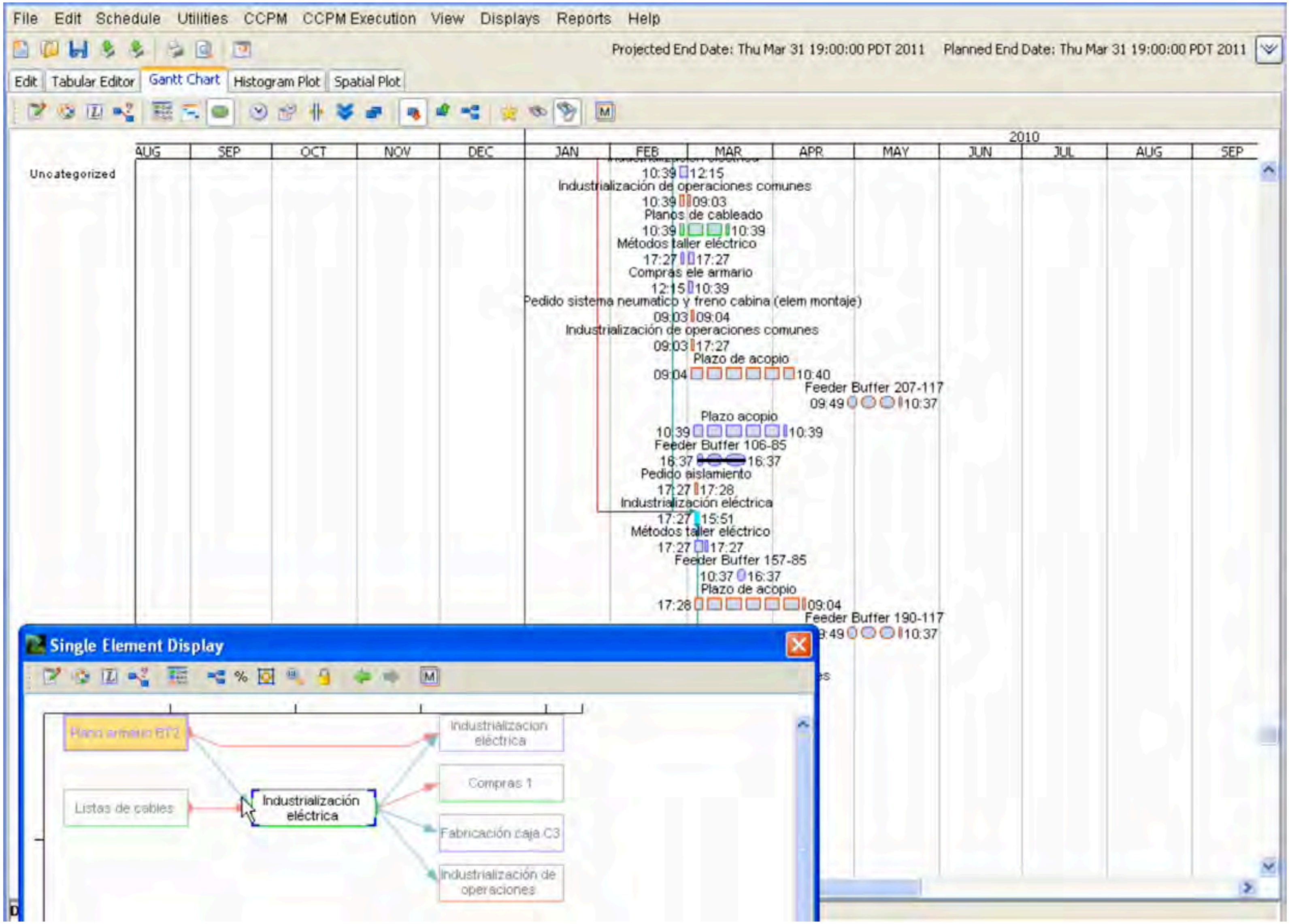
None built on Primavera P6

No other software even works with P6

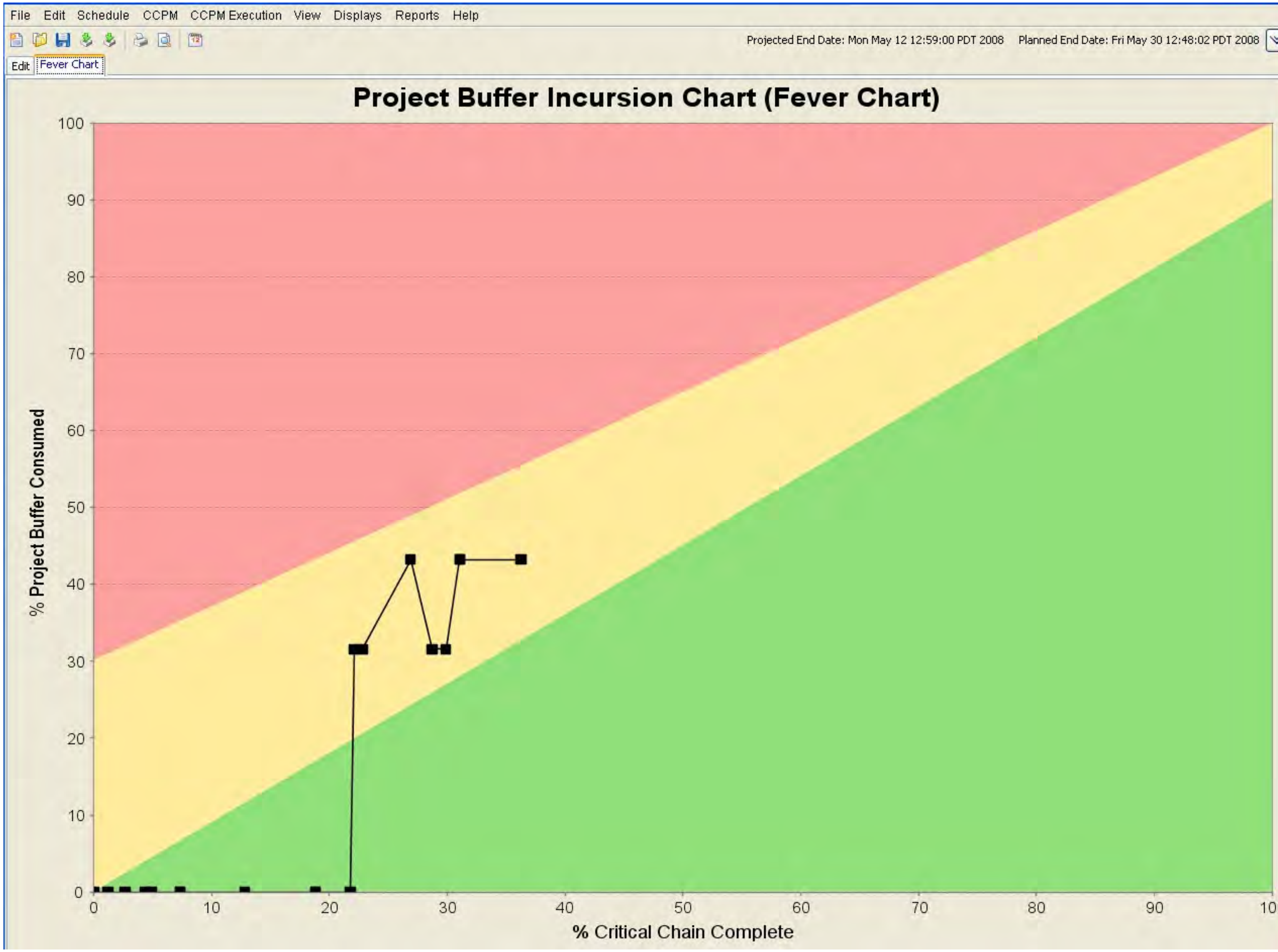
A Small Critical Chain Project (Critical Chain in Yellow w/ Thick Outline)



Gantt Chart & Single-element view
Note Feeder Buffers

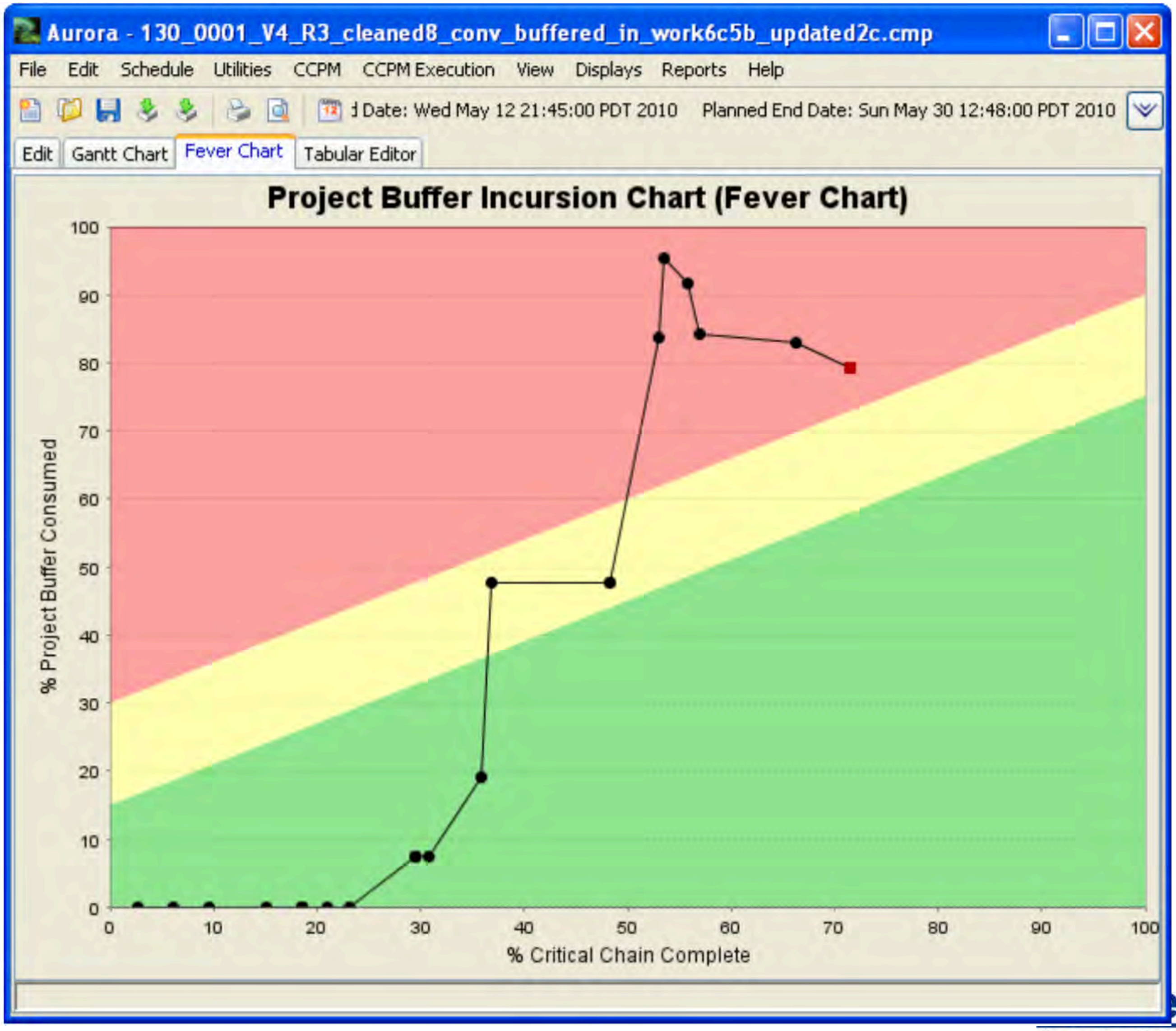


Fever Chart



File Edit Schedule CCPM CCPM Execution View Displays Reports Help
Projected End Date: Mon May 12 12:59:00 PDT 2008
Planned End Date: Fri May 30 12:48:02 PDT 2008
Edit
Fever Chart
Project Buffer Incursion Chart (Fever Chart)
% Project Buffer Consumed
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
% Critical Chain Complete

Fever Chart (2)



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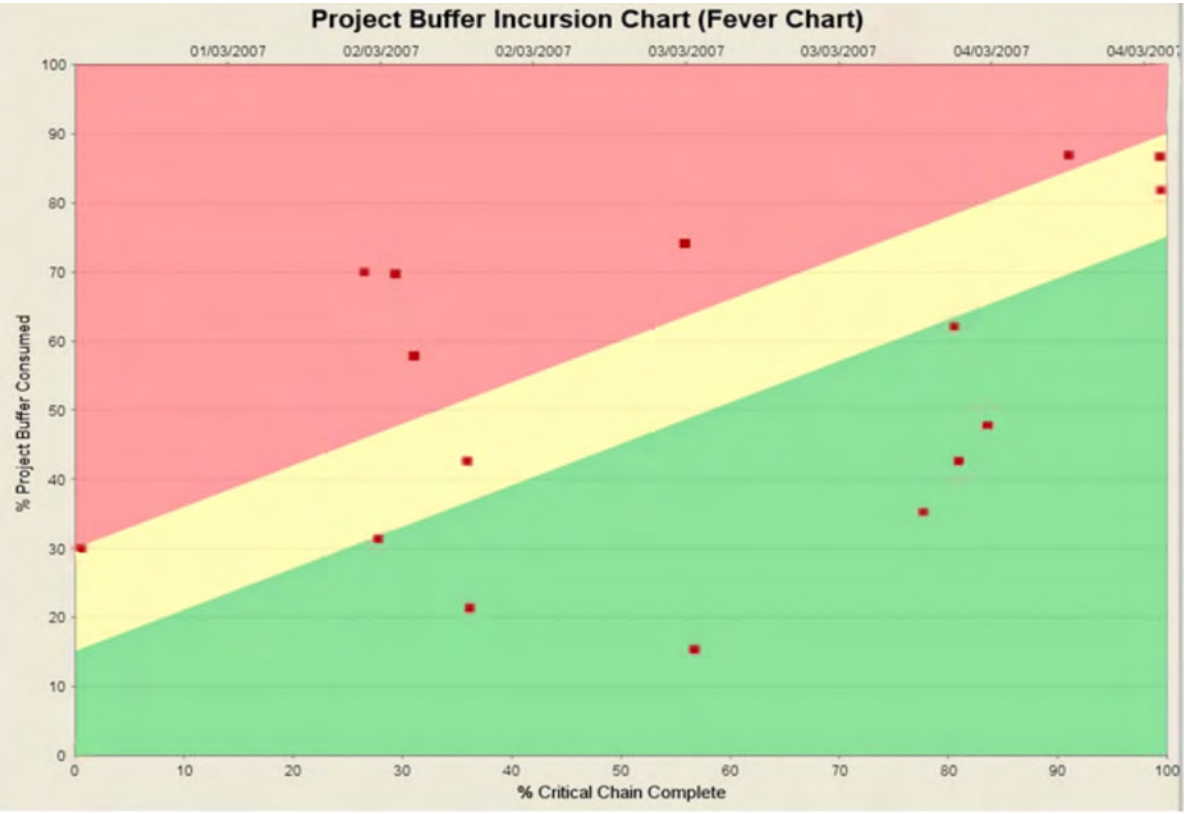
Multi-Project Fever Chart

Single point for each project

Click on a project to bring up the Fever Chart for the particular project.



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Work Assignments

- CCPM is primarily a scheduling tool, not a day-to-day / minute by minute work assignment tool.
  - It's a tool that sequences tasks and buffers them.
- Human still receives Prioritized Task List and determines next assignments
  - May need to inquire about latest time remaining estimates
- But, in highly interactive cases, blending the many resource types, timing and variation, this decision becomes a difficult one. Having intelligent scheduling software to reduce the decision space is beneficial to the human assigner.

Task Priority Report

Task Priority Report

Priority	Task Name	IP#	Predicted Project Incur...	Predicted Feeder Incursion	Project B...	Feeder Bu...	Start Date/Time	Status	Labor Resource
1	Open Cowls	FAD01DMTT080E	0.57	14.44	43.23	100.0	[2008:04:29:12:04:00]	On Hold	97109
2	Post Engine Run Check	FAD2ADMTT140E	0.57	14.44	43.23	100.0	[2008:04:29:12:37:00]		97109
3	Close Cowls	FAD01DMTT100E	0.57	14.44	43.23	100.0	[2008:04:29:16:24:00]		97109
4	Wait Time - Multiple Engine Run	FADWTDMTX000E	0.57	14.44	43.23	100.0	[2008:04:29:16:57:00]		
5	Start Gauntlet Preflight	FADMSDVTX785B	0.57	14.44	43.23	100.0	[2008:04:30:22:57:00]		
6	Gauntlet Preflight - Main Cabin Interior	FAD01DVTV810B	0.57	14.44	43.23	100.0	[2008:05:01:00:00:00]		97109
7	Gauntlet Preflight - Door Check	FAD01DVTV795B	0.57	14.44	43.23	100.0	[2008:05:01:16:41:00]		97109
8	Gauntlet Preflight - Airplane	FAD01DVTV790B	0.00	14.44	43.23	100.0	[2008:05:01:00:00:00]		97109
9	Gauntlet Preflight - Software Bump	FAD01DVTV830B	0.00	14.44	43.23	100.0	[2008:05:01:00:00:00]		97109
10	Gauntlet Preflight - Service Tires and S...	FAD01DVTV820B	0.00	14.44	43.23	100.0	[2008:05:01:00:00:00]		97109
11	Gauntlet Preflight - Flight Deck Avionics	FAD01DVTV805B	0.00	14.44	43.23	100.0	[2008:05:01:03:04:00]		97109
12	Gauntlet Preflight - Miscellaneous Servi...	FAD01DVTV815B	0.00	14.44	43.23	100.0	[2008:05:01:00:00:00]		97109
13	Gauntlet Preflight - Service Water and ...	FAD01DVTV825B	0.00	14.44	43.23	100.0	[2008:05:01:04:36:00]		97109
14	Gauntlet Preflight - Cabin Avionics	FAD01DVTV840B	0.00	14.44	43.23	100.0	[2008:05:01:08:23:00]		97109
15	Gauntlet Preflight - Emergency Lights ...	FAD01DVTV800B	0.00	14.44	43.23	100.0	[2008:05:01:09:55:00]		97109
16	Gauntlet Preflight - LMI's Interior and E...	FAD01DVTV835B	0.57	14.44	43.23	100.0	[2008:05:01:18:13:00]		97109
17	Gauntlet Post Flight - Safety Check	FAD01DMTT070P	0.57	14.44	43.23	100.0	[2008:05:02:02:31:00]		97109
18	Gauntlet Post Flight - Squawks	FADWTDMTX005P	0.57	14.44	43.23	100.0	[2008:05:02:07:50:00]		
19	Start Taxi Ground Test Preflight	FADMSDVTX000S	0.57	14.44	43.23	100.0	[2008:05:03:08:13:00]		
20	Taxi Ground Test Preflight - Main Cabin...	FAD01DVTV243B	0.57	14.44	43.23	100.0	[2008:05:05:00:00:00]		97109
21	Taxi Ground Test Preflight -Door Check	FAD01DVTV240B	0.57	14.44	43.23	100.0	[2008:05:05:16:41:00]		97109
22	Taxi Ground Test Preflight - Preflight Ai...	FAD01DVTV249B	0.00	14.44	43.23	100.0	[2008:05:05:00:00:00]		97109
23	Taxi Ground Test Preflight - Flight Deck...	FAD01DVTV246B	0.00	14.44	43.23	100.0	[2008:05:05:00:00:00]		97109
24	Taxi Ground Test Preflight - Service tir...	FAD01DVTV244B	0.00	14.44	43.23	100.0	[2008:05:05:00:00:00]		97109
25	Taxi Ground Test Preflight -Miscellaneo...	FAD01DVTV241B	0.00	14.44	43.23	100.0	[2008:05:05:00:00:00]		97109
26	Taxi Ground Test Preflight -Software b...	FAD01DVTV242B	0.00	14.44	43.23	100.0	[2008:05:05:03:04:00]		97109
27	Taxi Ground Test Preflight - Service W...	FAD01DVTV245B	0.00	14.44	43.23	100.0	[2008:05:05:03:04:00]		97109
28	Taxi Ground Test Preflight - Cabin Avio...	FAD01DVTV248B	0.00	14.44	43.23	100.0	[2008:05:05:04:36:00]		97109
29	Taxi Ground Test Preflight - Emergenc...	FAD01DVTV247B	0.00	14.44	43.23	100.0	[2008:05:05:08:23:00]		97109
30	Taxi Ground Test Preflight -LMI's Exteri...	FAD01DVTV250B	0.57	14.44	43.23	100.0	[2008:05:05:18:13:00]		97109
31	Taxi Ground Test Post Flight - Park and...	FAD01DMTT075P	0.57	14.44	43.23	100.0	[2008:05:06:02:31:00]		97109
32	Taxi Ground Test - Intermediate Accep...	FAD01DVTV263V	0.57	14.44	43.23	100.0	[2008:05:06:08:06:00]		97109

Aurora/Aurora-CCPM Applications

- Boeing 787 Aircraft Assembly (replaced 20 year, in-house Timepiece product)
- Space Shuttle Processing
- Space Station Processing Facility (SSPF) floor space and resources
- Navy Ship System Upgrades
- Crew Exploration Vehicle (CEV) In-space crew/resource
- Ballistic missile intercepts
- Air Force satellite downlink scheduling
- Navy submarine maintenance

In every domain attempted, Aurora has surpassed all existing scheduling systems

Boeing Airplane Assembly Scheduling

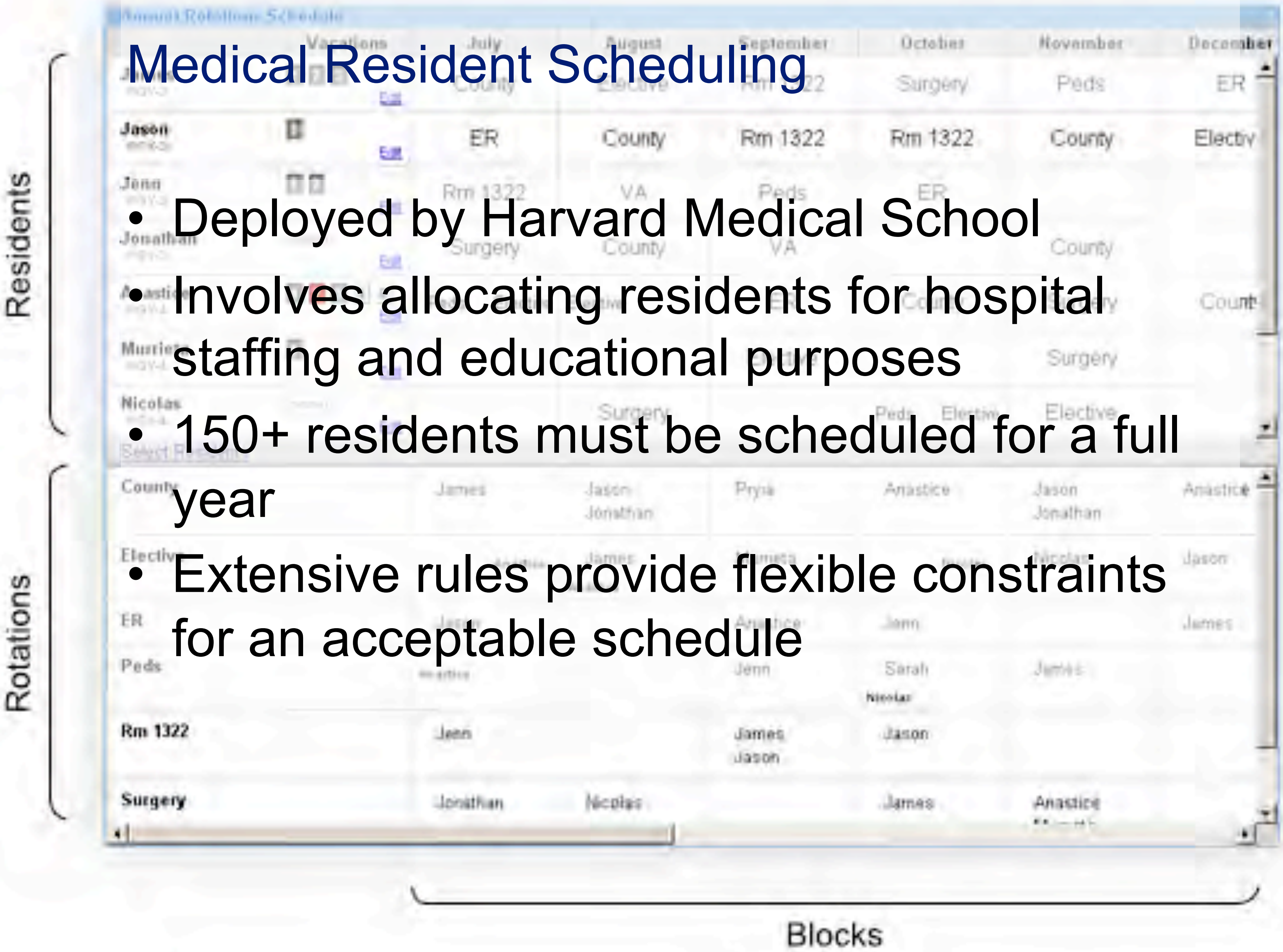
- Very large, complex models
  - Large numbers of resource contentions, constraints
- Widely distributed users working on different projects
- Part of integrated management system
  - Accepts inputs from modeling system, sends outputs to shop floor management system

Learjet Multi-Phase Assembly Scheduling

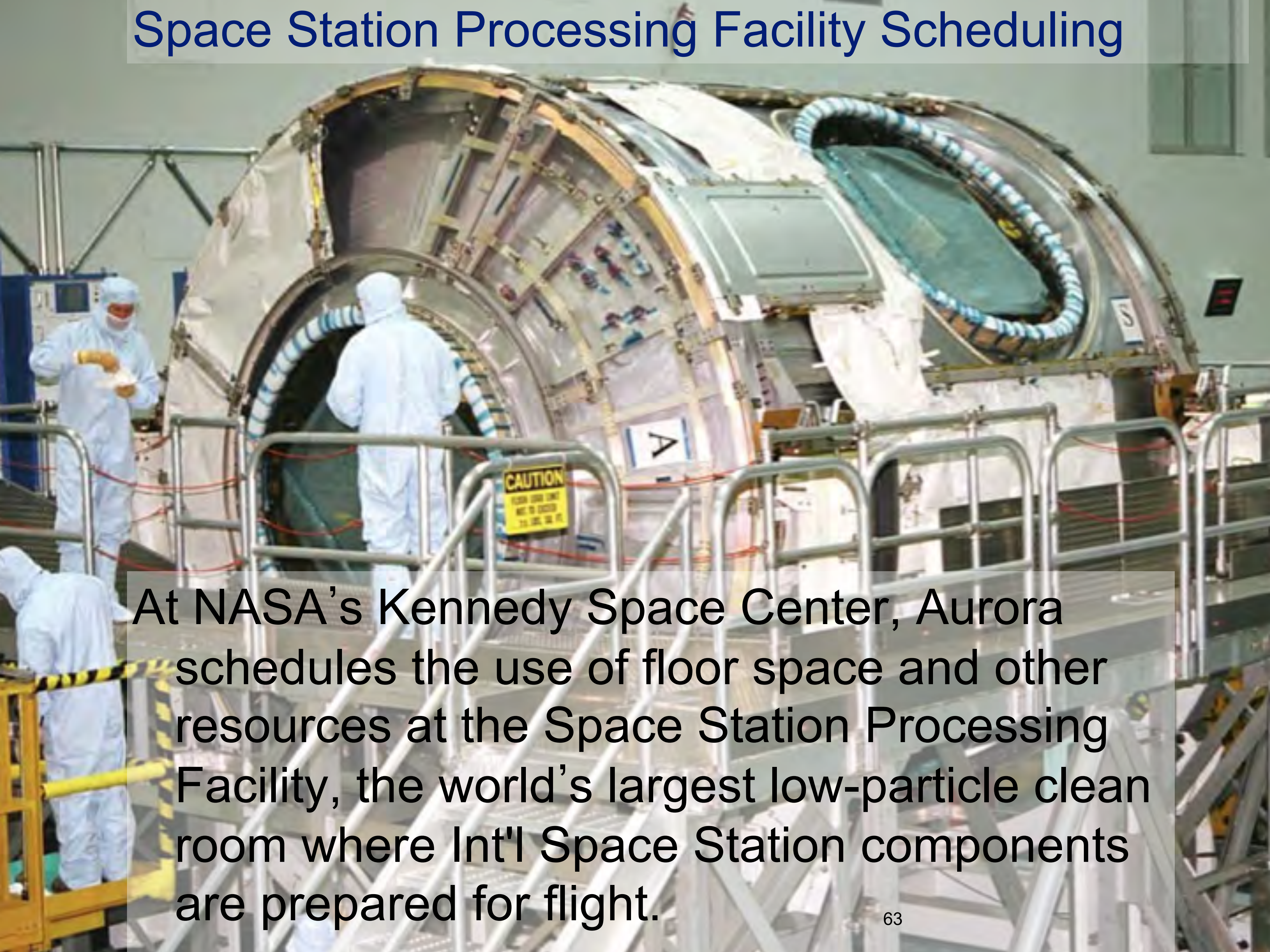
- Many small, inter-related models
- Each model must be managed separately, but may impact other models
- Significant resource contention, moderate additional constraints
- In long term, models to be used both for long-term projections and short-term recovery management

Medical Resident Scheduling

- Deployed by Harvard Medical School
- Involves allocating residents for hospital staffing and educational purposes
- 150+ residents must be scheduled for a full year
- Extensive rules provide flexible constraints for an acceptable schedule



Space Station Processing Facility Scheduling



At NASA's 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 where Int'l Space Station components are prepared for flight.

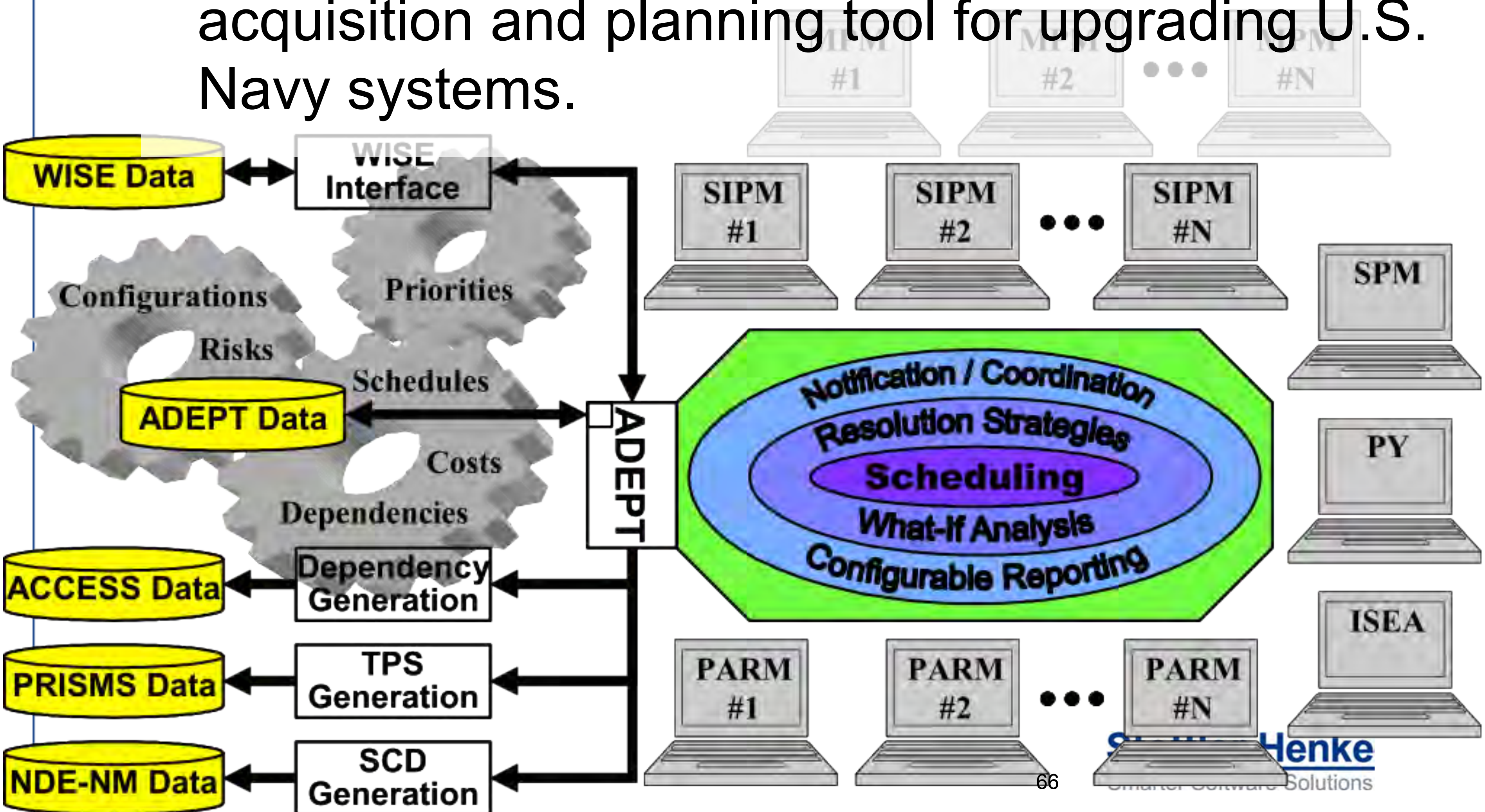
The Value of Aurora: NASA

“Aurora is used daily to support major processing and space shuttle launch decisions; to coordinate our launches with those of Russia, Japan, and the European Space Agency; and to determine NASA's launch requirements and flight rates," says NASA Shuttle Processing Manager Tom Overton. "It enables us to generate complex schedules in a few hours, compared to days or weeks required by our previous scheduling systems."

NASA: Shuttle Maintenance, Repair & Overhaul

Acquisition Decision Expert Planning Tool (ADEPT)

Aurora was included in ADEPT, an intelligent acquisition and planning tool for upgrading U.S. Navy systems.

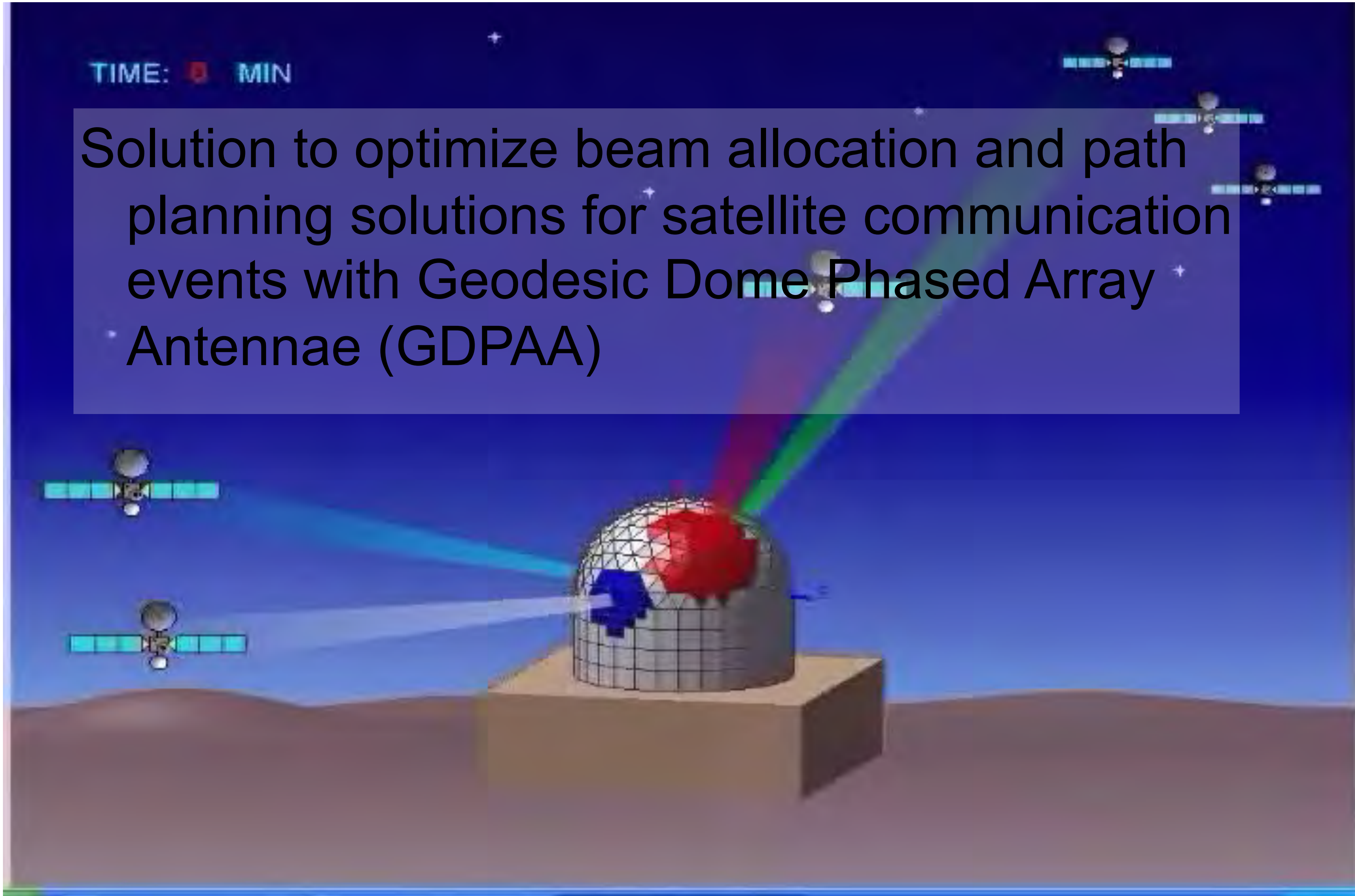


Temporis

Aurora is included in Temporis, a scheduling system by the United Space Alliance, to be used by NASA crew members on-board next generation of space vehicles.

Phased Array Smart Allocation and Planning (PASAP)

Solution to optimize beam allocation and path planning solutions for satellite communication events with Geodesic Dome Phased Array Antennae (GDPAA)



Managed Intelligent Deconfliction And Scheduling (MIDAS)

Performs automated resource assignment, scheduling, and deconfliction for Defensive Space Control and Space Situational Awareness operations.

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

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

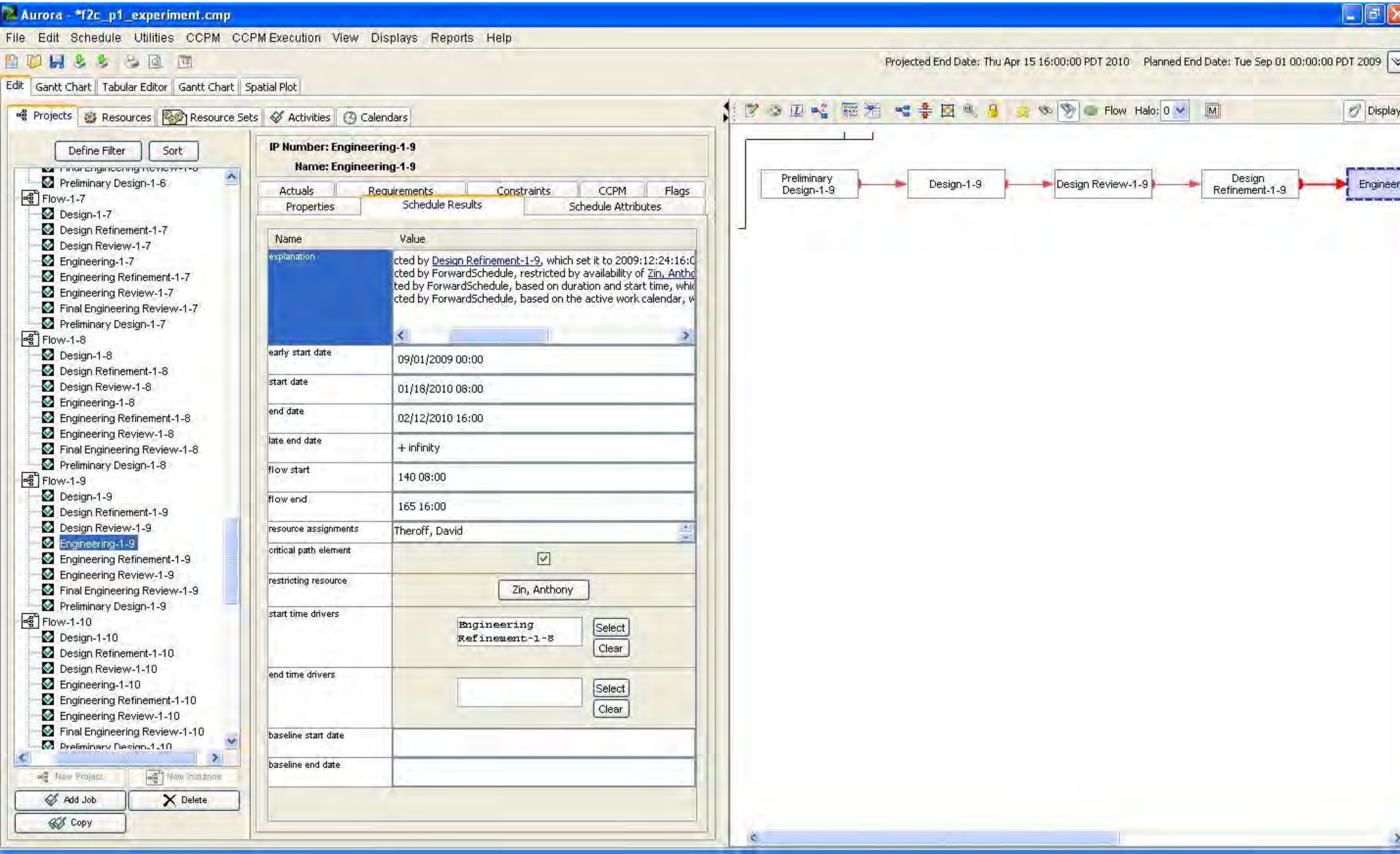
Mixed-mode scheduling

- Forward and backward scheduling is set on a task-by-task basis.

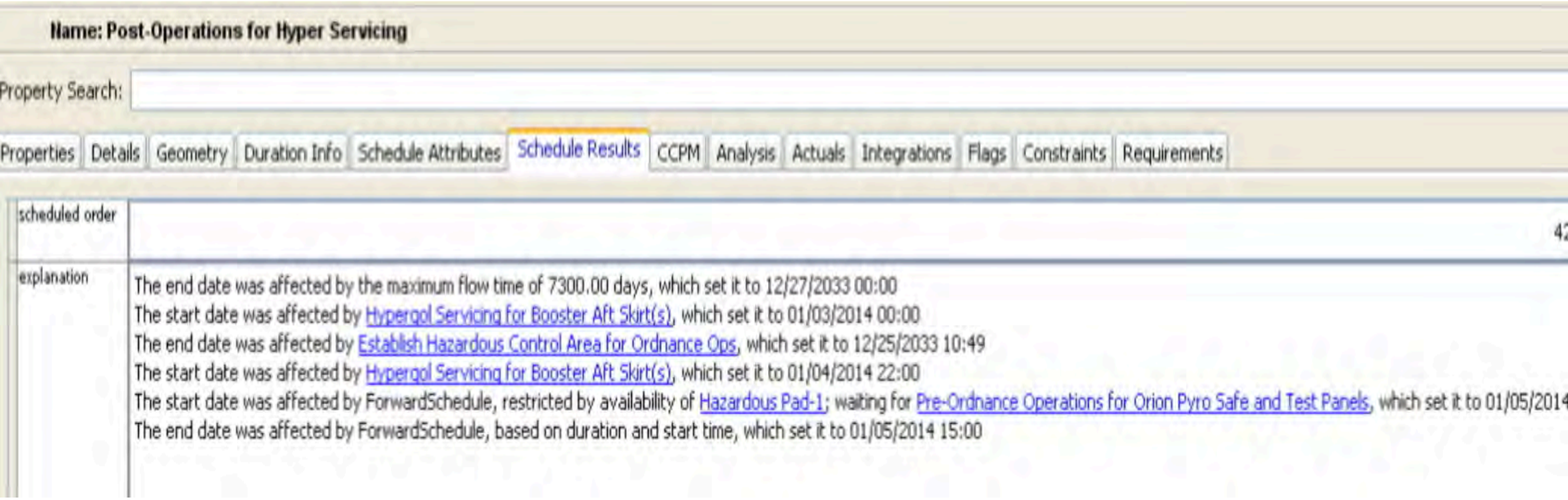
Schedule Rationale

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.

Explanation of Why each Task was Scheduled Where it was



Schedule Results: Explanation



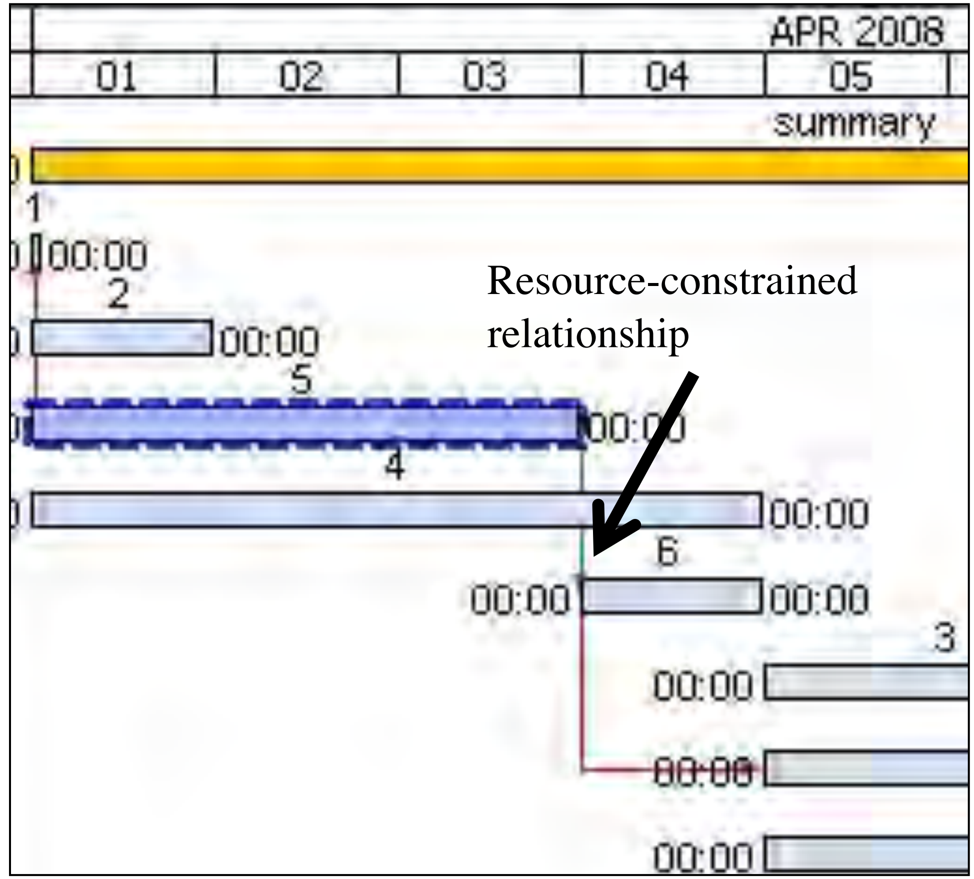
Resource Contention: Visual

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.

Stottler Henke
Smarter Software Solutions

Resource Contention: Task 6

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

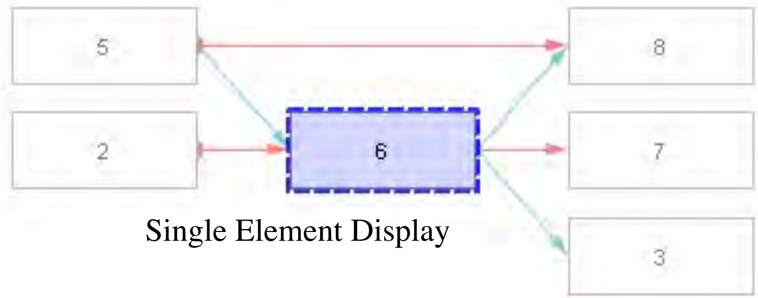
- Blue-grey lines denote a resource-constrained work flow
- Red lines denote temporally-constrained work flow

Referring to the three diagrams to the right:

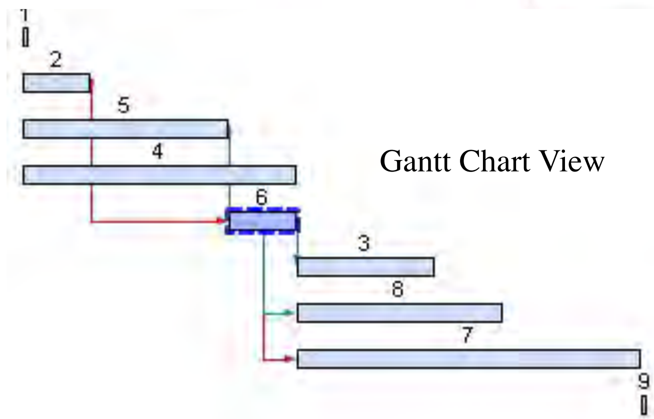
- Task 6 can start any time after Task 2 is completed (red line in Single Element Display), but must wait for Task 5 to release resources (blue-grey line).

- 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)

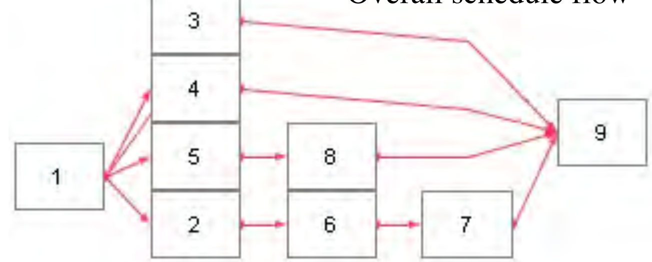


Single Element Display

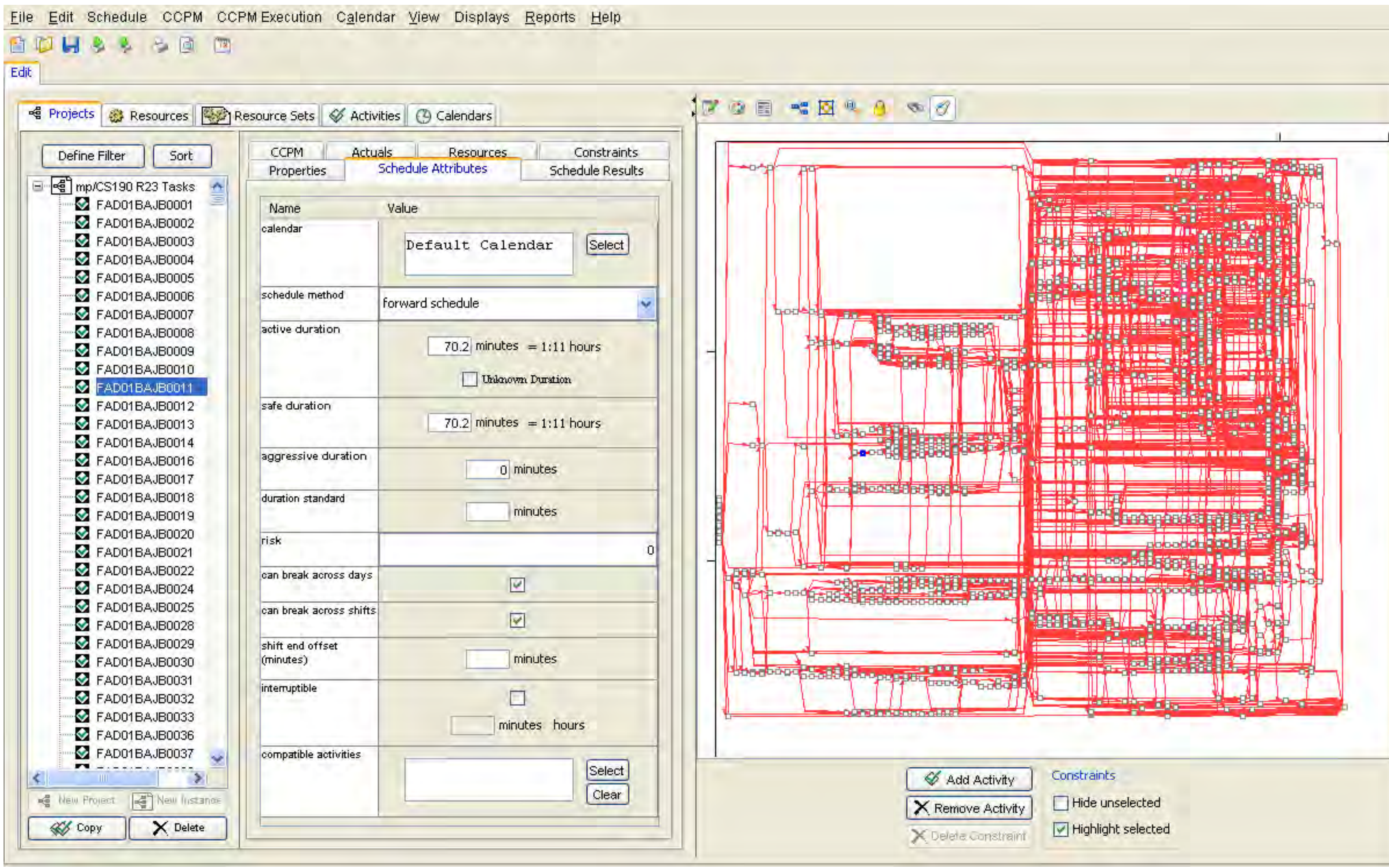


Gantt Chart View

Overall schedule flow



Aurora: Screenshot



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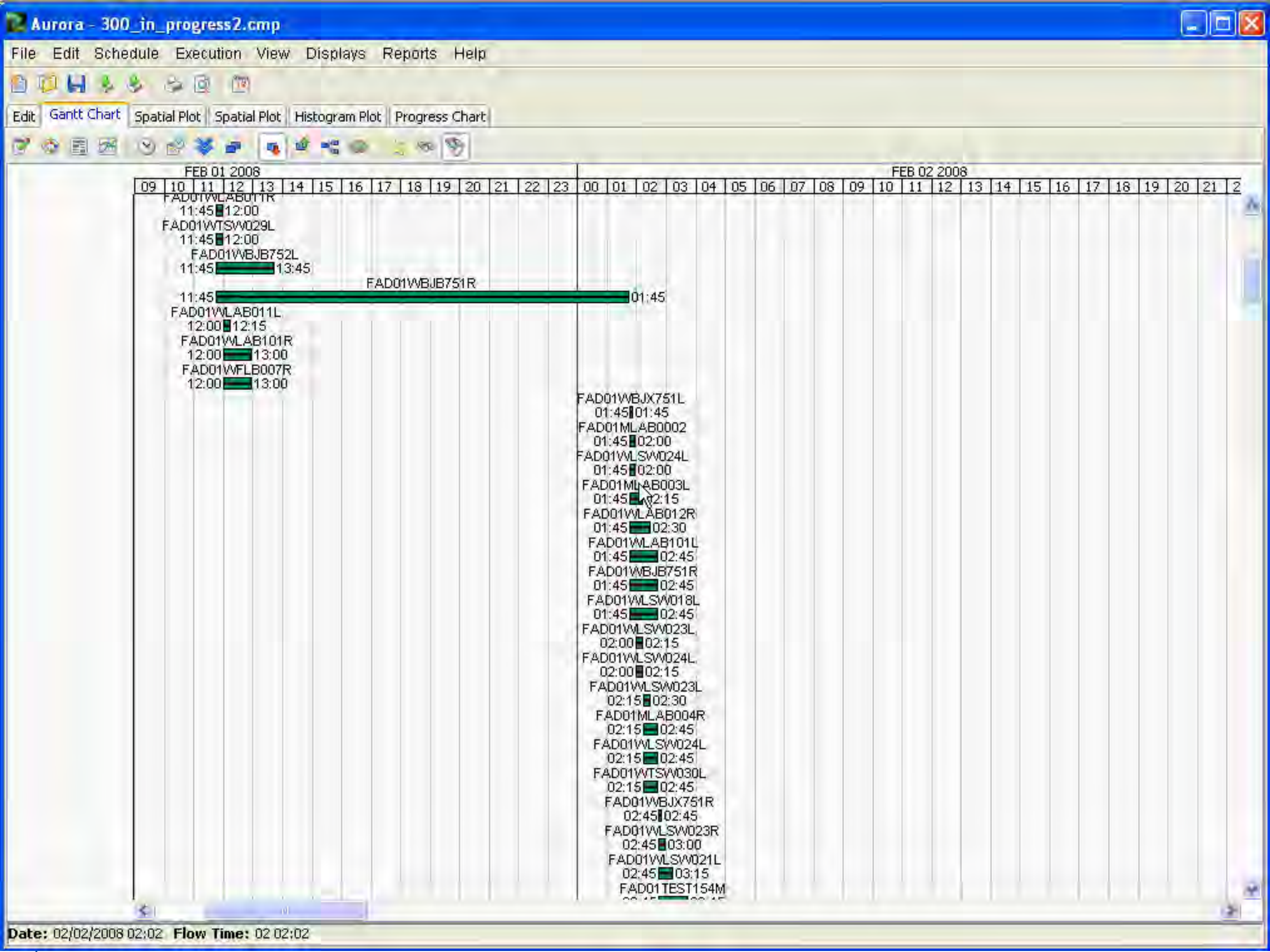
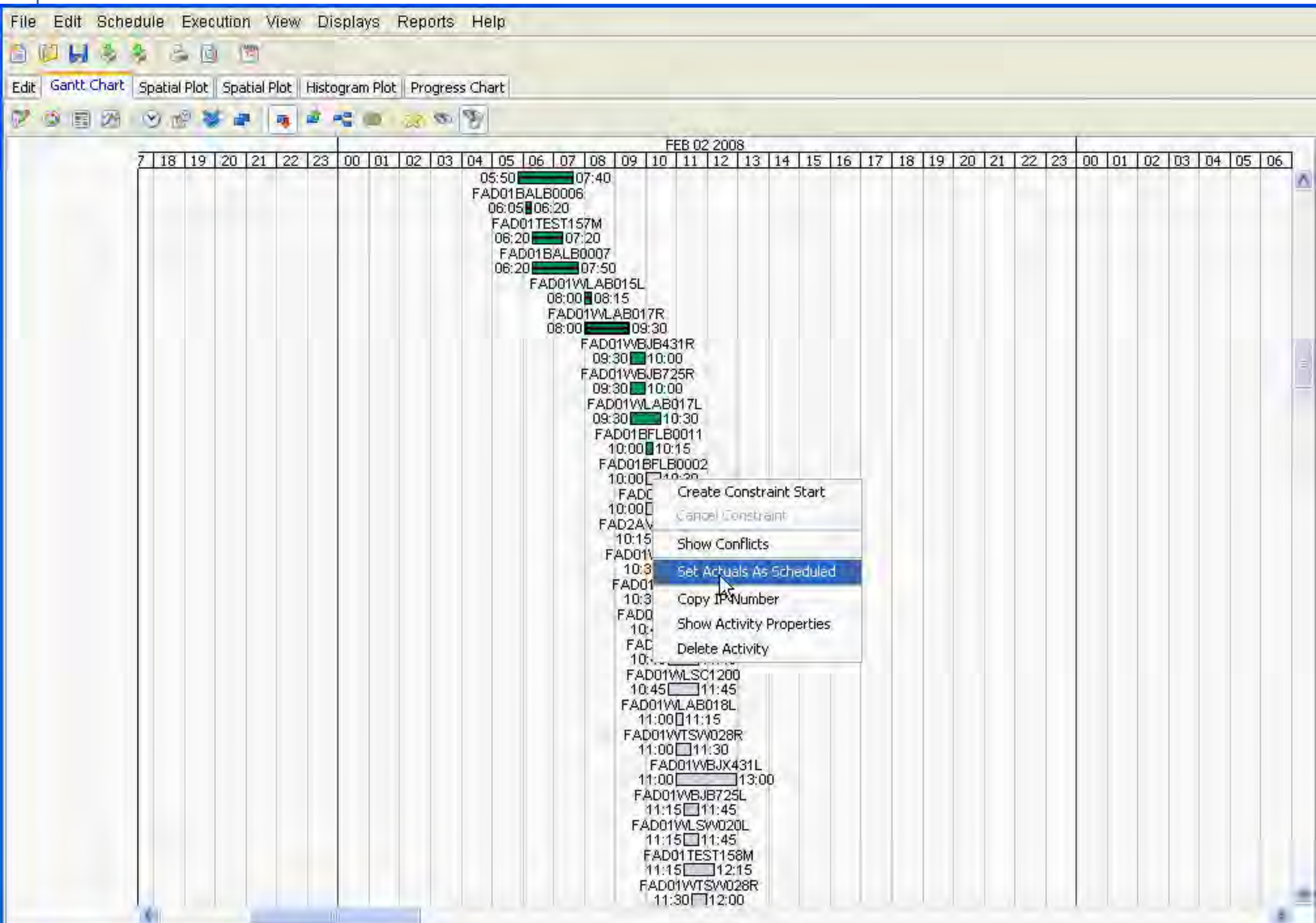
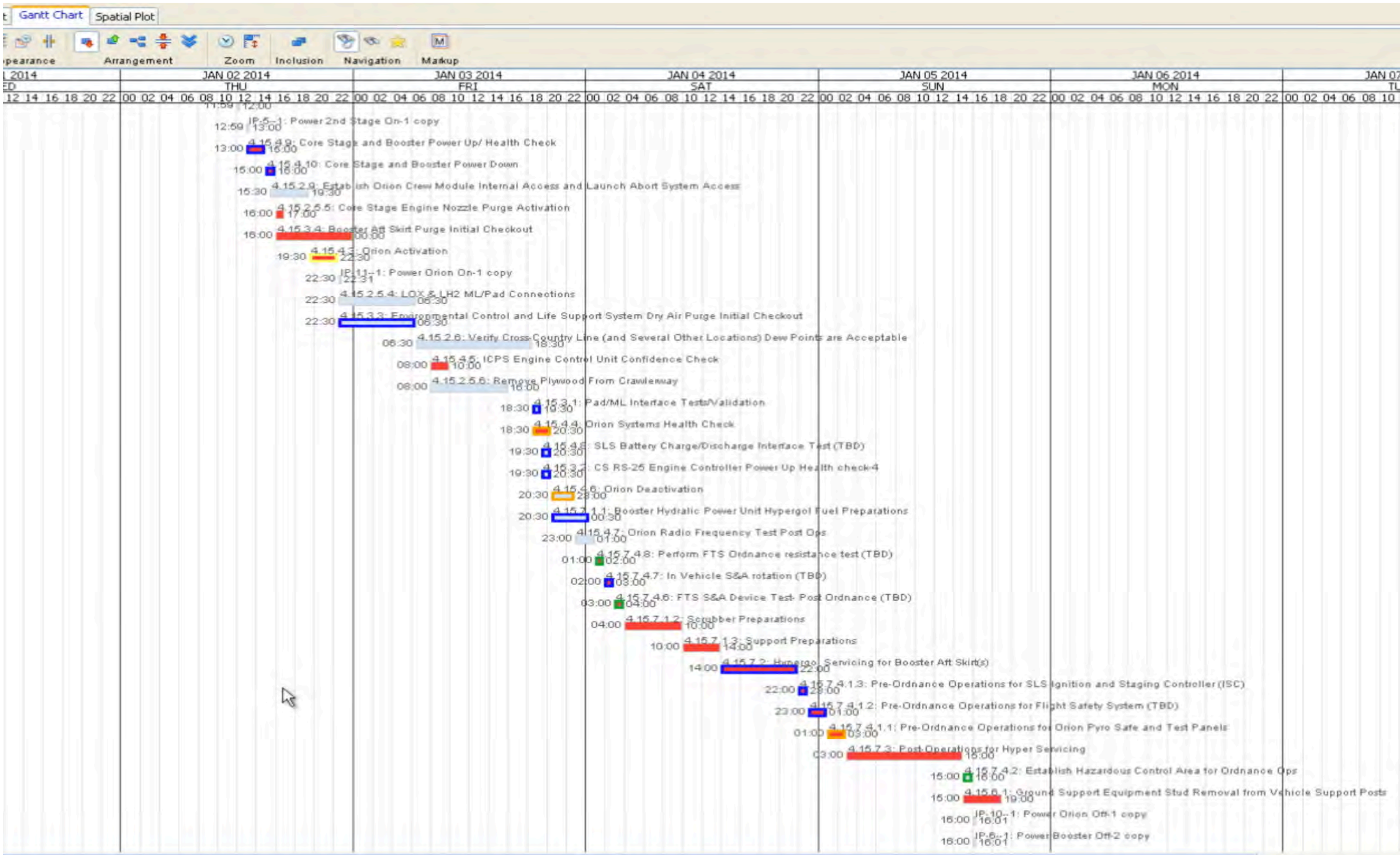

Aurora - 300_in_progress2.cmp
File Edit Schedule Execution View Displays Reports Help
Edit
Gantt Chart
Spatial Plot
Spatial Plot
Histogram Plot
Progress Chart
FEB 01 2008
FEB 02 2008
09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21
11:45 12:00
FAD01WTSW029L
11:45 12:00
FAD01WBJB752L
11:45 13:45
FAD01WBJB751R
11:45 01:45
FAD01WLAB011L
12:00 12:15
FAD01WLAB101R
12:00 13:00
FAD01WFLB007R
12:00 13:00
FAD01WBJX751L
01:45 01:45
FAD01MLAB0002
01:45 02:00
FAD01WLSW024L
01:45 02:00
01:45
FAD01WLAB012R
01:45 02:30
FAD01WLAB101L
01:45 02:45
FAD01WBJB751R
01:45 02:45
FAD01WLSW018L
01:45 02:45
FAD01WLSW023L
02:00 02:15
FAD01WLSW024L
02:00 02:15
FAD01WLSW023L
02:15 02:30
FAD01MLAB004R
02:15 02:45
FAD01WLSW024L
02:15 02:45
FAD01WTSW030L
02:15 02:45
FAD01WBJX751R
02:45 02:45
FAD01WLSW023R
02:45 03:00
FAD01WLSW021L
02:45 03:15
FAD01TEST154M
Date: 02/02/2008 02:02 Flow Time: 02 02:02


File Edit Schedule Execution View Displays Reports Help
Edit
Gantt Chart
Spatial Plot
Spatial Plot
Histogram Plot
Progress Chart
FEB 02 2008
05:50 07:40
FAD01BALB0006
06:05 06:20
FAD01TEST157M
06:20 07:20
FAD01BALB0007
06:20 07:50
FAD01WLAB015L
08:00 08:15
FAD01WLAB017R
08:00 09:30
FAD01WBJB431R
09:30 10:00
FAD01WBJB725R
09:30 10:00
FAD01WLAB017L
09:30 10:30
FAD01BFLB0011
10:00 10:15
FAD01BFLB0002
Create Constraint Start
Cancel Constraint
Show Conflicts
Set Actuals As Scheduled
Copy IP Number
Show Activity Properties
Delete Activity
FAD01WLSC1200
10:45 11:45
FAD01WLAB018L
11:00 11:15
FAD01WTSW028R
11:00 11:30
FAD01WBJX431L
11:00 13:00
FAD01WBJB725L
11:15 11:45
FAD01WLSW020L
11:15 11:45
FAD01TEST158M
11:15 12:15
FAD01WTSW028R
11:30 12:00

Gantt: Color-coded (per different requirements)



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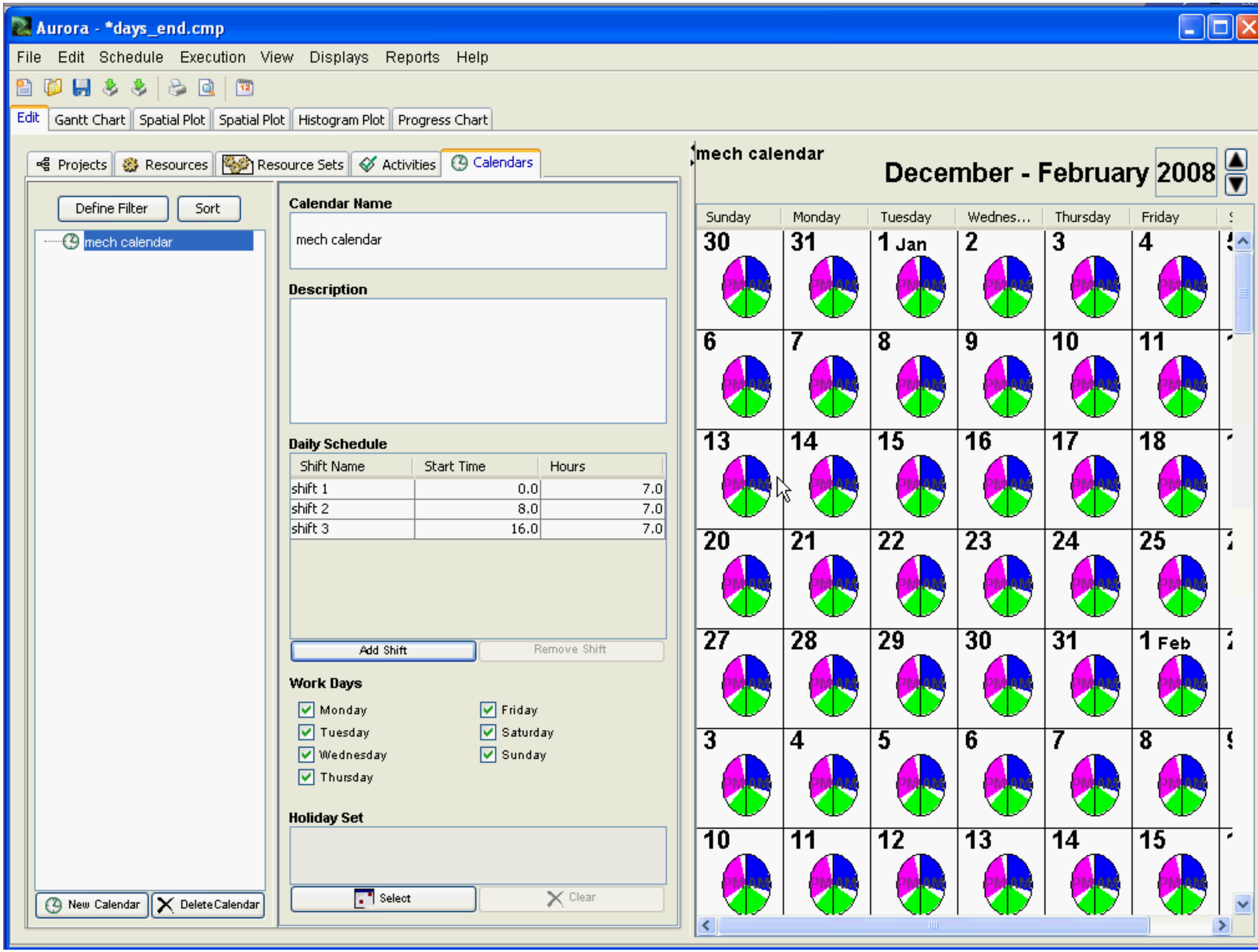
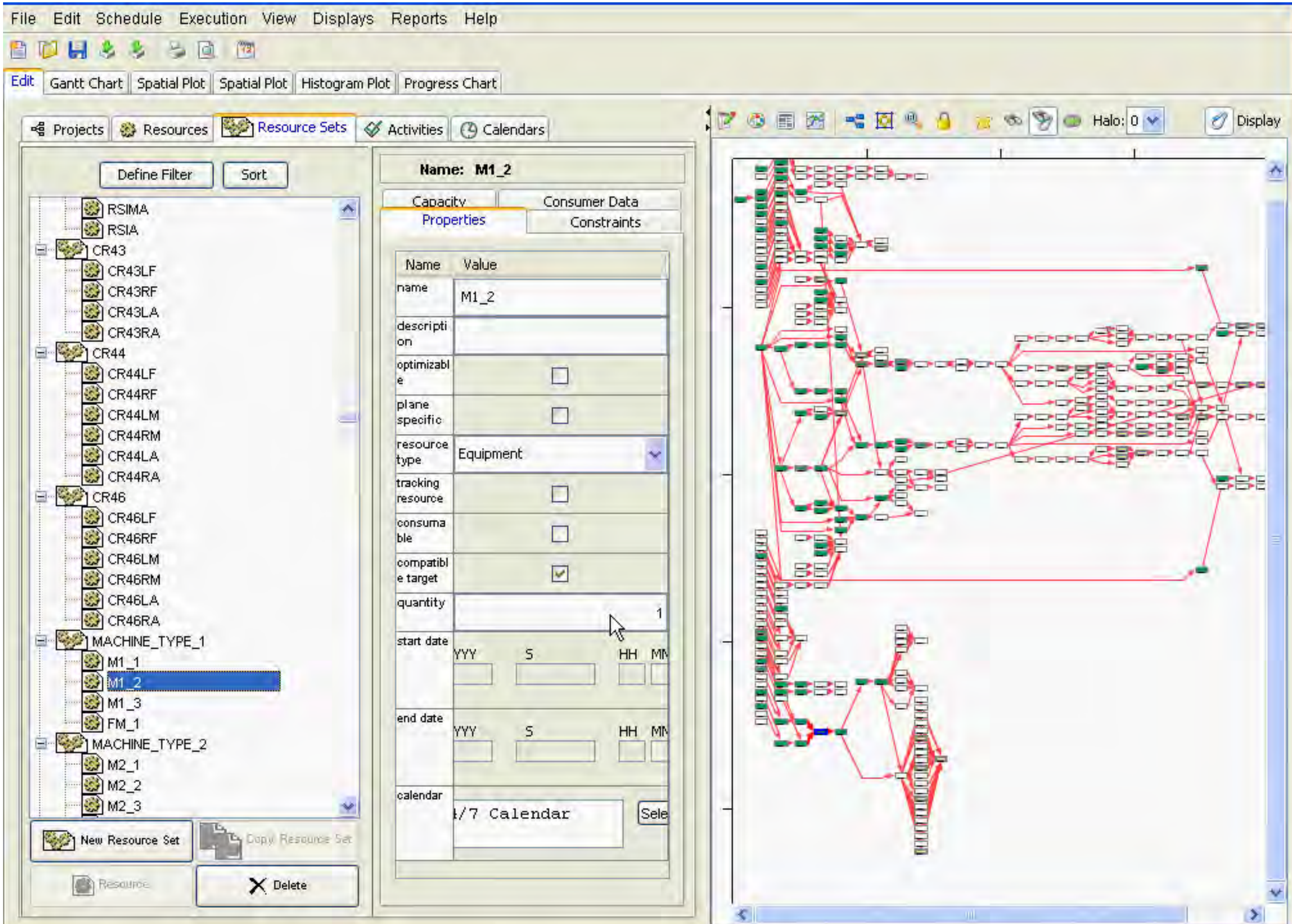
Calendars

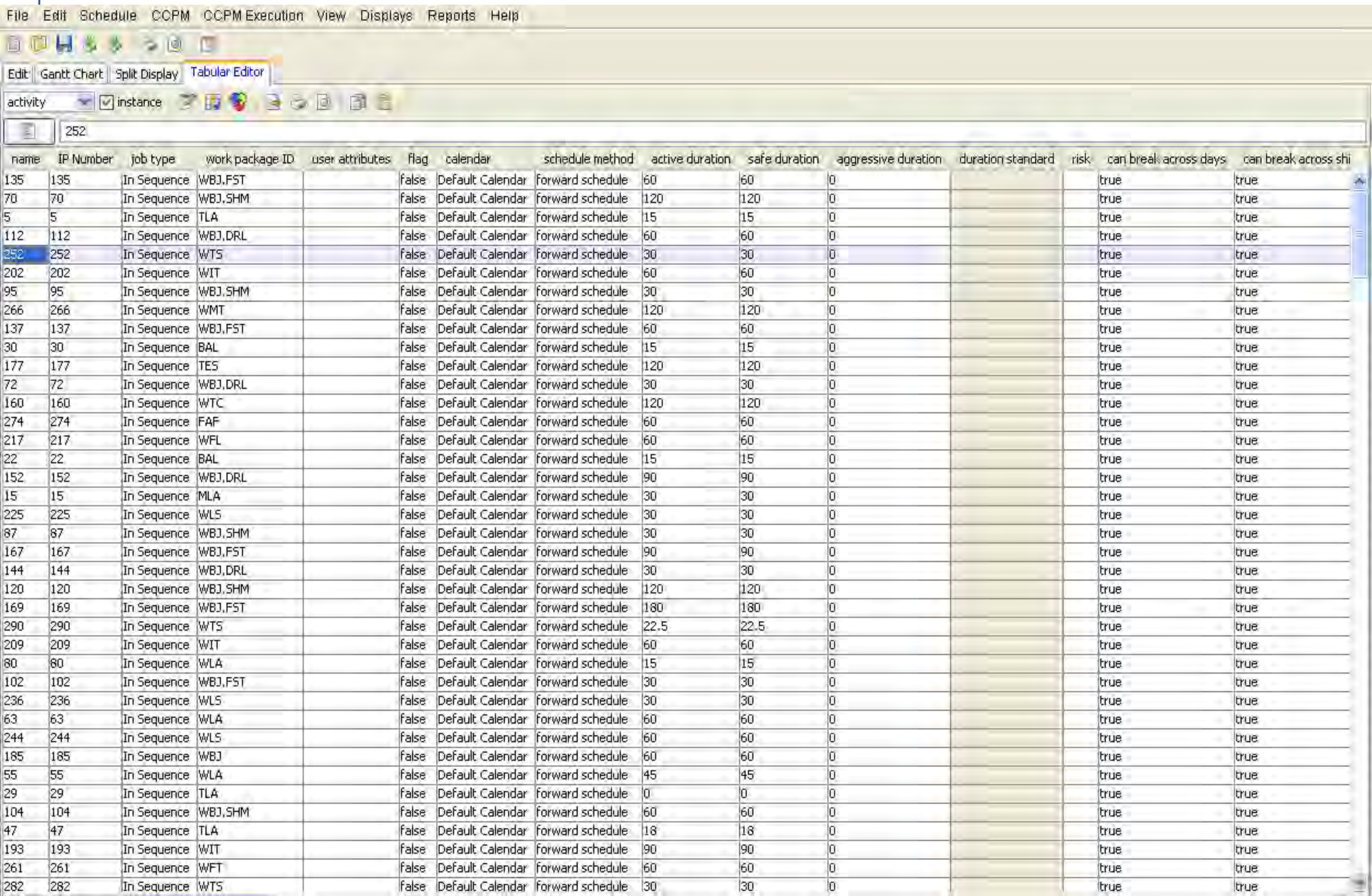


Aurora - *days_end.cmp
File Edit Schedule Execution View Displays Reports Help
Edit Gantt Chart Spatial Plot Spatial Plot Histogram Plot Progress Chart
Projects Resources Resource Sets Activities Calendars
Define Filter Sort
mech calendar
New Calendar Delete Calendar
Calendar Name
mech calendar
Description
Daily Schedule
Shift Name Start Time Hours
shift 1 0.0 7.0
shift 2 8.0 7.0
shift 3 16.0 7.0
Add Shift Remove Shift
Work Days
Monday Tuesday Wednesday Thursday Friday Saturday Sunday
Holiday Set
Select Clear
mech calendar
December - February 2008
Sunday Monday Tuesday Wednes... Thursday Friday

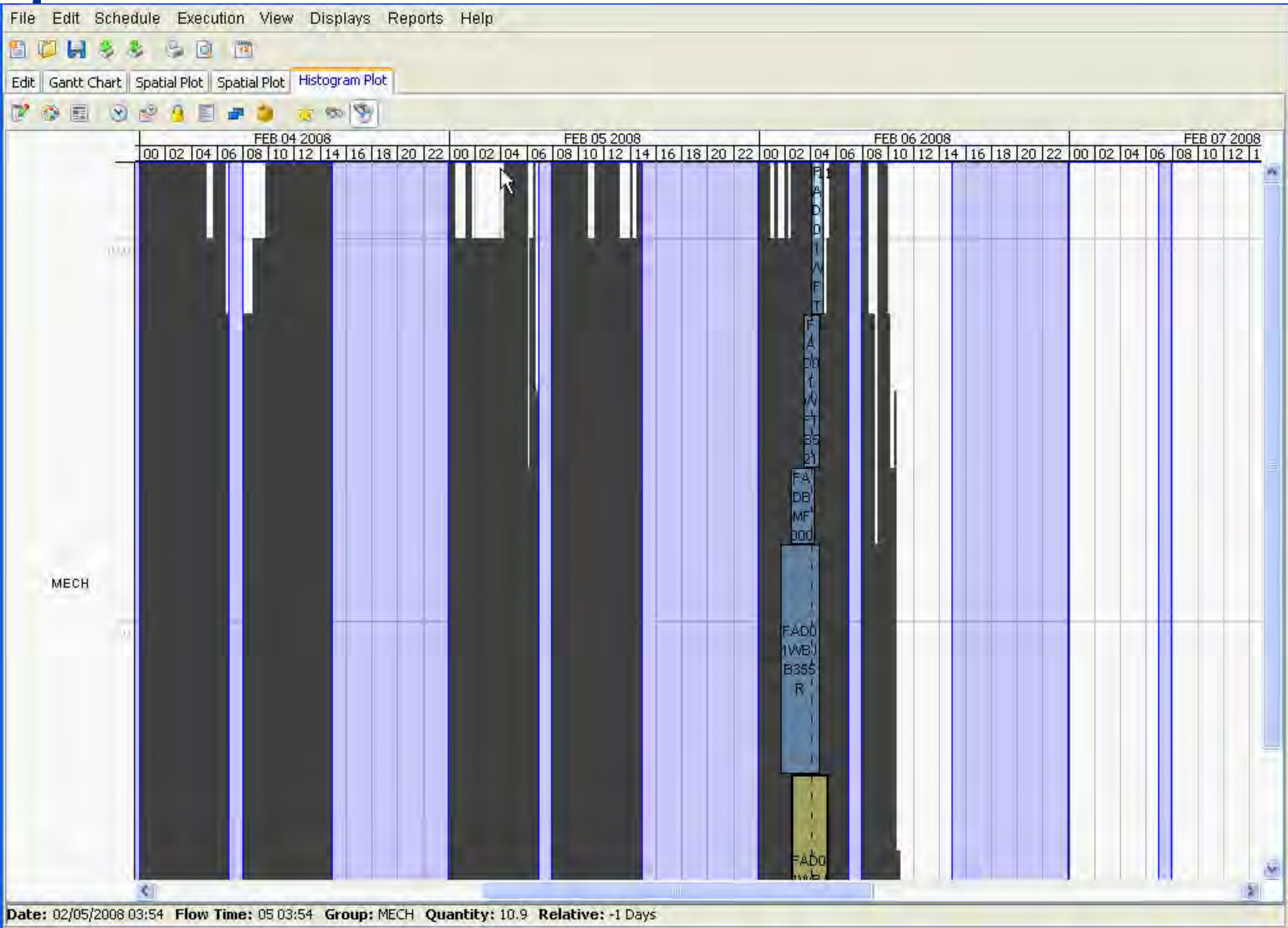
Resource Sets



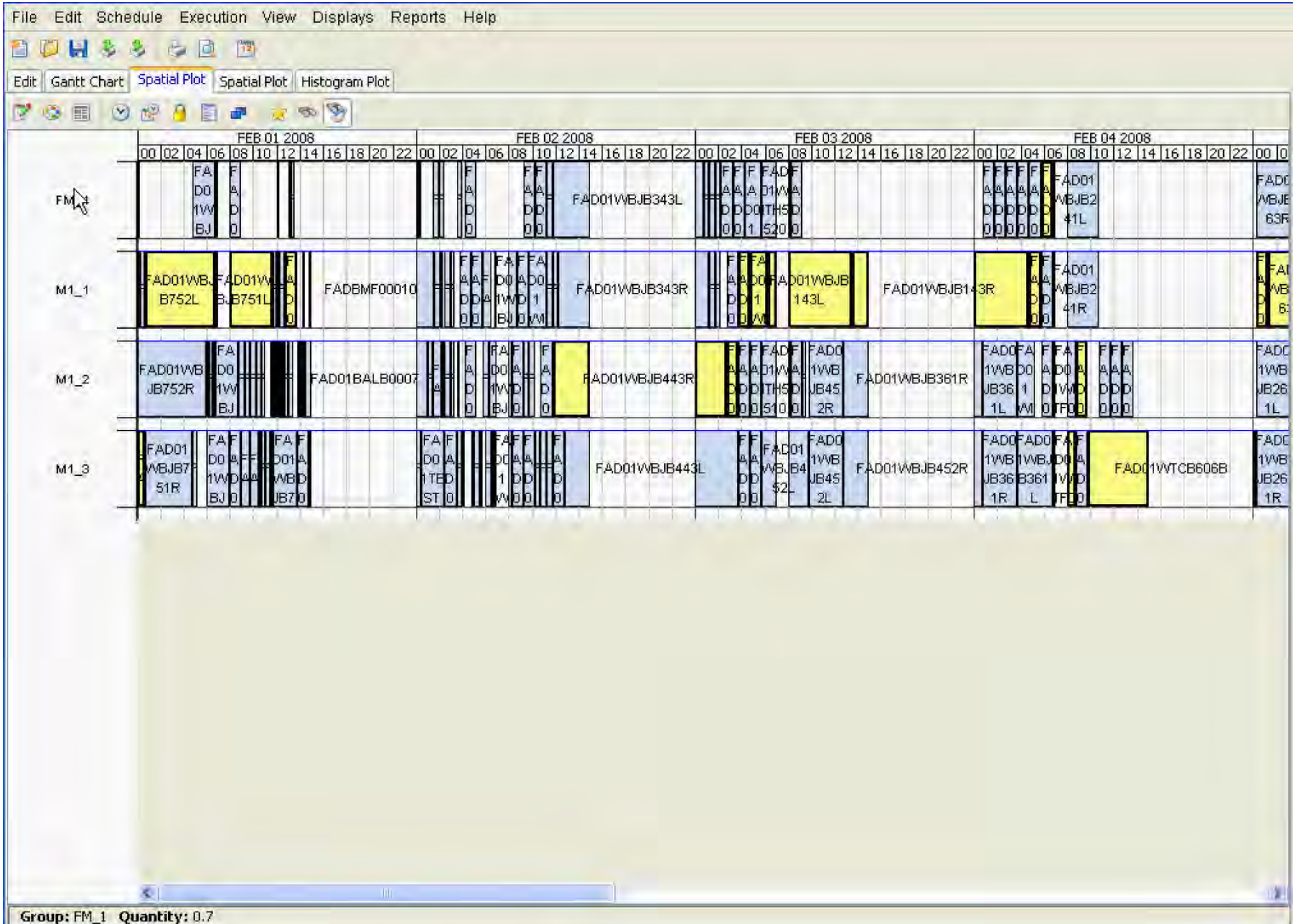
Tabular Editor



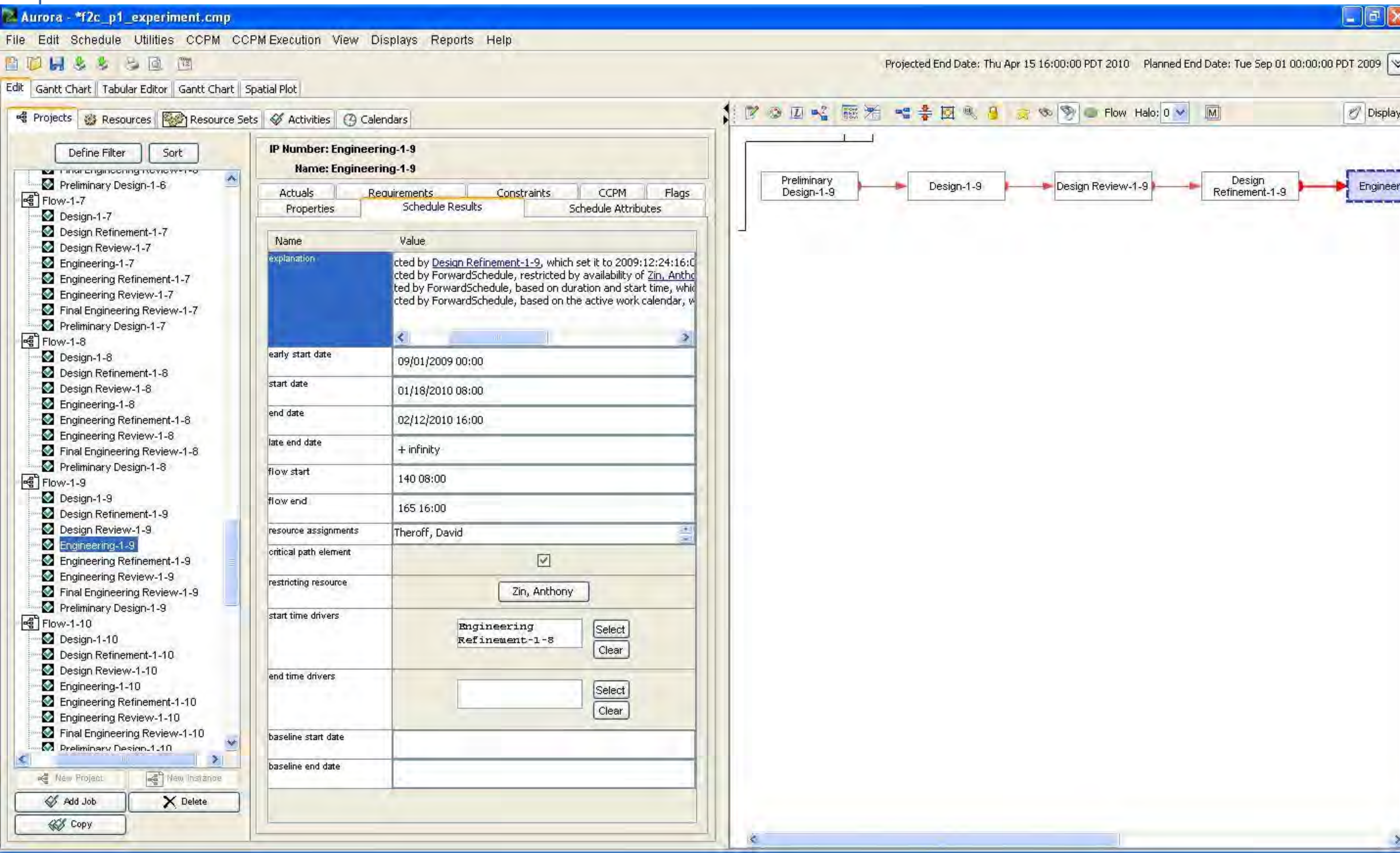
name	IP Number	job type	work package ID	user attributes	flag	calendar	schedule method	active duration	safe duration	aggressive duration	duration standard	risk	can break across days	can break across shi
135	135	In Sequence	WBJ.FST		false	Default Calendar	forward schedule	60	60	0			true	true
70	70	In Sequence	WBJ.SHM		false	Default Calendar	forward schedule	120	120	0			true	true
5	5	In Sequence	TLA		false	Default Calendar	forward schedule	15	15	0			true	true
112	112	In Sequence	WBJ.DRL		false	Default Calendar	forward schedule	60	60	0			true	true
252	252	In Sequence	WTS		false	Default Calendar	forward schedule	30	30	0			true	true
202	202	In Sequence	WIT		false	Default Calendar	forward schedule	60	60	0			true	true
95	95	In Sequence	WBJ.SHM		false	Default Calendar	forward schedule	30	30	0			true	true
266	266	In Sequence	WMT		false	Default Calendar	forward schedule	120	120	0			true	true
137	137	In Sequence	WBJ.FST		false	Default Calendar	forward schedule	60	60	0			true	true
30	30	In Sequence	BAL		false	Default Calendar	forward schedule	15	15	0			true	true
177	177	In Sequence	TES		false	Default Calendar	forward schedule	120	120	0			true	true
72	72	In Sequence	WBJ.DRL		false	Default Calendar	forward schedule	30	30	0			true	true
160	160	In Sequence	WTC		false	Default Calendar	forward schedule	120	120	0			true	true
274	274	In Sequence	FAF		false	Default Calendar	forward schedule	60	60	0			true	true
217	217	In Sequence	WFL		false	Default Calendar	forward schedule	60	60	0			true	true
22	22	In Sequence	BAL		false	Default Calendar	forward schedule	15	15	0			true	true
152	152	In Sequence	WBJ.DRL		false	Default Calendar	forward schedule	90	90	0			true	true
15	15	In Sequence	MLA		false	Default Calendar	forward schedule	30	30	0			true	true
225	225	In Sequence	WLS		false	Default Calendar	forward schedule	30	30	0			true	true
87	87	In Sequence	WBJ.SHM		false	Default Calendar	forward schedule	30	30	0			true	true
167	167	In Sequence	WBJ.FST		false	Default Calendar	forward schedule	90	90	0			true	true
144	144	In Sequence	WBJ.DRL		false	Default Calendar	forward schedule	30	30	0			true	true
120	120	In Sequence	WBJ.SHM		false	Default Calendar	forward schedule	120	120	0			true	true
169	169	In Sequence	WBJ.FST		false	Default Calendar	forward schedule	180	180	0			true	true
290	290	In Sequence	WTS		false	Default Calendar	forward schedule	22.5	22.5	0			true	true
209	209	In Sequence	WIT		false	Default Calendar	forward schedule	60	60	0			true	true
80	80	In Sequence	WLA		false	Default Calendar	forward schedule	15	15	0			true	true
102	102	In Sequence	WBJ.FST		false	Default Calendar	forward schedule	30	30	0			true	true
236	236	In Sequence	WLS		false	Default Calendar	forward schedule	30	30	0			true	true
63	63	In Sequence	WLA		false	Default Calendar	forward schedule	60	60	0			true	true
244	244	In Sequence	WLS		false	Default Calendar	forward schedule	60	60	0			true	true
185	185	In Sequence	WBJ		false	Default Calendar	forward schedule	60	60	0			true	true
55	55	In Sequence	WLA		false	Default Calendar	forward schedule	45	45	0			true	true
29	29	In Sequence	TLA		false	Default Calendar	forward schedule	0	0	0			true	true
104	104	In Sequence	WBJ.SHM		false	Default Calendar	forward schedule	60	60	0			true	true
47	47	In Sequence	TLA		false	Default Calendar	forward schedule	18	18	0			true	true
193	193	In Sequence	WIT		false	Default Calendar	forward schedule	90	90	0			true	true
261	261	In Sequence	WFT		false	Default Calendar	forward schedule	60	60	0			true	true
282	282	In Sequence	WTS		false	Default Calendar	forward schedule	30	30	0			true	true


File Edit Schedule Execution View Displays Reports Help
Edit
Gantt Chart
Spatial Plot
Spatial Plot
Histogram Plot
FEB 04 2008
FEB 05 2008
FEB 06 2008
FEB 07 2008
00 02 04 06 08 10 12 14 16 18 20 22
MECH
FAD01WBJB355R
FADBMF000
Date: 02/05/2008 03:54 Flow Time: 05 03:54 Group: MECH Quantity: 10.9 Relative: -1 Days

Spatial Plot

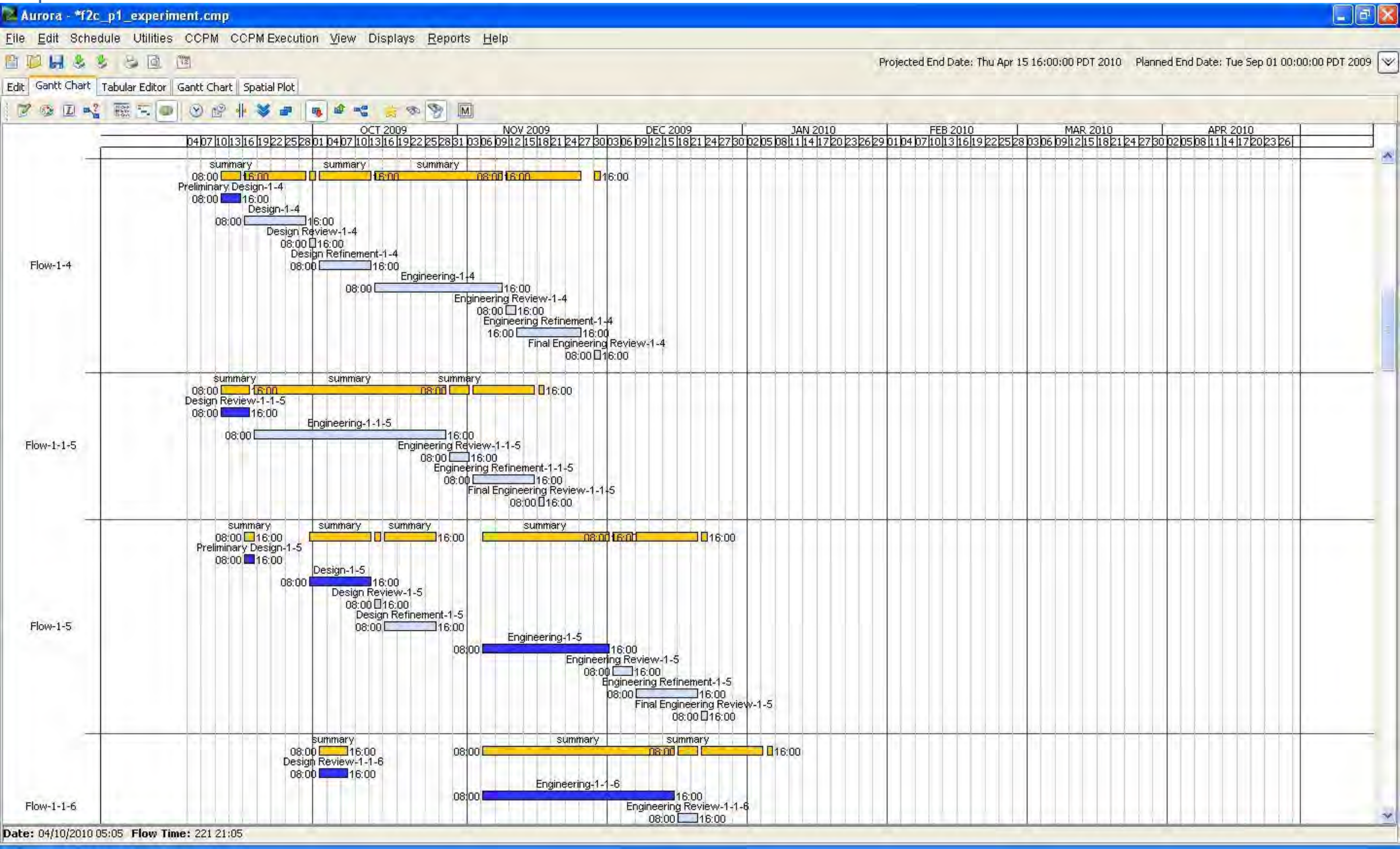


Edit Tab: Schedule Results

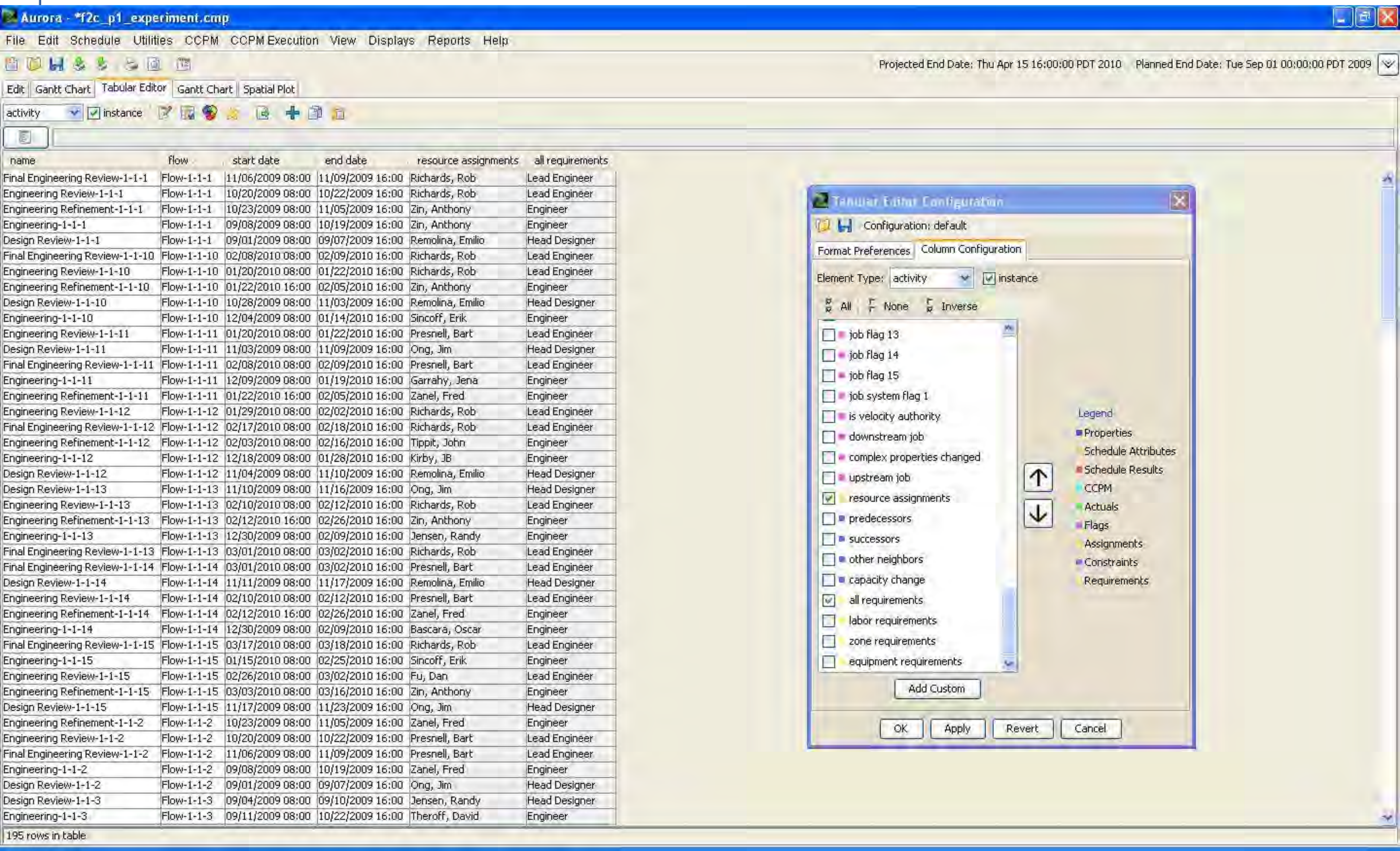


Gantt Chart: Multiple Projects

Activities delayed by resource contention in blue

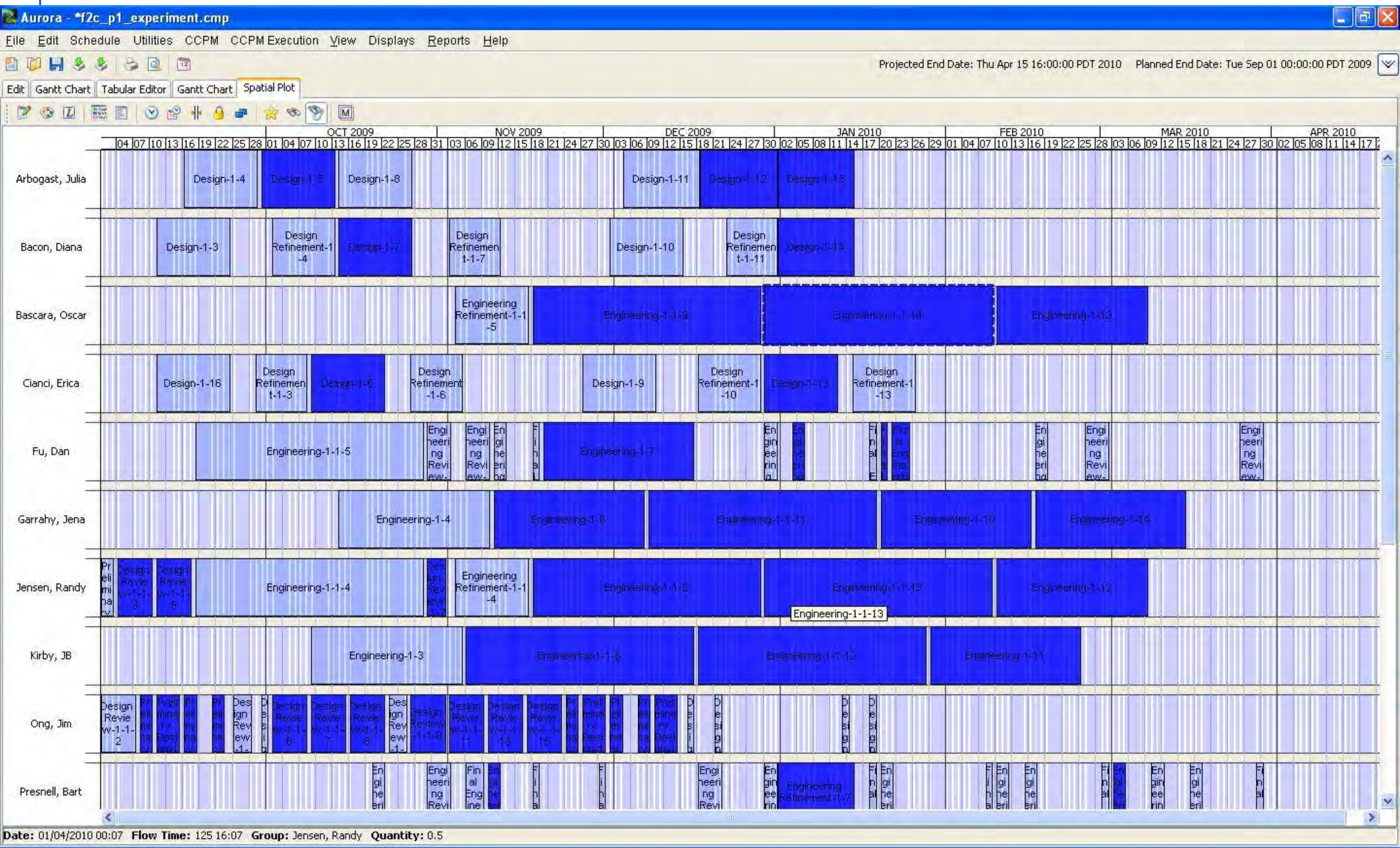


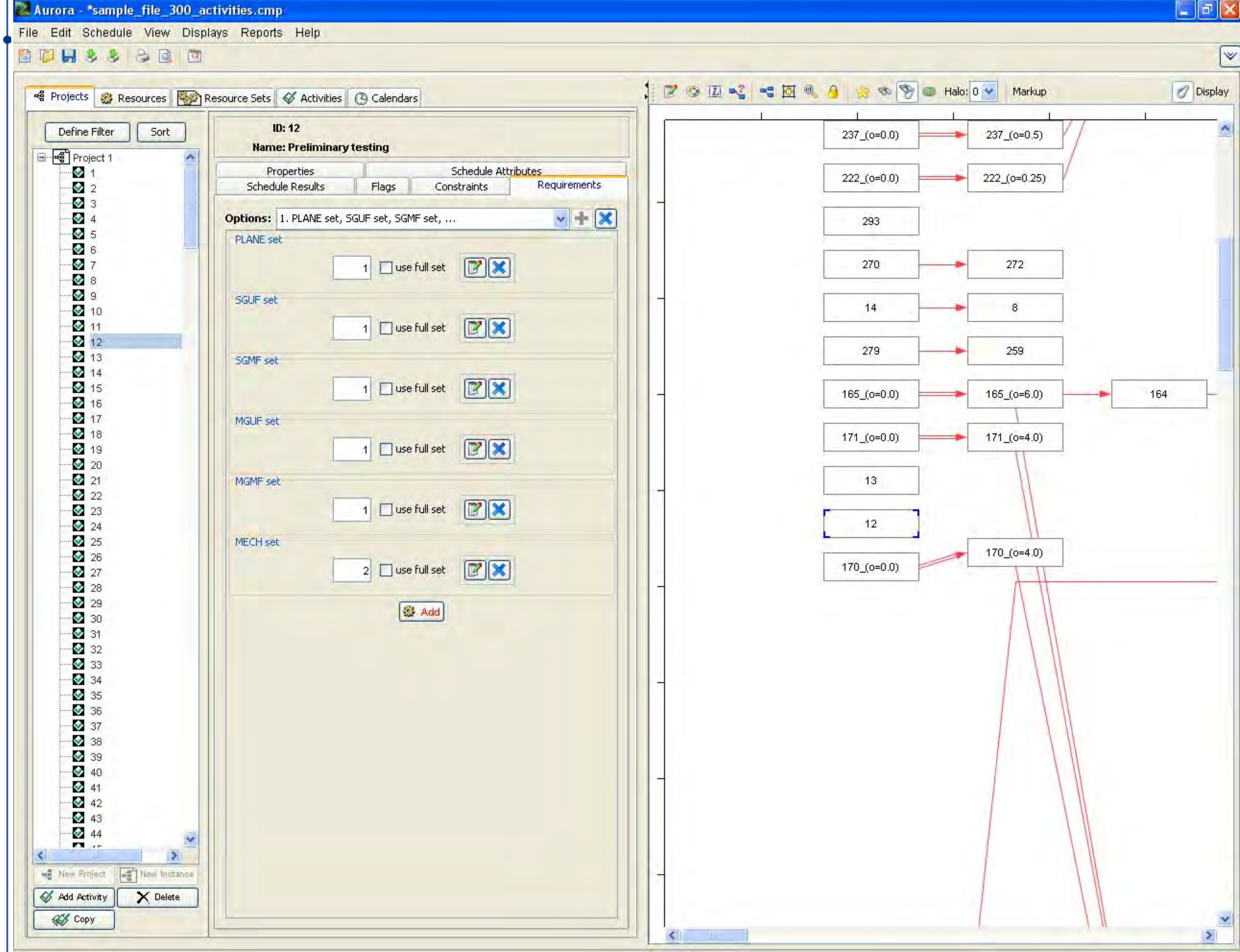
Tabular Editor: Configuration

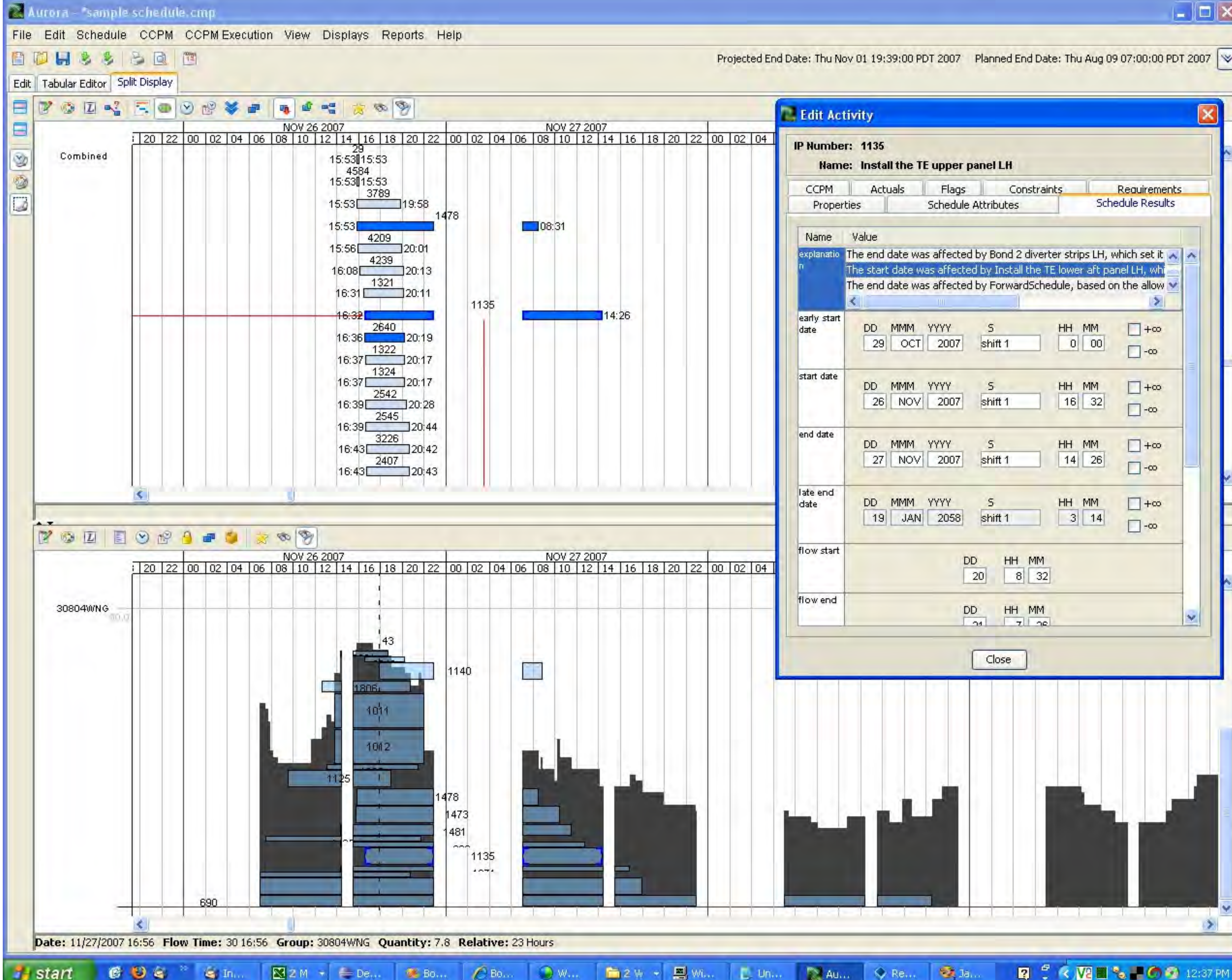


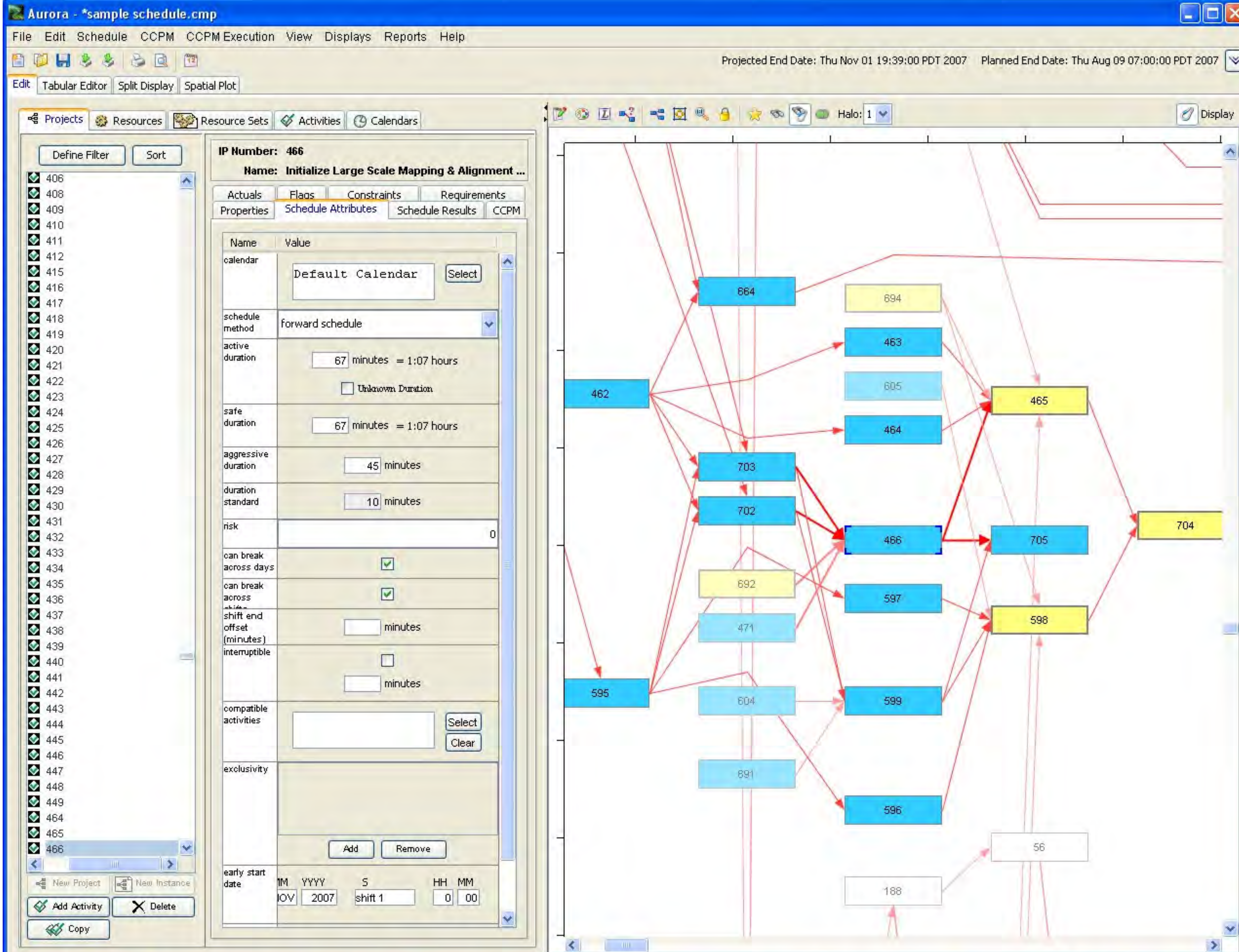
Personnel View

Activities delayed by resource contention in blue




Aurora - *sample_file_300_activities.cmp
File Edit Schedule View Displays Reports Help
Projects
Resources
Resource Sets
Activities
Calendars
Define Filter
Sort
Project 1
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
ID: 12
Name: Preliminary testing
Properties
Schedule Attributes
Schedule Results
Flags
Constraints
Requirements
Options: 1. PLANE set, SGUF set, SGMF set, ...
PLANE set
1 use full set
SGUF set
1 use full set
SGMF set
1 use full set
MGUF set
1 use full set
MGMF set
1 use full set
MECH set
2 use full set
Add
Halo: 0
Markup
Display
237_(o=0.0)
237_(o=0.5)
222_(o=0.0)
222_(o=0.25)
293
270
272
14
8
279
259
165_(o=0.0)
165_(o=6.0)
164
171_(o=0.0)
171_(o=4.0)
13
12
170_(o=4.0)
170_(o=0.0)


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
Combined
NOV 26 2007
NOV 27 2007
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
start date
end date
late end date
flow start
flow end
DD MMM YYYY S HH MM
29 OCT 2007 shift 1 0 00
26 NOV 2007 shift 1 16 32
27 NOV 2007 shift 1 14 26
19 JAN 2058 shift 1 3 14
20 8 32
Close
30804WNG
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 shifts
shift end offset (minutes)
minutes
interruptible
minutes
compatible activities
Select
Clear
exclusivity
Add
Remove
early start date
MM YYYY S HH MM
IOV 2007 shift 1 0 00
Halo: 1
Display
664
694
463
605
462
465
464
703
702
466
705
704
692
597
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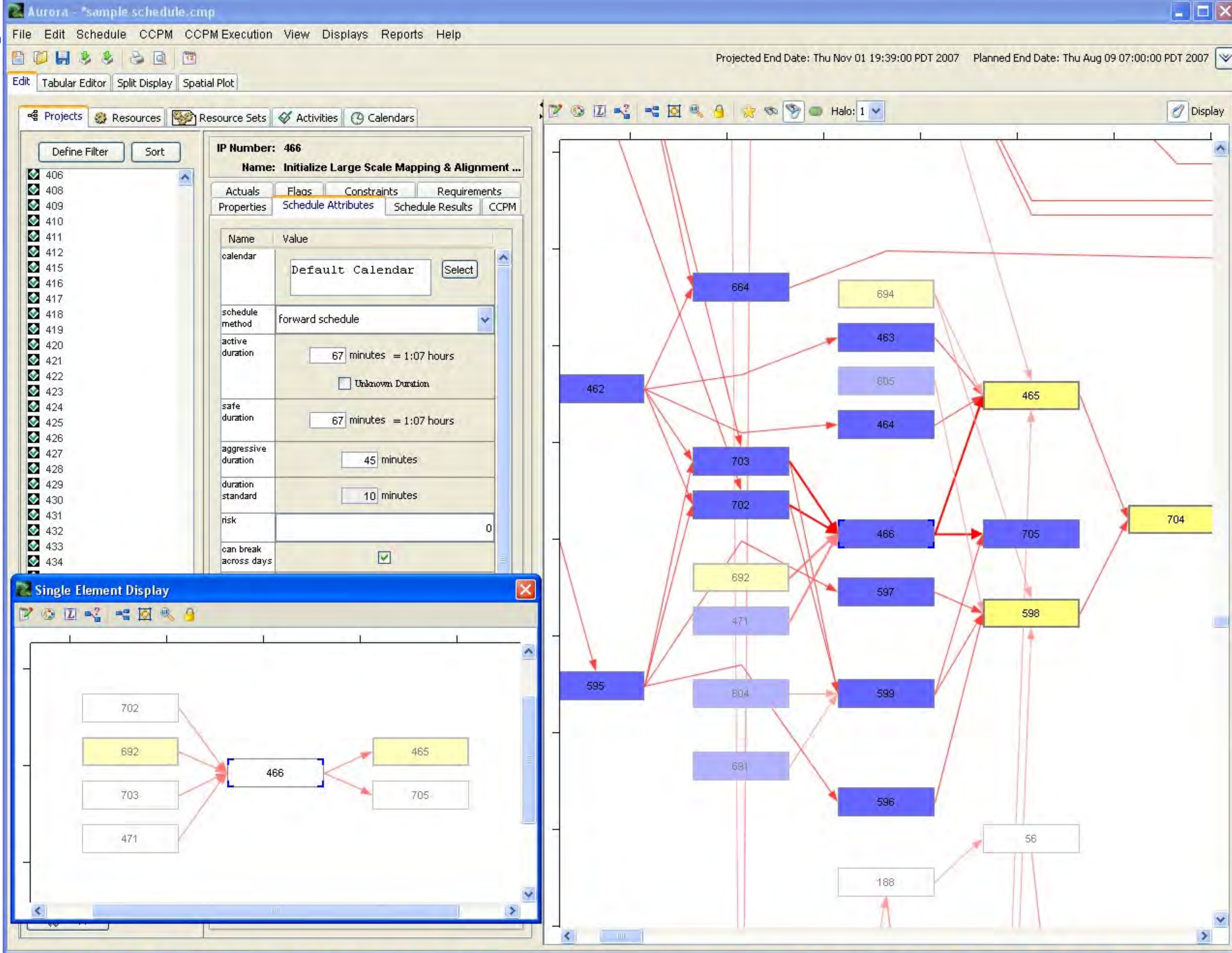
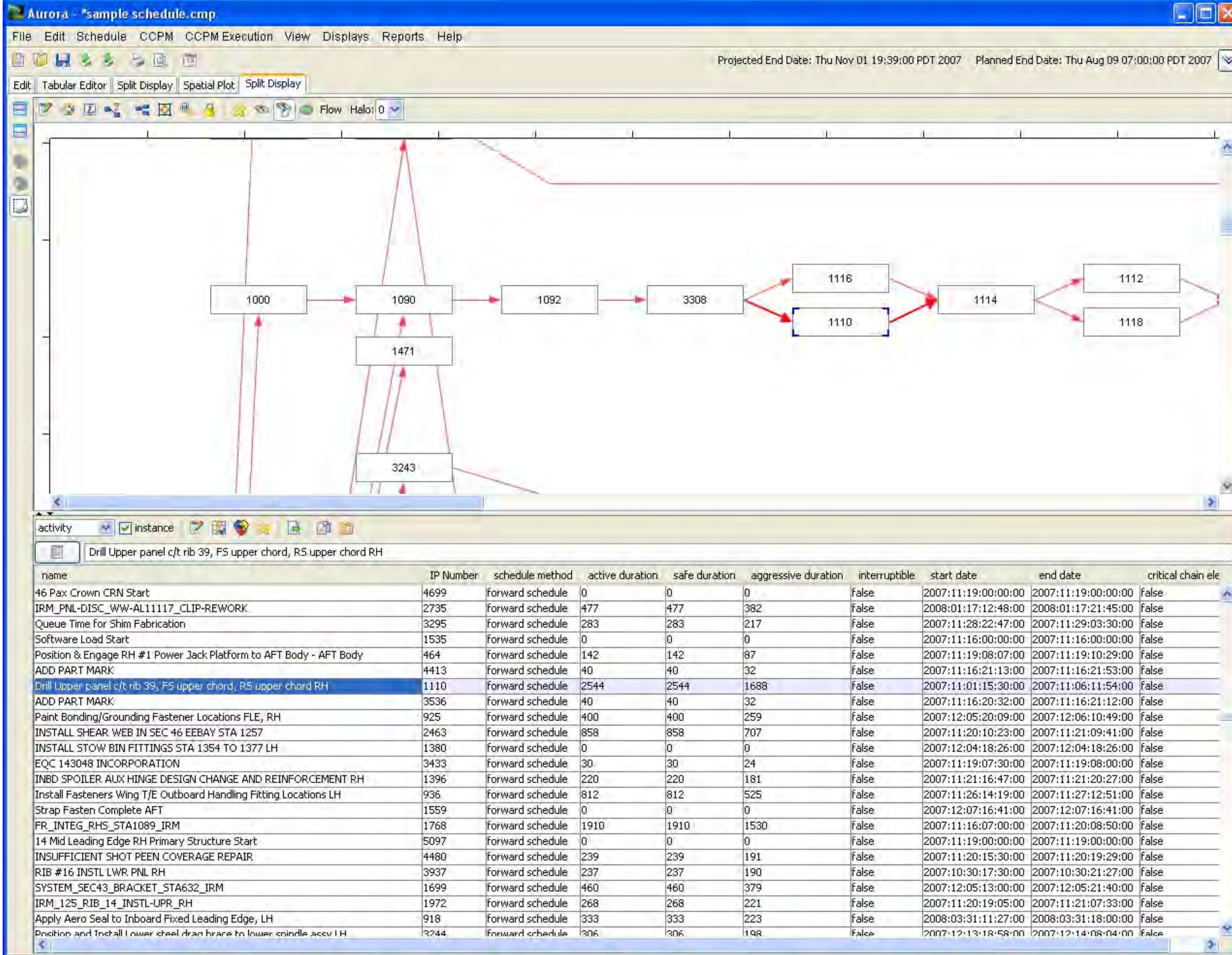
604
599
691
596
56
188



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
664 694 463 605 462 465 464 703 702 466 705 704 692 597 471 598 595 604 599 691 596 56 188
Single Element Display
702 692 703 471 466 465 705



name	IP Number	schedule method	active duration	safe duration	aggressive duration	interruptible	start date	end date	critical chain ele
46 Pax Crown CRN Start	4699	forward schedule	0	0	0	false	2007:11:19:00:00:00	2007:11:19:00:00:00	false
IRM_PNL-DISC_WW-AL11117_CLIP-REWORK	2735	forward schedule	477	477	382	false	2008:01:17:12:48:00	2008:01:17:21:45:00	false
Queue Time for Shim Fabrication	3295	forward schedule	283	283	217	false	2007:11:28:22:47:00	2007:11:29:03:30:00	false
Software Load Start	1535	forward schedule	0	0	0	false	2007:11:16:00:00:00	2007:11:16:00:00:00	false
Position & Engage RH #1 Power Jack Platform to AFT Body - AFT Body	464	forward schedule	142	142	87	false	2007:11:19:08:07:00	2007:11:19:10:29:00	false
ADD PART MARK	4413	forward schedule	40	40	32	false	2007:11:16:21:13:00	2007:11:16:21:53:00	false
Drill Upper panel c/t rib 39, FS upper chord, RS upper chord RH	1110	forward schedule	2544	2544	1688	false	2007:11:01:15:30:00	2007:11:06:11:54:00	false
ADD PART MARK	3536	forward schedule	40	40	32	false	2007:11:16:20:32:00	2007:11:16:21:12:00	false
Paint Bonding/Grounding Fastener Locations FLE, RH	925	forward schedule	400	400	259	false	2007:12:05:20:09:00	2007:12:06:10:49:00	false
INSTALL SHEAR WEB IN SEC 46 EEBAY STA 1257	2463	forward schedule	858	858	707	false	2007:11:20:10:23:00	2007:11:21:09:41:00	false
INSTALL STOW BIN FITTINGS STA 1354 TO 1377 LH	1380	forward schedule	0	0	0	false	2007:12:04:18:26:00	2007:12:04:18:26:00	false
EQC 143048 INCORPORATION	3433	forward schedule	30	30	24	false	2007:11:19:07:30:00	2007:11:19:08:00:00	false
INBD SPOILER AUX HINGE DESIGN CHANGE AND REINFORCEMENT RH	1396	forward schedule	220	220	181	false	2007:11:21:16:47:00	2007:11:21:20:27:00	false
Install Fasteners Wing T/E Outboard Handling Fitting Locations LH	936	forward schedule	812	812	525	false	2007:11:26:14:19:00	2007:11:27:12:51:00	false
Strap Fasten Complete AFT	1559	forward schedule	0	0	0	false	2007:12:07:16:41:00	2007:12:07:16:41:00	false
FR_INTEG_RHS_STA1089_IRM	1768	forward schedule	1910	1910	1530	false	2007:11:16:07:00:00	2007:11:20:08:50:00	false
14 Mid Leading Edge RH Primary Structure Start	5097	forward schedule	0	0	0	false	2007:11:19:00:00:00	2007:11:19:00:00:00	false
INSUFFICIENT SHOT PEEN COVERAGE REPAIR	4480	forward schedule	239	239	191	false	2007:11:20:15:30:00	2007:11:20:19:29:00	false
RIB #16 INSTL LWR PNL RH	3937	forward schedule	237	237	190	false	2007:10:30:17:30:00	2007:10:30:21:27:00	false
SYSTEM_SEC43_BRACKET_STA632_IRM	1699	forward schedule	460	460	379	false	2007:12:05:13:00:00	2007:12:05:21:40:00	false
IRM_125_RIB_14_INSTL-UPR_RH	1972	forward schedule	268	268	221	false	2007:11:20:19:05:00	2007:11:21:07:33:00	false
Apply Aero Seal to Inboard Fixed Leading Edge, LH	918	forward schedule	333	333	223	false	2008:03:31:11:27:00	2008:03:31:18:00:00	false
Position and Install Lower steel drag brace to lower spindle assy LH	3244	forward schedule	306	306	198	false	2007:12:13:18:58:00	2007:12:14:08:04:00	false

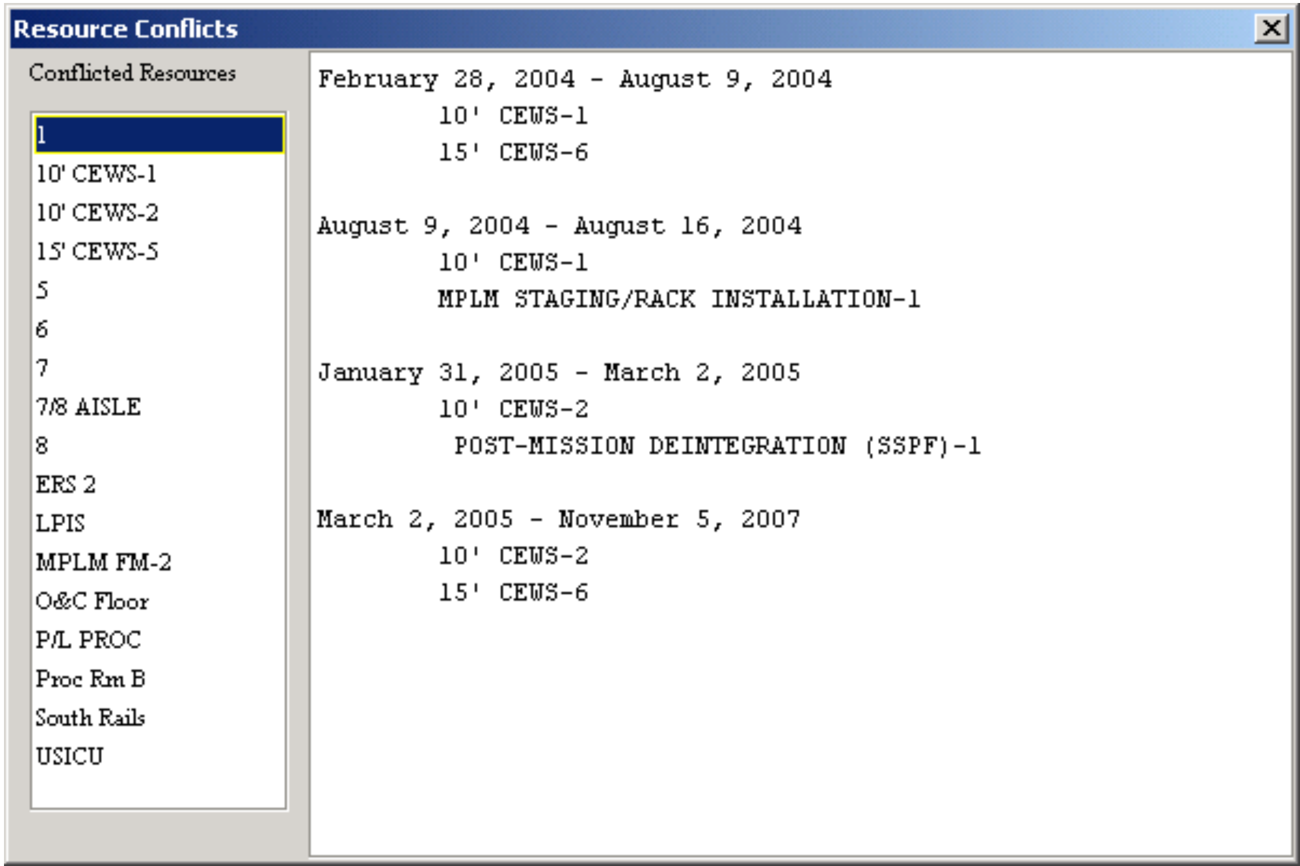
Aurora - *demo2_1_start_dates_set_col.cmp
File Edit Schedule Utilities CCPM CCPM Execution View Displays Reports Help
Projected End Date: Wed Mar 02 09:02:00 PST 2011 Planned End Date: Wed Apr 01 09:00:00 PDT 2009
Edit Tabular Editor Gantt Chart Histogram Plot
2010
2011
APR MAY JUN JUL AUG SEP OCT NOV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



Enhancing Resource-Leveling via Intelligent Scheduling

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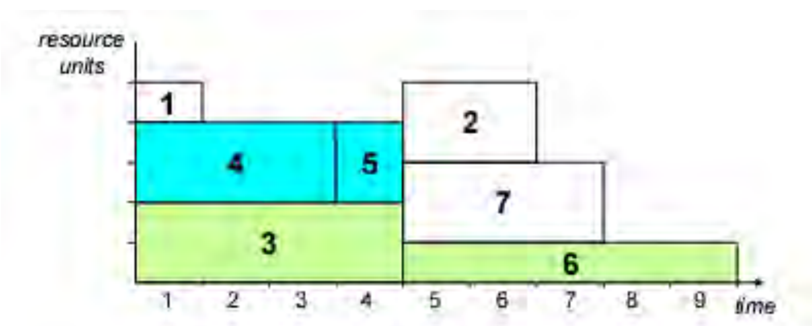
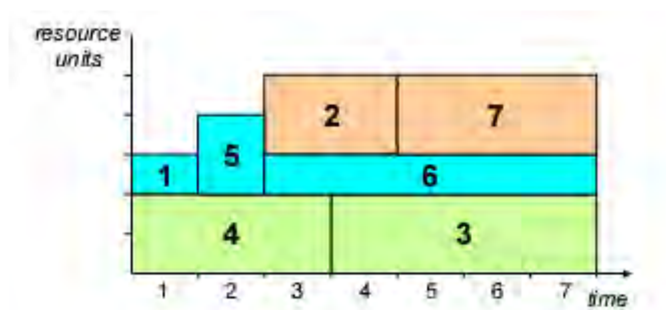
SCHEDULING ISN'T ROCKET SCIENCE

It's harder

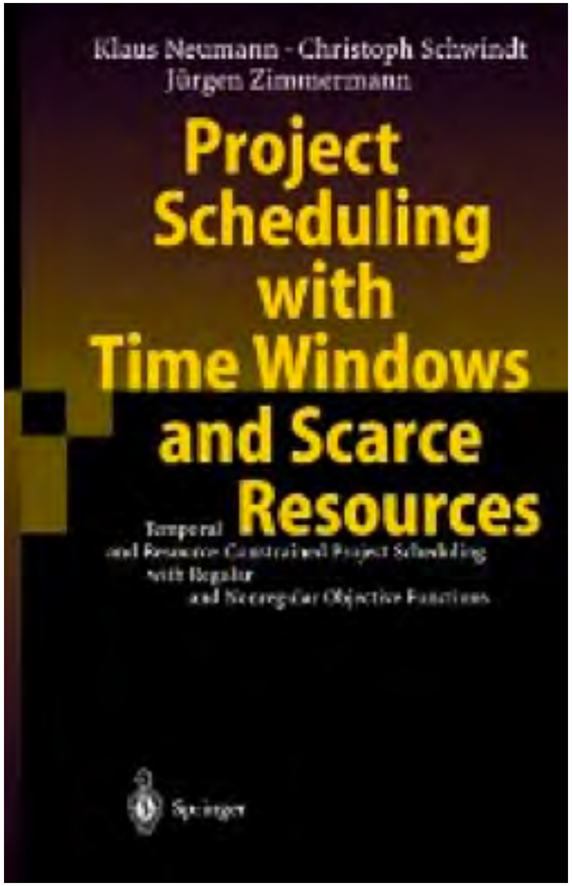
Reducing Project Duration via Intelligent Scheduling

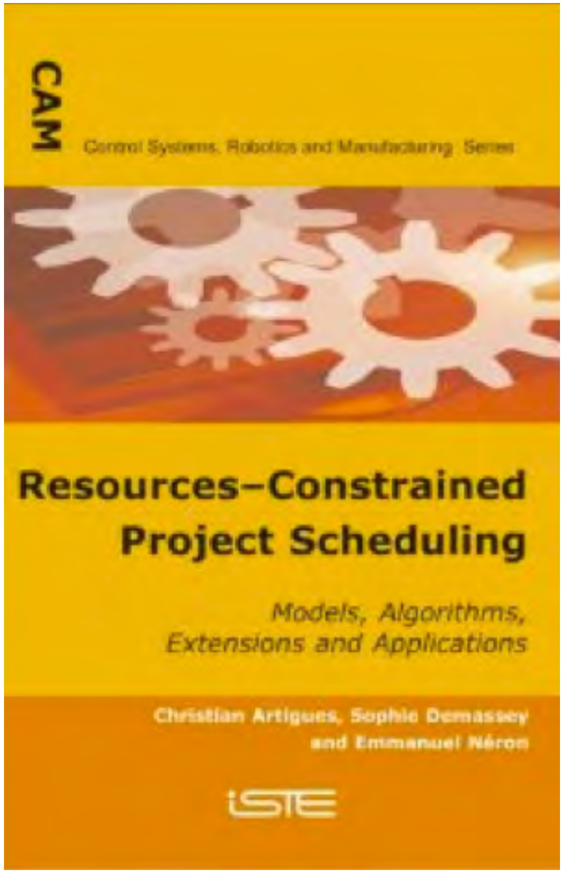
This (without) or this (with)





Many Books & Papers on Subject: Little in Software





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Bottom Line Results

- Productivity Increases
- &/or Costs Decrease

- Unfair Competitive Advantage

Resources and Resource Loaded Critical Path

- Large organizations developing and building complex systems rely on schedules and project management.
- Many CPPM 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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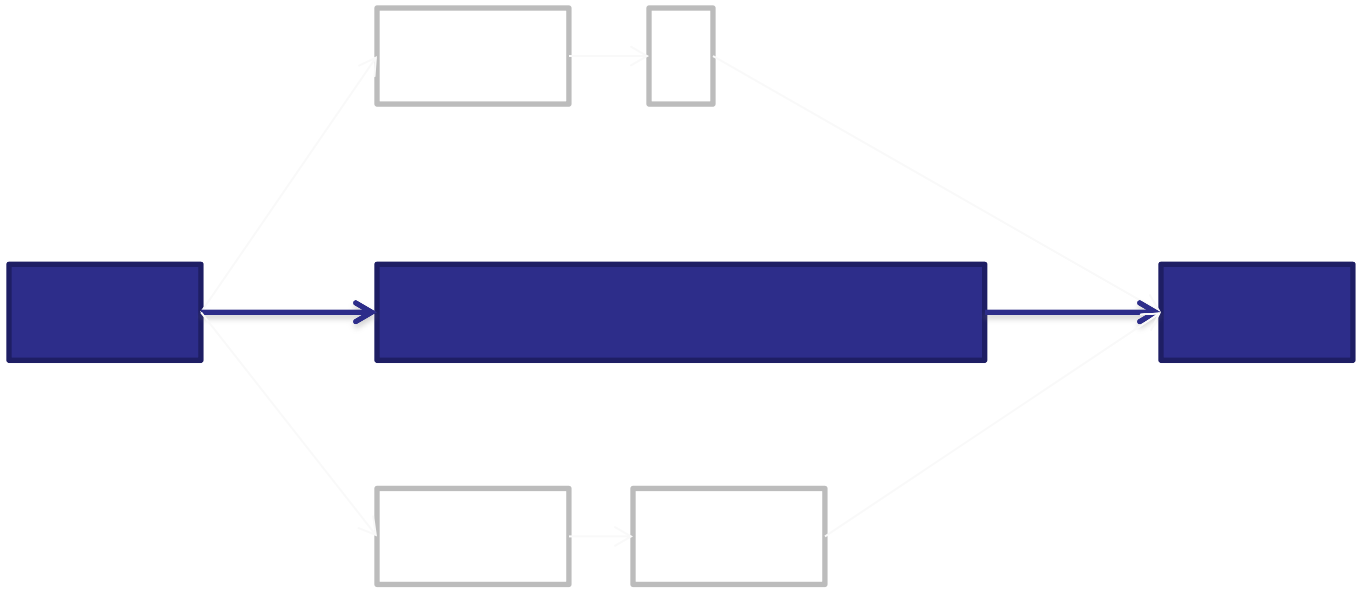
Critical Path (Infinite Resources) vs Critical Chain

- Critical Chain = Resource Constrained Critical Path

Critical Path

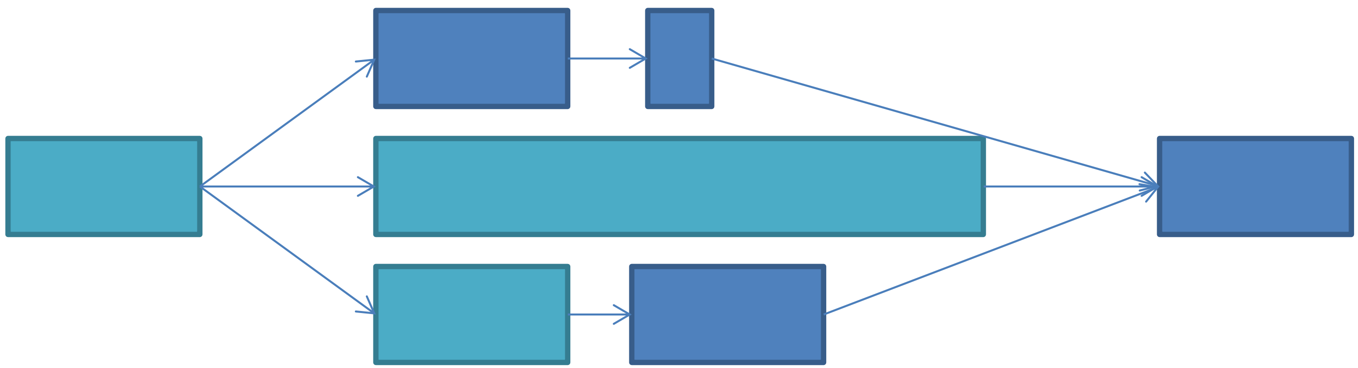
- Shortest path through the network, taking duration into account



Critical Chain = Resource Constrained Critical Path

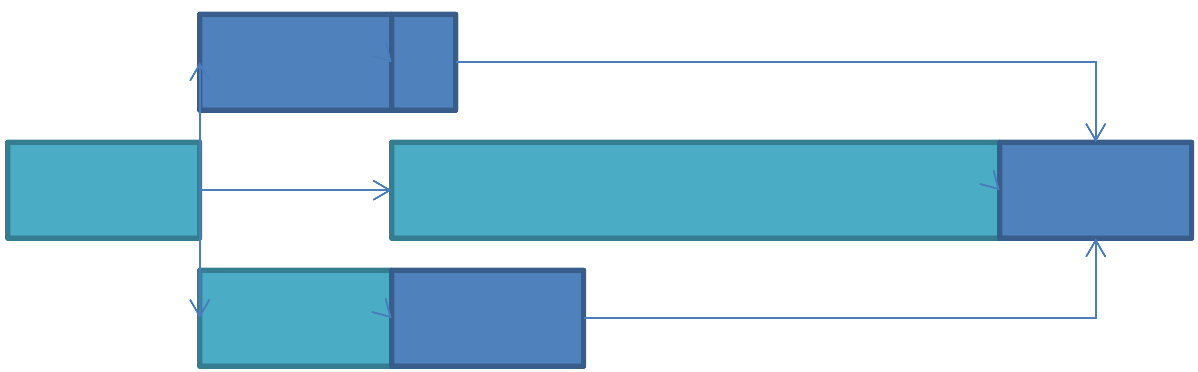
- Shortest path through the resource-loaded schedule, *taking resource contentions into account*
- Multiple possibilities for the same network, based on the resource requirements and schedule results

Critical Chain – Example 1



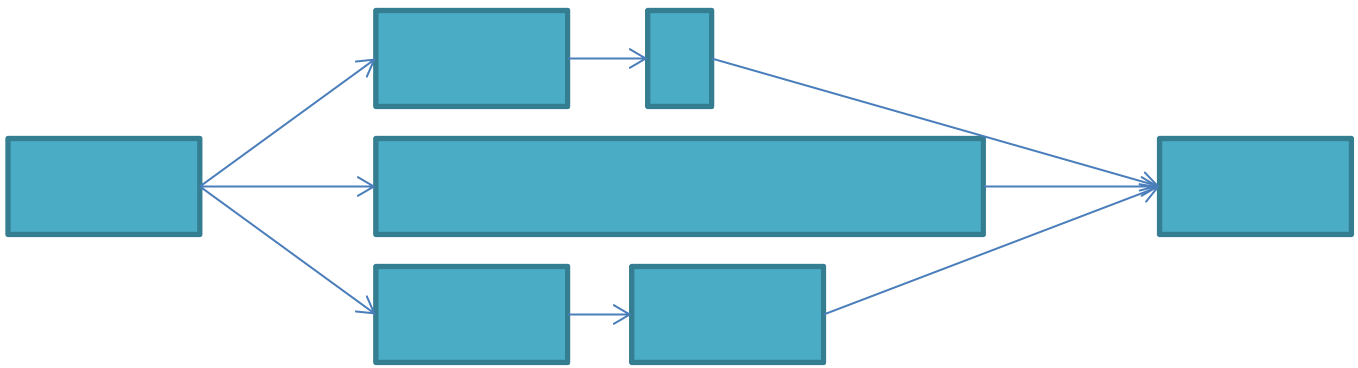
Requires resource 1

As scheduled:



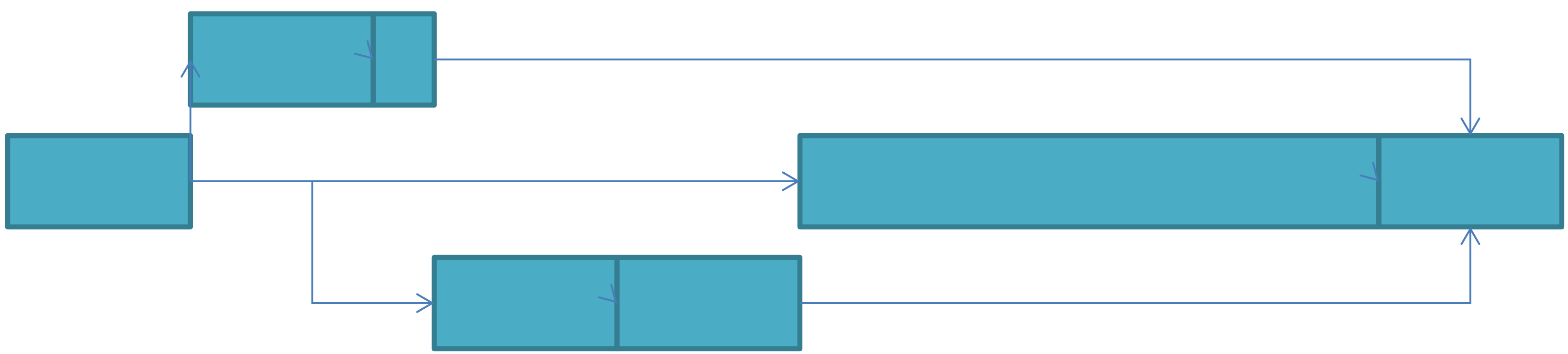
Critical chain:

Critical Chain – Example 2



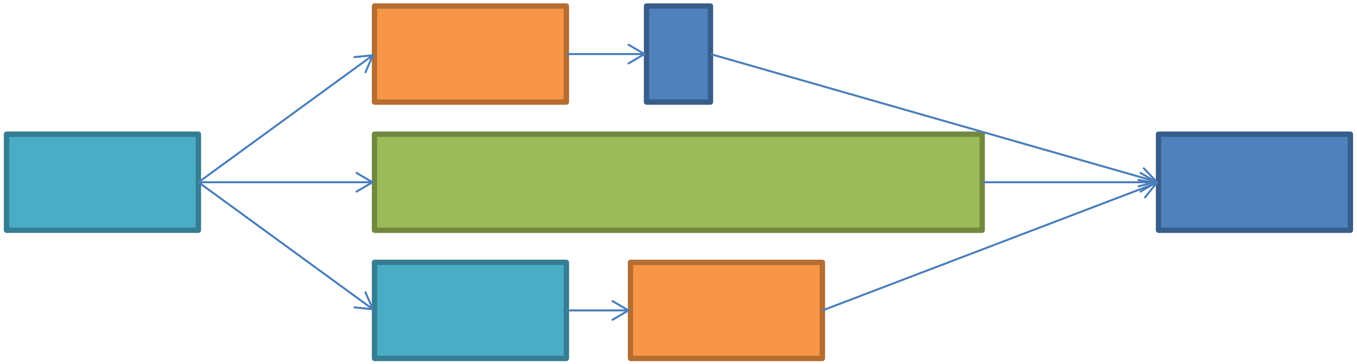
Requires resource 1 (all require same bottlenecking resource)

As scheduled:



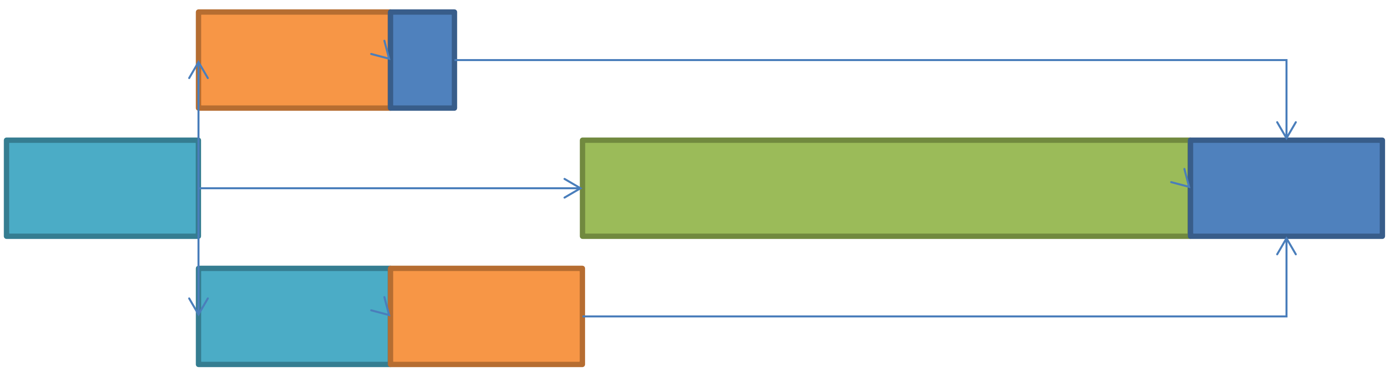
Critical chain:

Critical Chain – Example 3



Requires resource 1 | Requires resource 2 | Requires resource 1 and 2

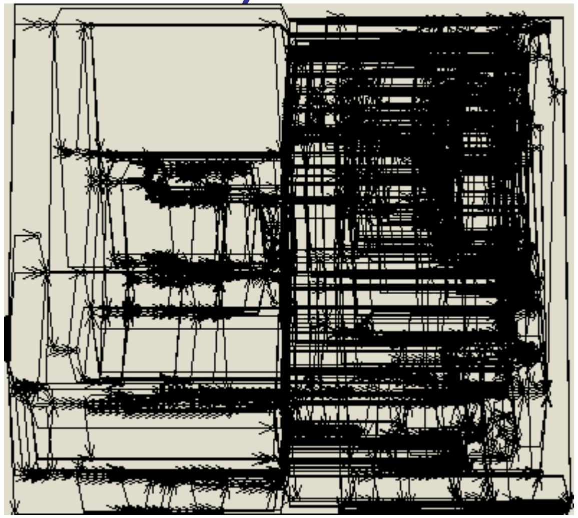
As scheduled:



Critical chain:

Where in the PM Space?

- Project Management
  - …
  - Critical Path (Resource Constrained)
    - …
    - Scheduling / Level Resources ←←
    - …
  - …



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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)

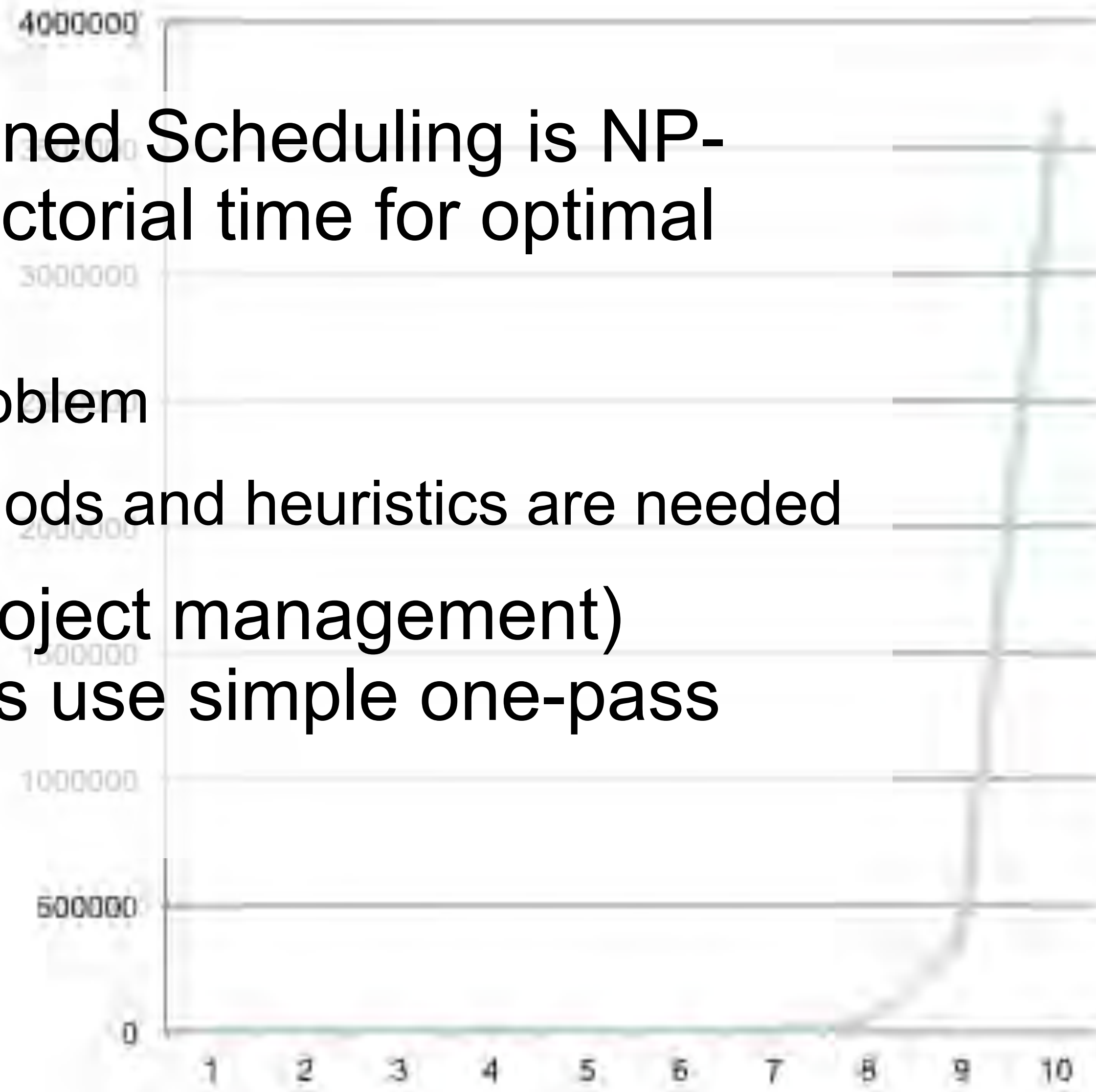
Expert Knowledge & Experience Needed

- 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.

Scheduling is Difficult

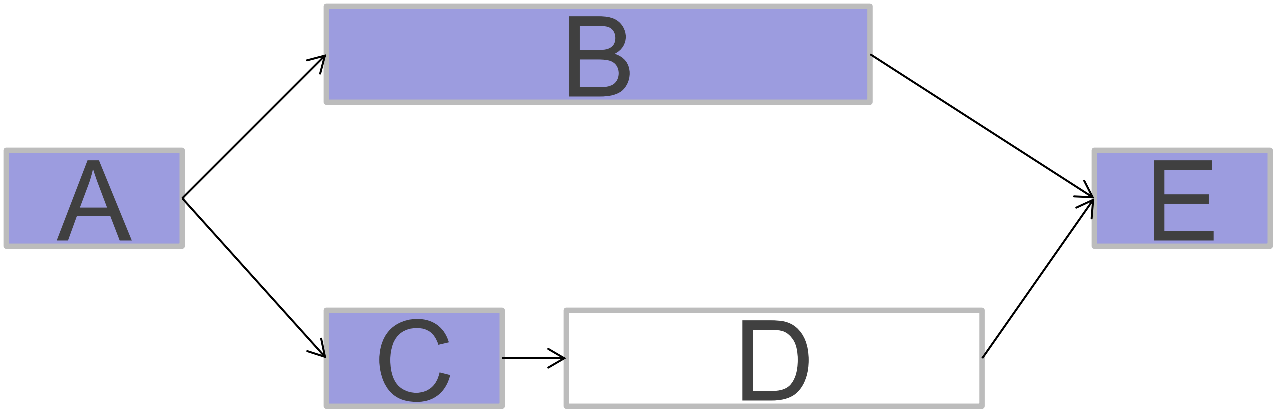
1	1
2	2
3	6
4	24
5	120
6	720
7	5040
8	40320
9	362880
10	3628800

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

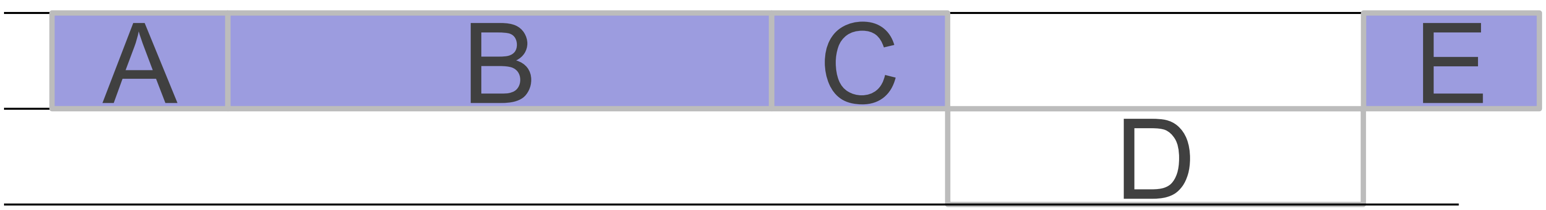


Why order matters?

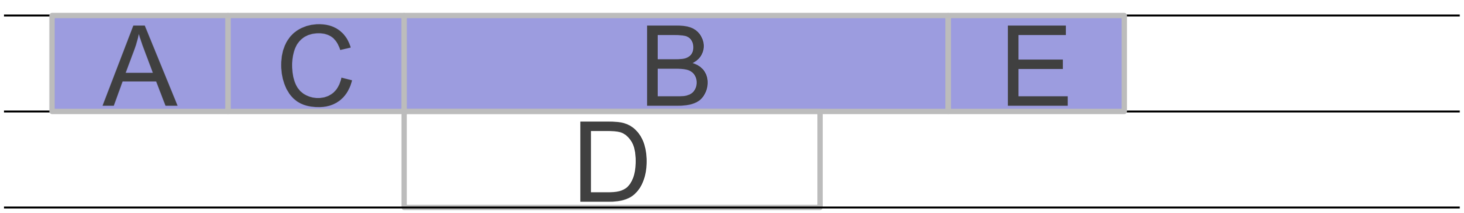
The example below involves jobs using two resources, purple and white



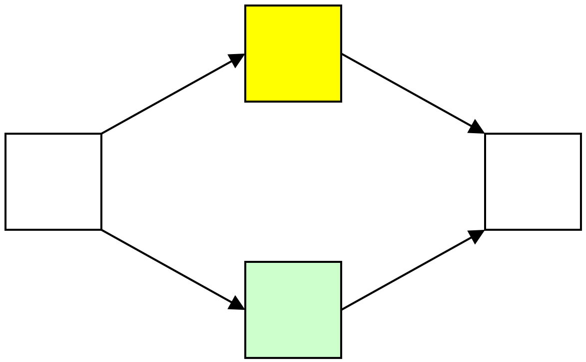
Schedule 1: B before C



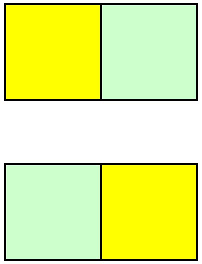
Schedule 2: C before B



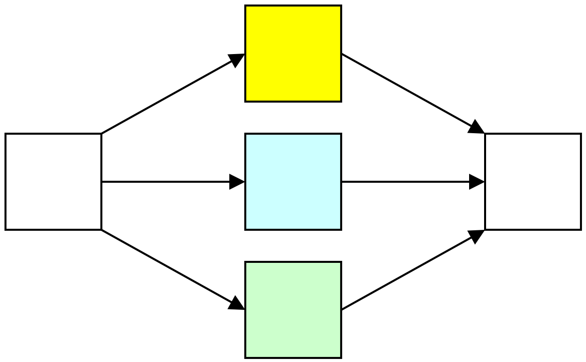
Two tasks that can occur in either order (one at a time)



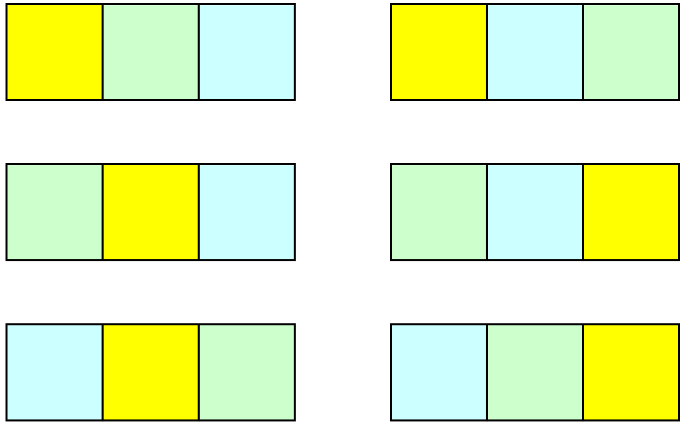
results in two options



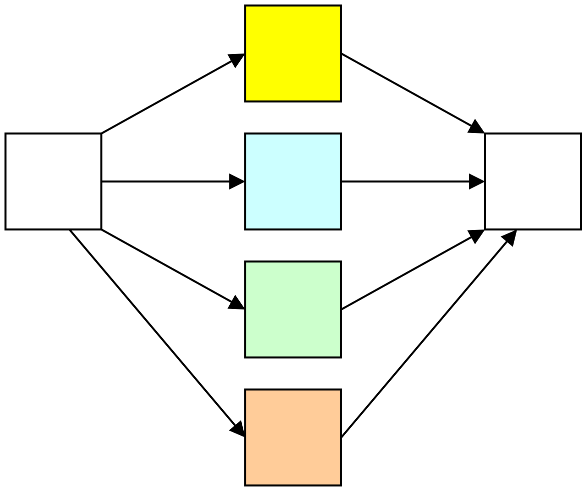
Three tasks that can occur in any order (one at a time)



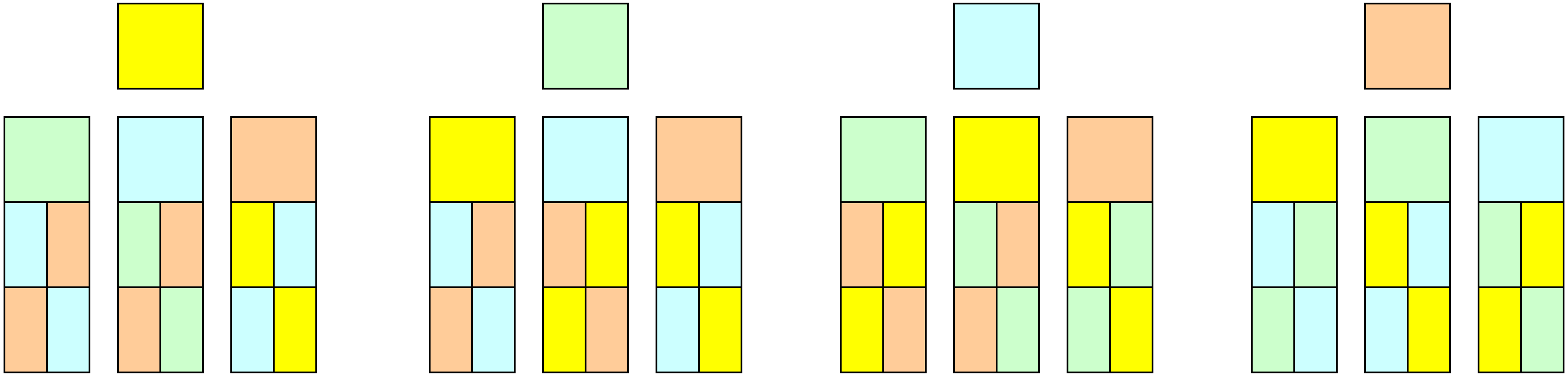
results in six options



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



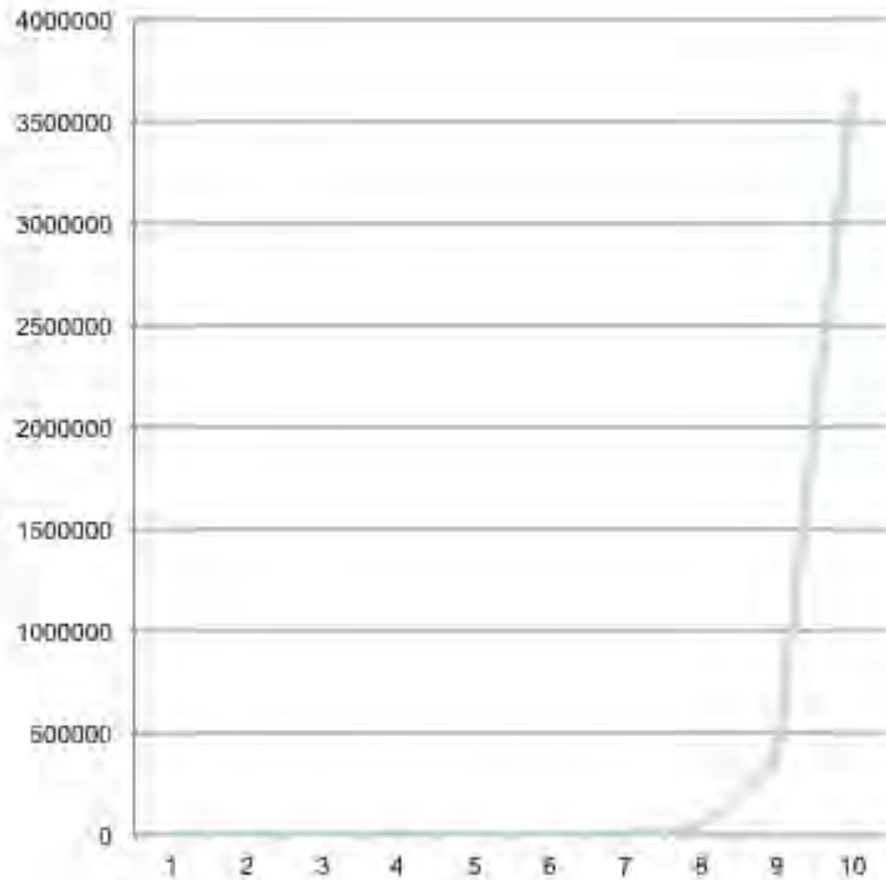
results in twenty-four options



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?

Resource-loaded scheduling is difficult

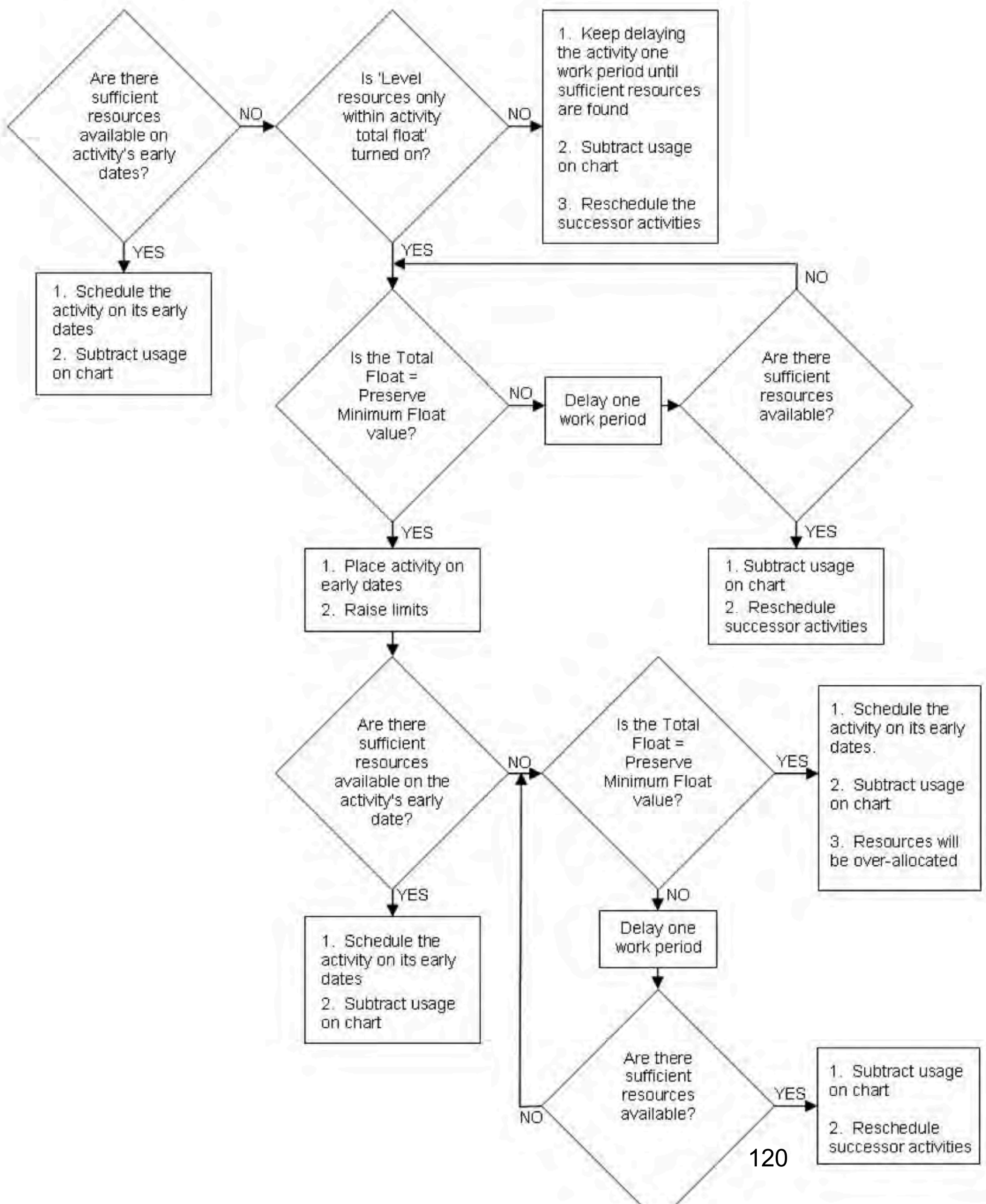
- Whole field of Operations Research

Not leveraged in the Project Management domains that Primavera serves

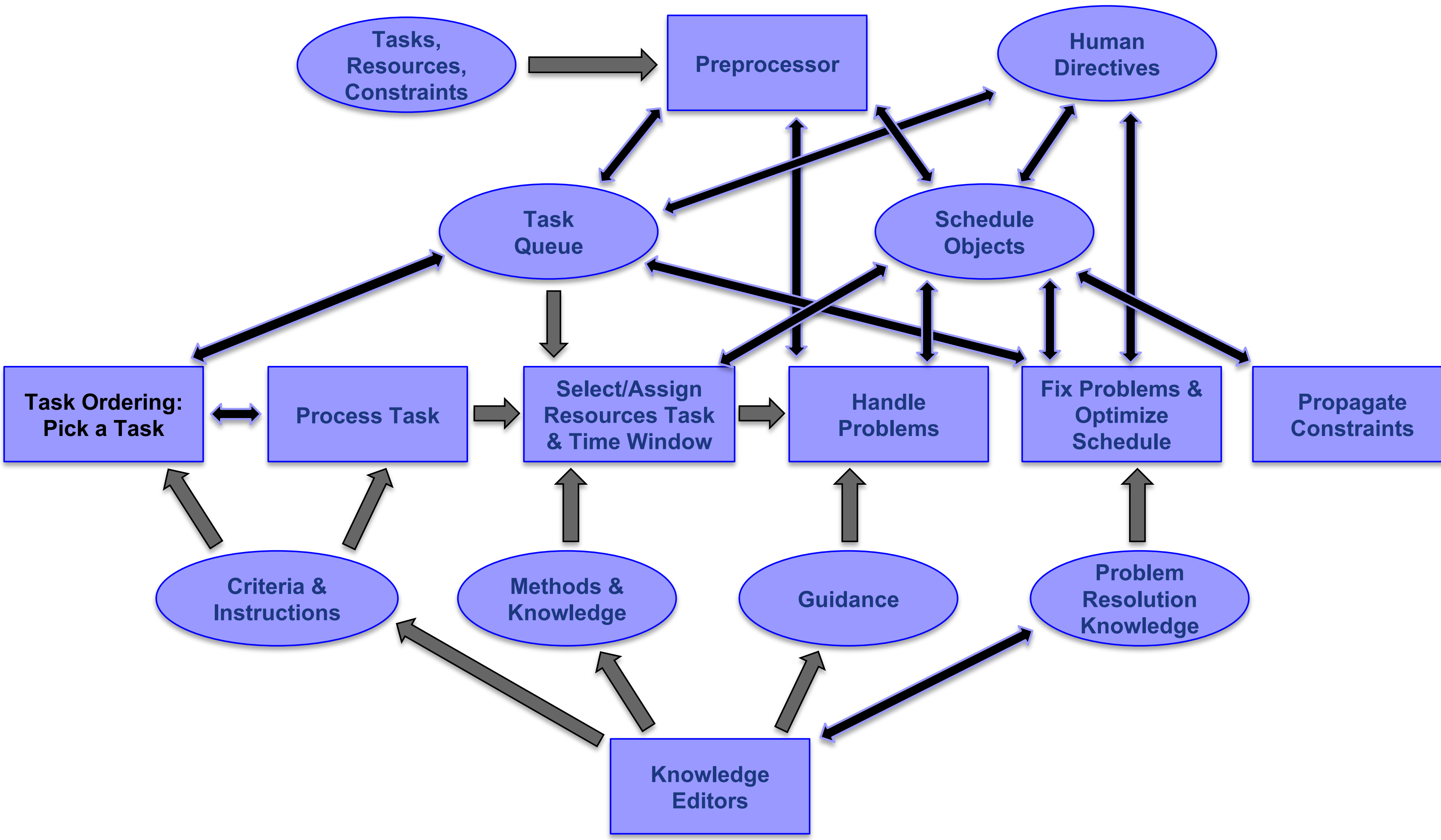
Usually demand is generated from knowledgeable users

Not promoted by solution providers

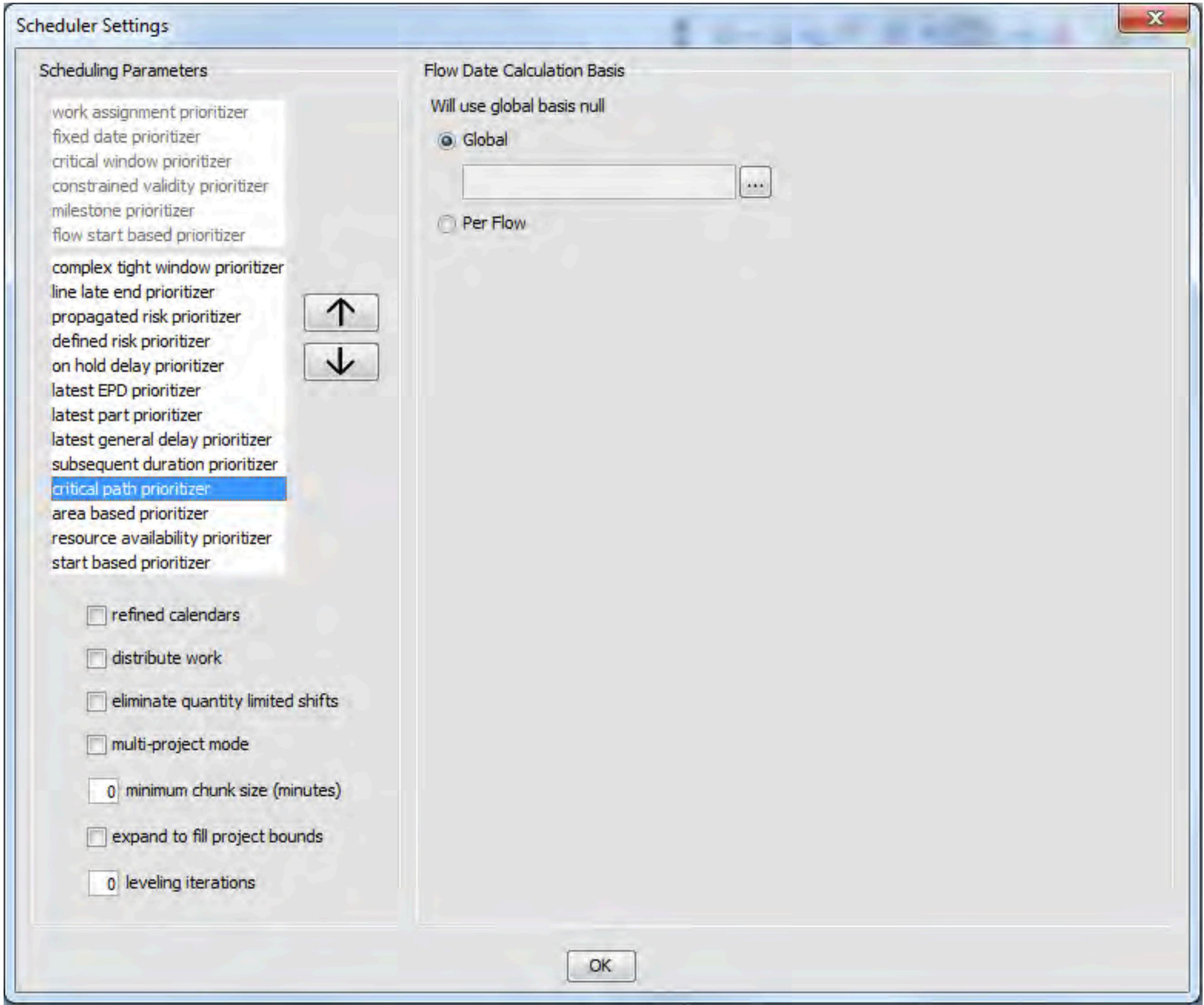
Primavera Resource Leveling flowchart



Aurora Architecture



Artificial Intelligence: Capture Human Knowledge – How best to schedule



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

Why Important?

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?

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?

How about 25+% longer?

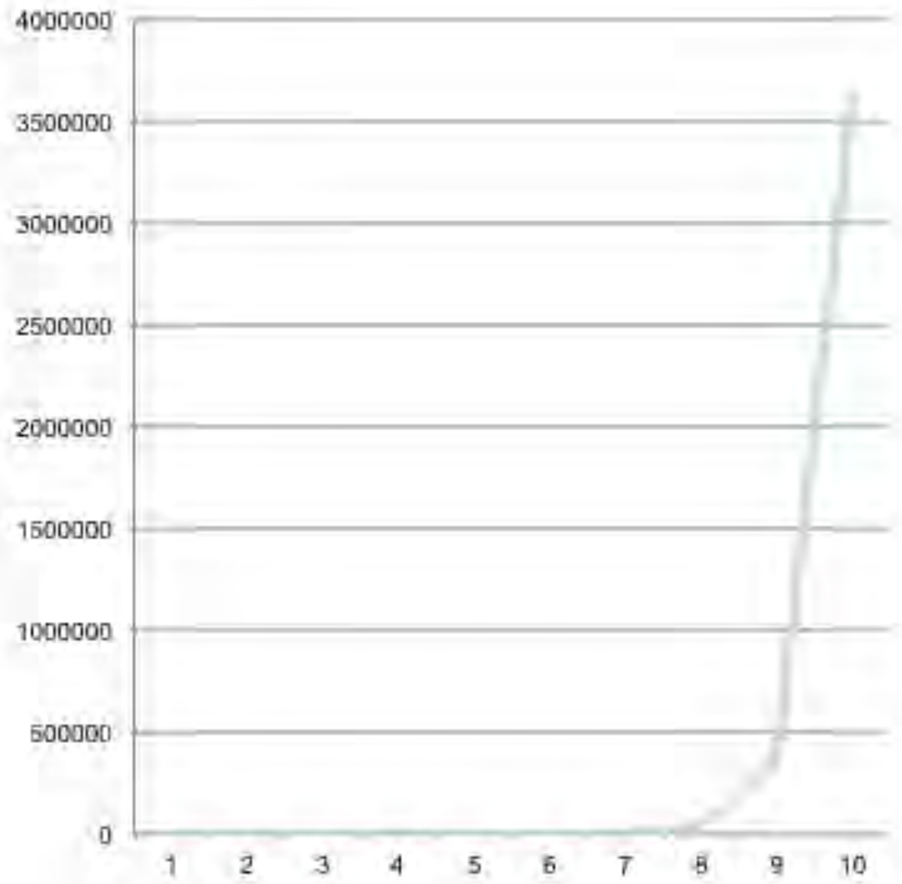
Motivation: Visual

- 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

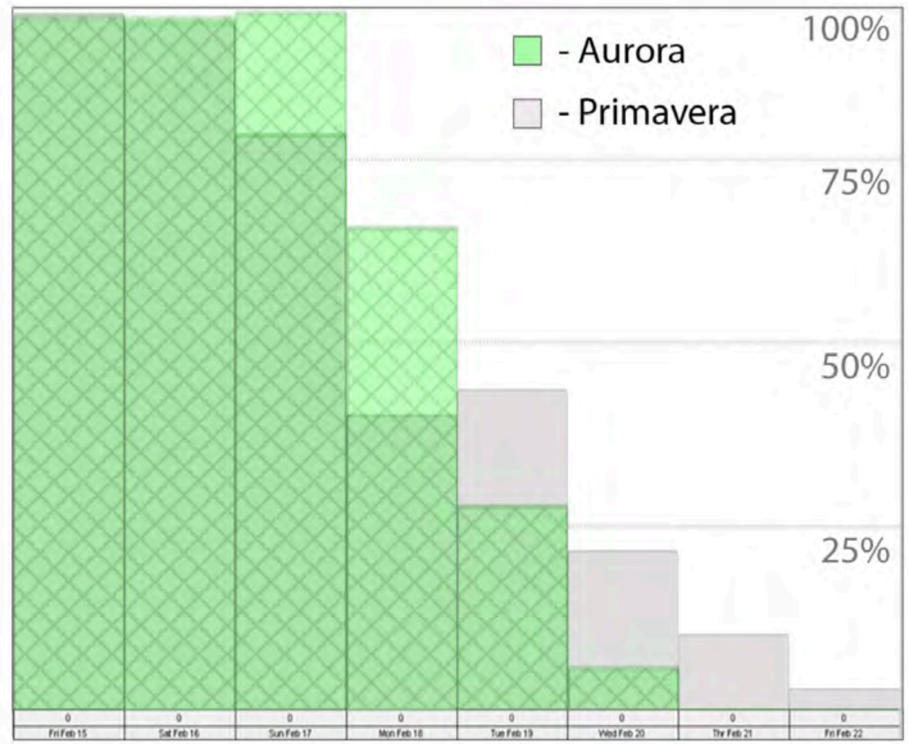
Why can't you search for the best order?

- Ordering options scale as N!

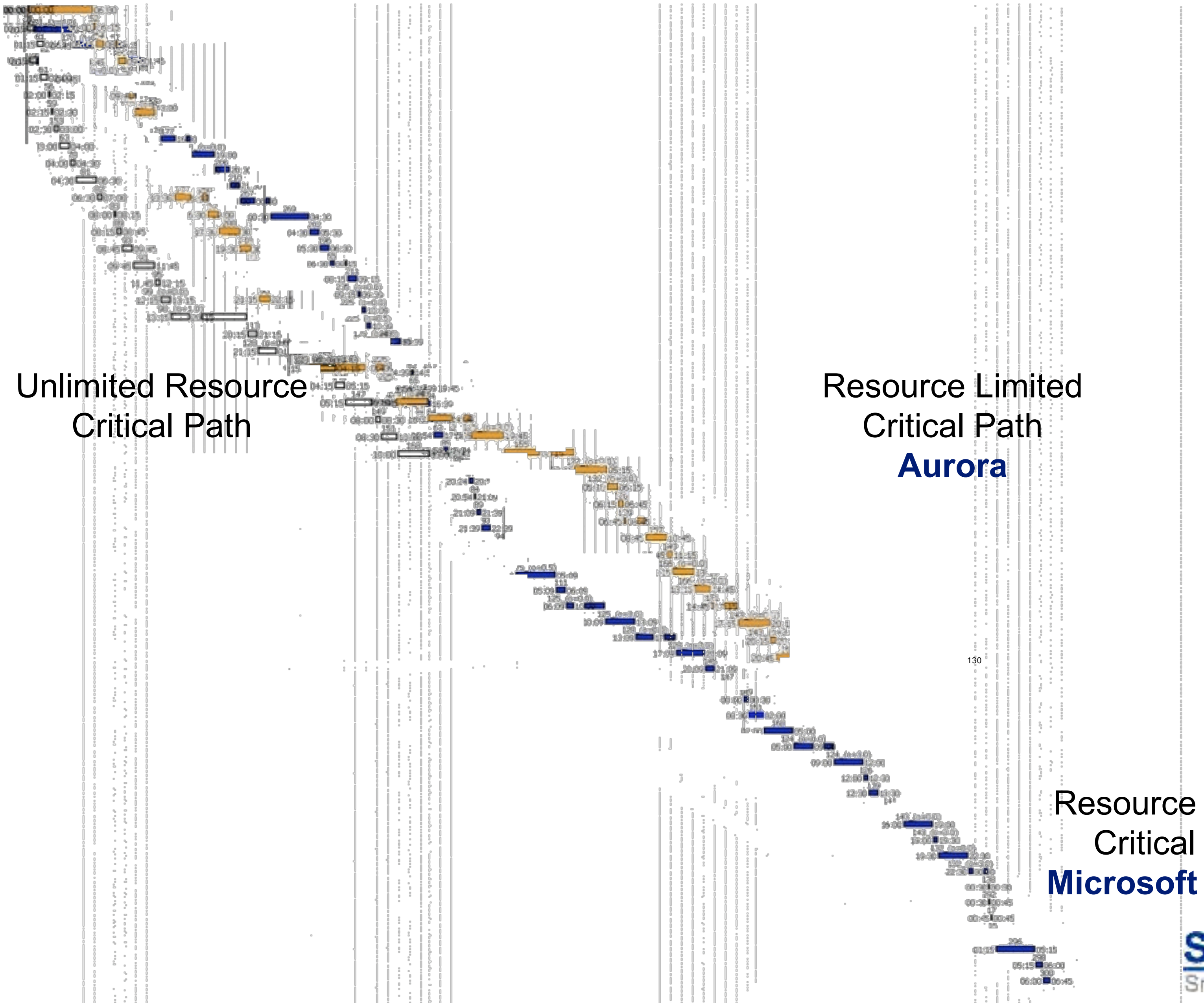
1	1
2	2
3	6
4	24
5	120
6	720
7	5040
8	40320
9	362880
10	3628800



Example: P6 vs Aurora (last set of tasks)



Scheduling Engine Comparison: Gantt Chart



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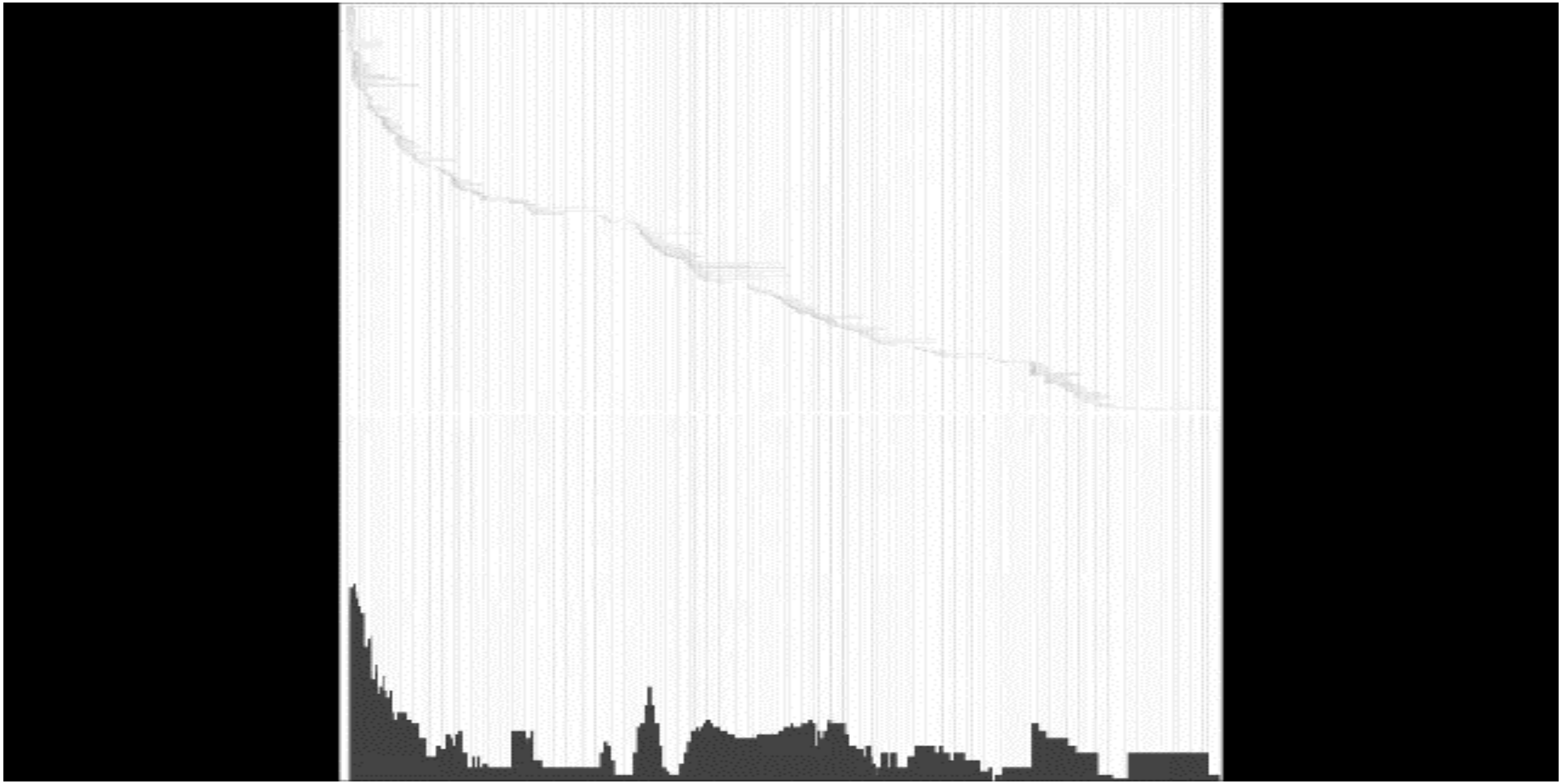
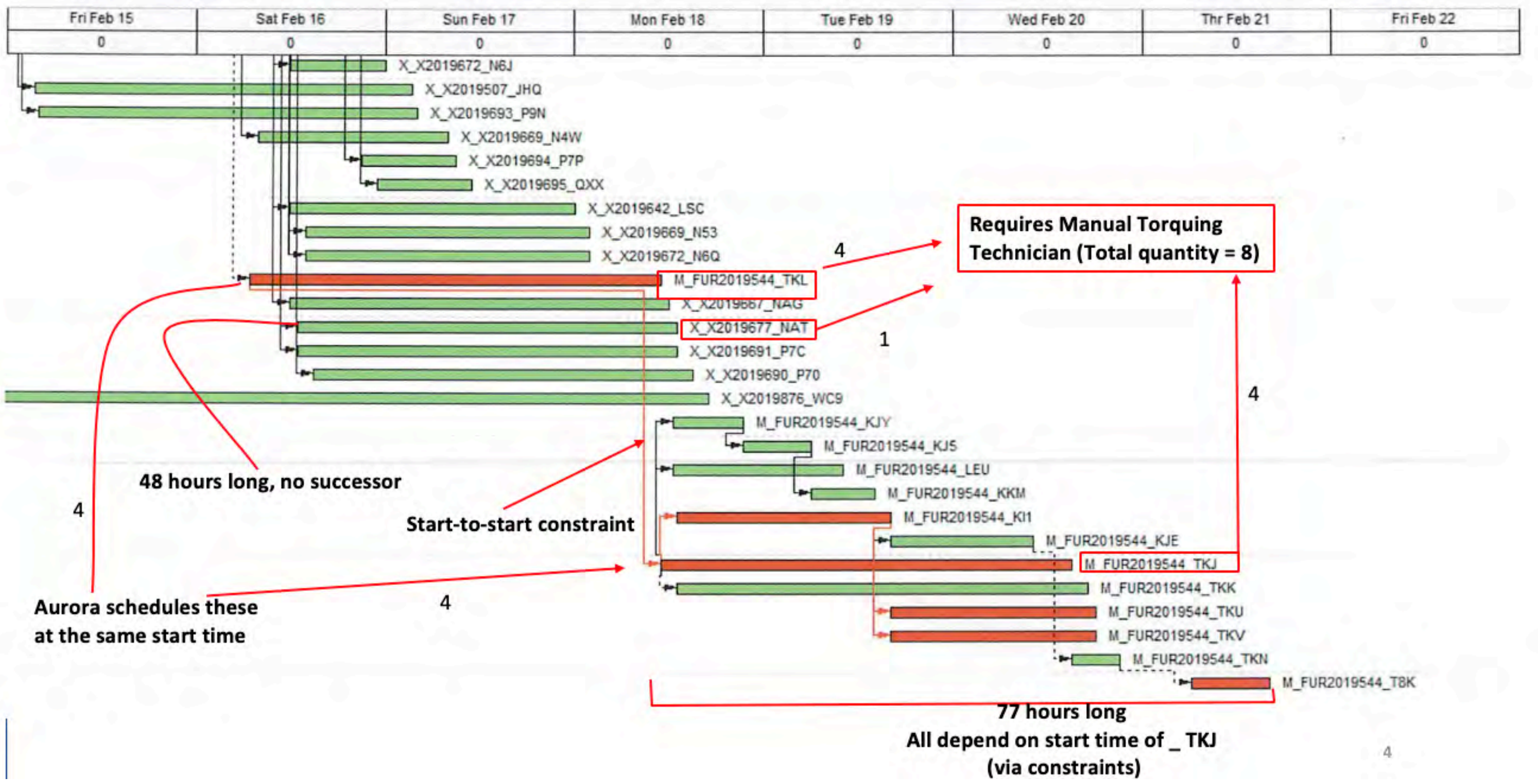
MS Project results (START) vs Aurora results (END): Animation



Example: P6 vs Aurora (End of Schedule)



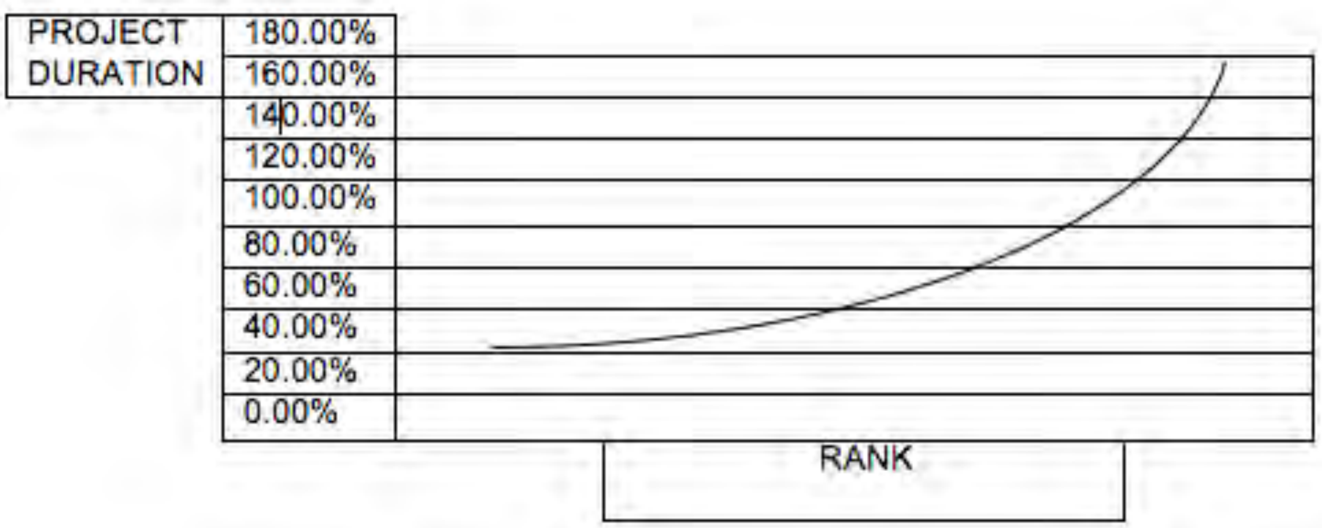
Construction Examples

(Kastor & Sirakoulis, 2009)

	1st Example			2nd Example		
Product	**Resource Unlimited Duration (days)**	**Resource Loaded Duration (days)**	**Increase from Resource Unlimited Duration**	**Resource Unlimited Duration (days)**	**Resource Loaded Duration (days)**	**Increase from Resource Unlimited Duration**
Primavera P6	464	709	**53 %**	238	308	**29 %**
MS Project	464	744	**60 %**	238	314	**32 %**

Different Resource-Leveling Techniques

- Deviation from Critical Path Duration



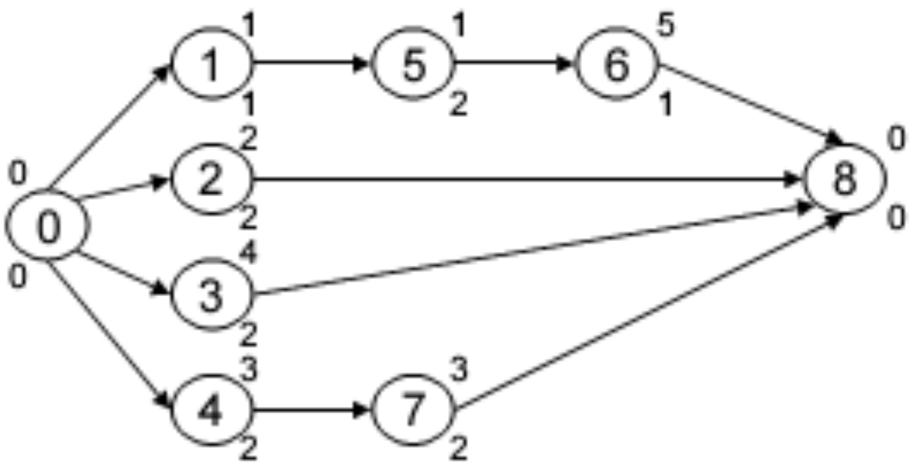
Benefits of Sophisticated Underlying Scheduler

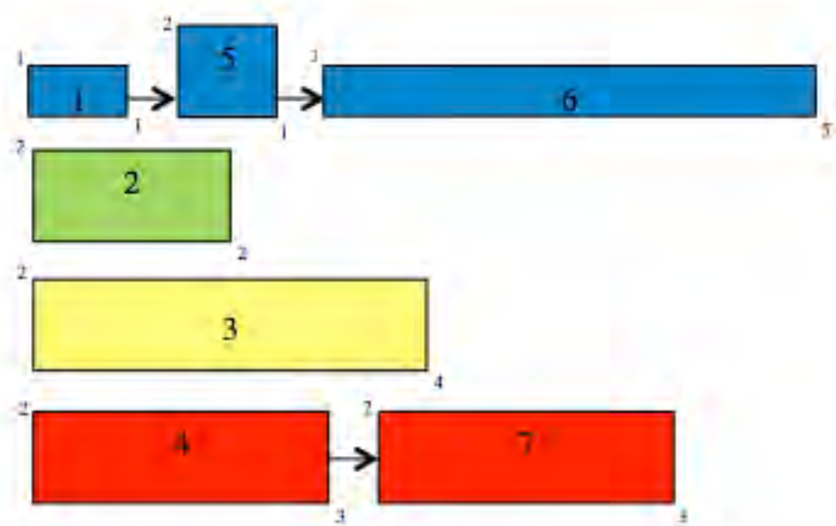
- Results in a better initial schedule
- Execution: Schedule is more flexible and better able to accommodate change.
  - Schedule is "self-aware" of what tasks can most easily be moved. I.e., tasks store information about why it was placed (where it is placed).

Maybe Only for ‘Big’ Problems?

Let’s look at a toy problem …

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



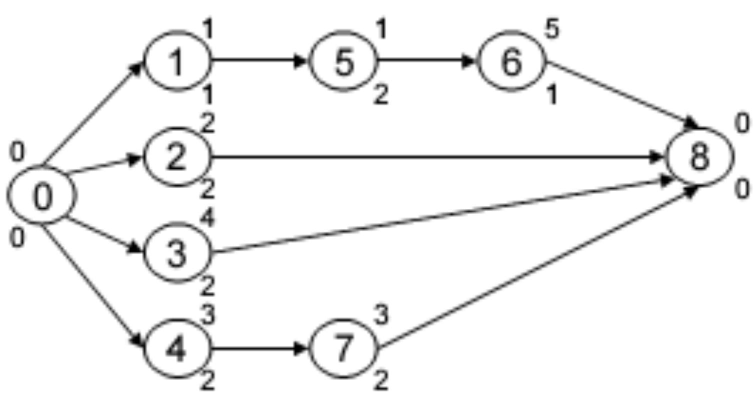


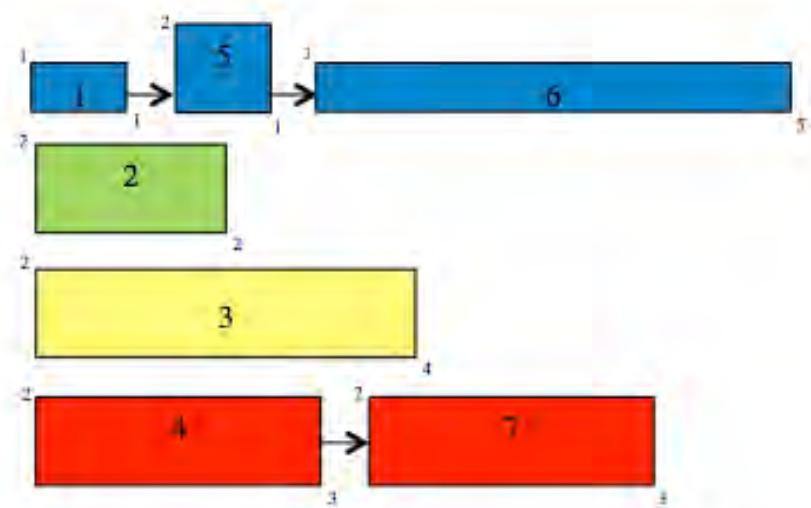
‘Simple’ Network details

Number superscript of circle is duration in days

Number subscript of circle is resources needed

There is only 1 type of resource





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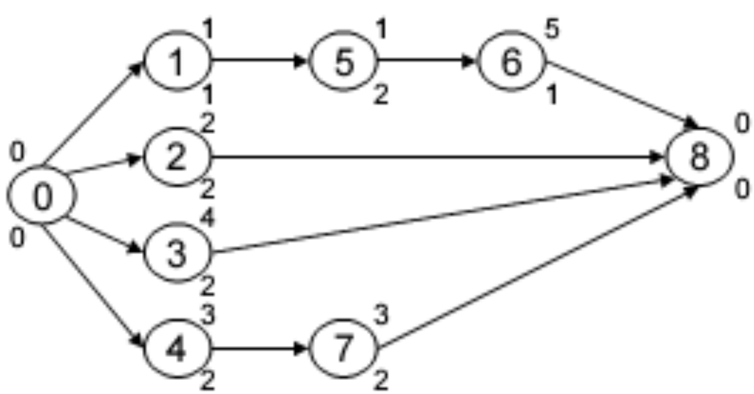
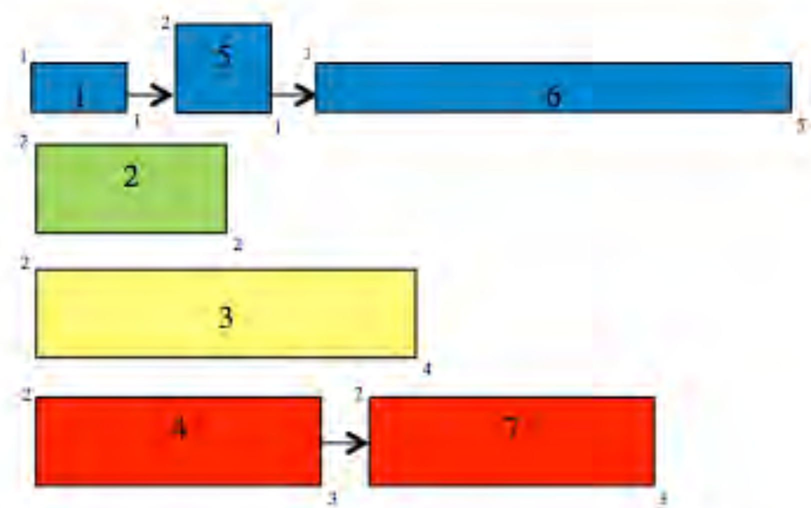
Critical Path of Network

Solution when infinite resources available

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

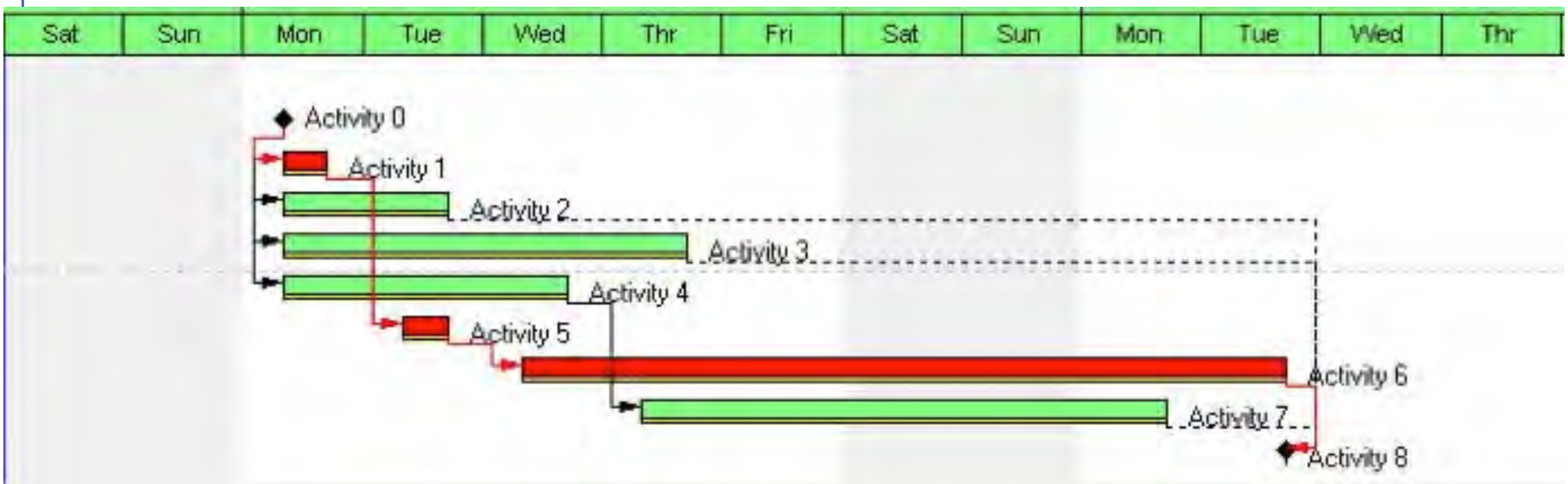
So Critical Path is 7 days





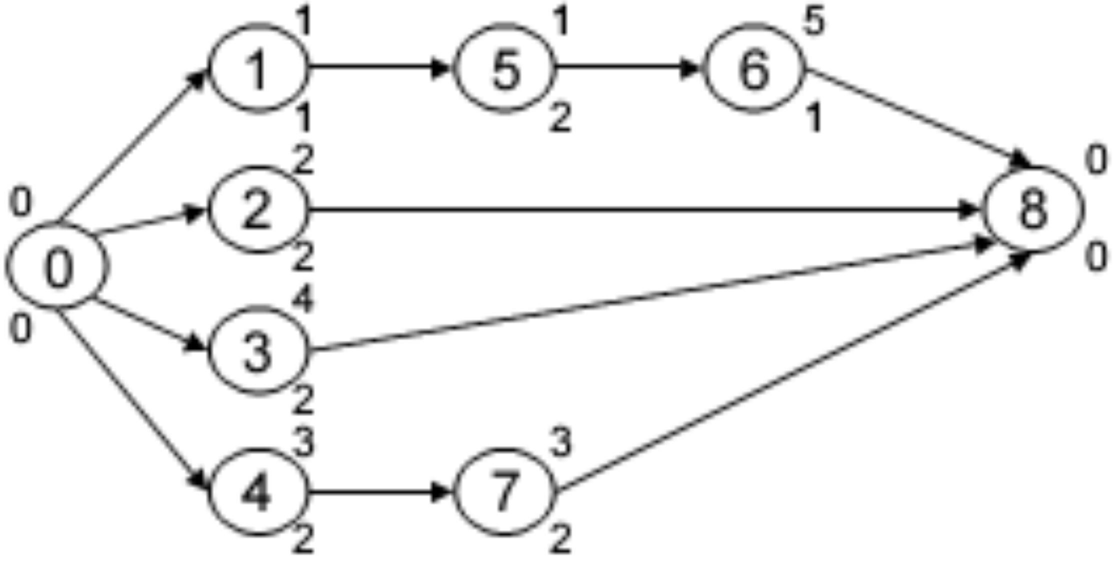
Gantt Chart of Critical Path

Note: Sat/Sun are not workdays



Set Resource Pool to 5

Only one type of resource to make the problem 'simple'



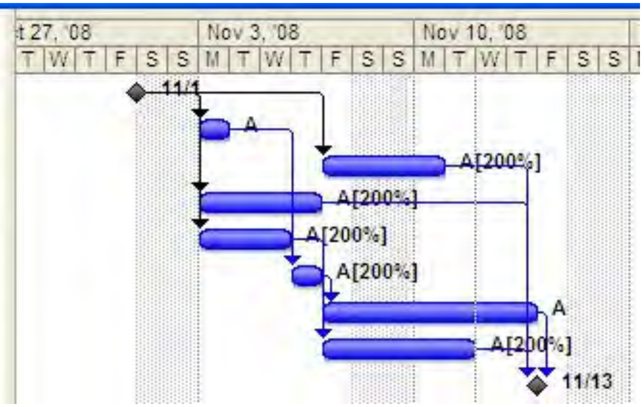
Gantt Chart Showing the Critical Path & Histogram

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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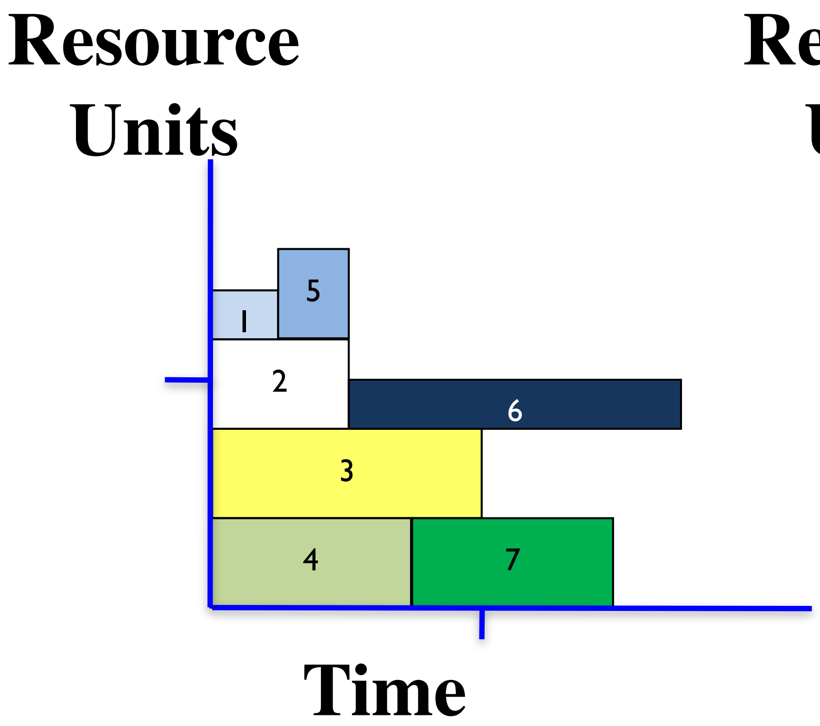
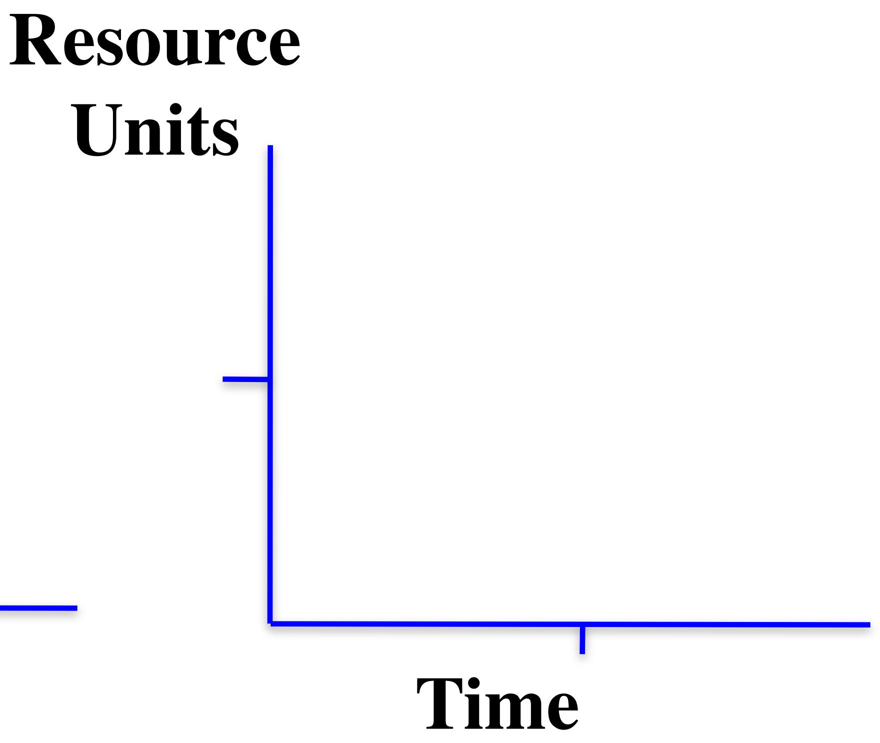
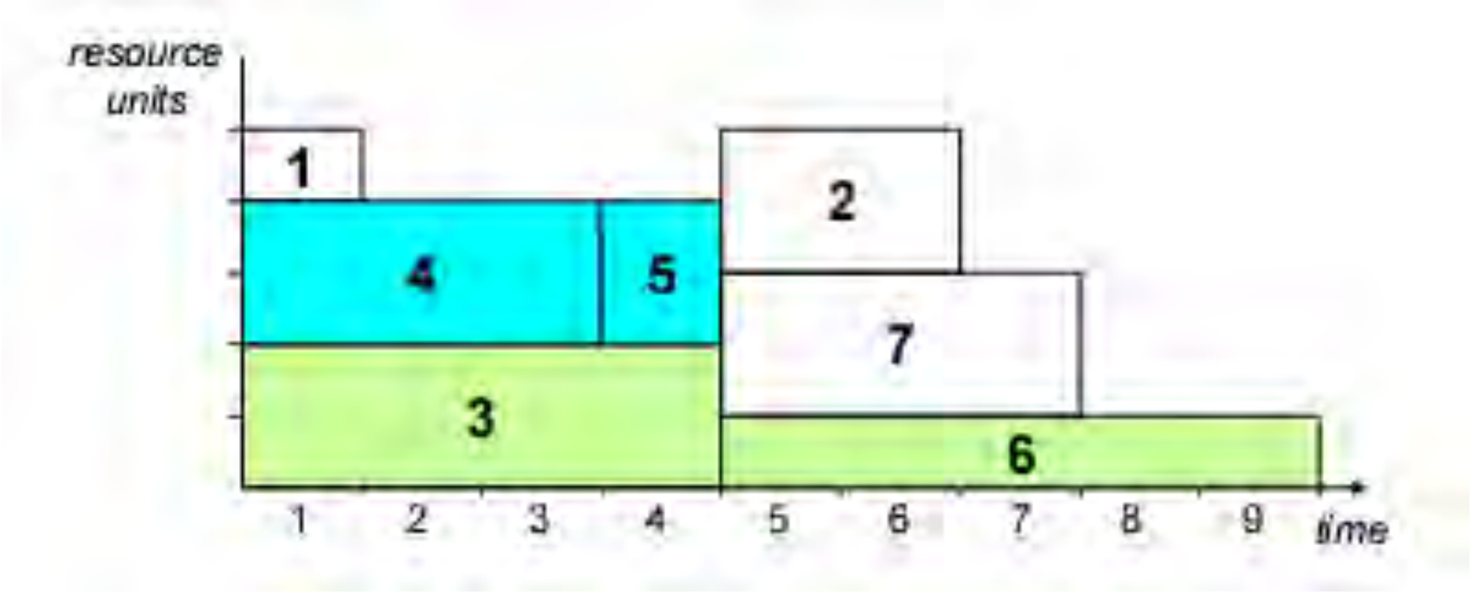
Taking a Closer Look





Simple Enough, Right?

Another view of the solution



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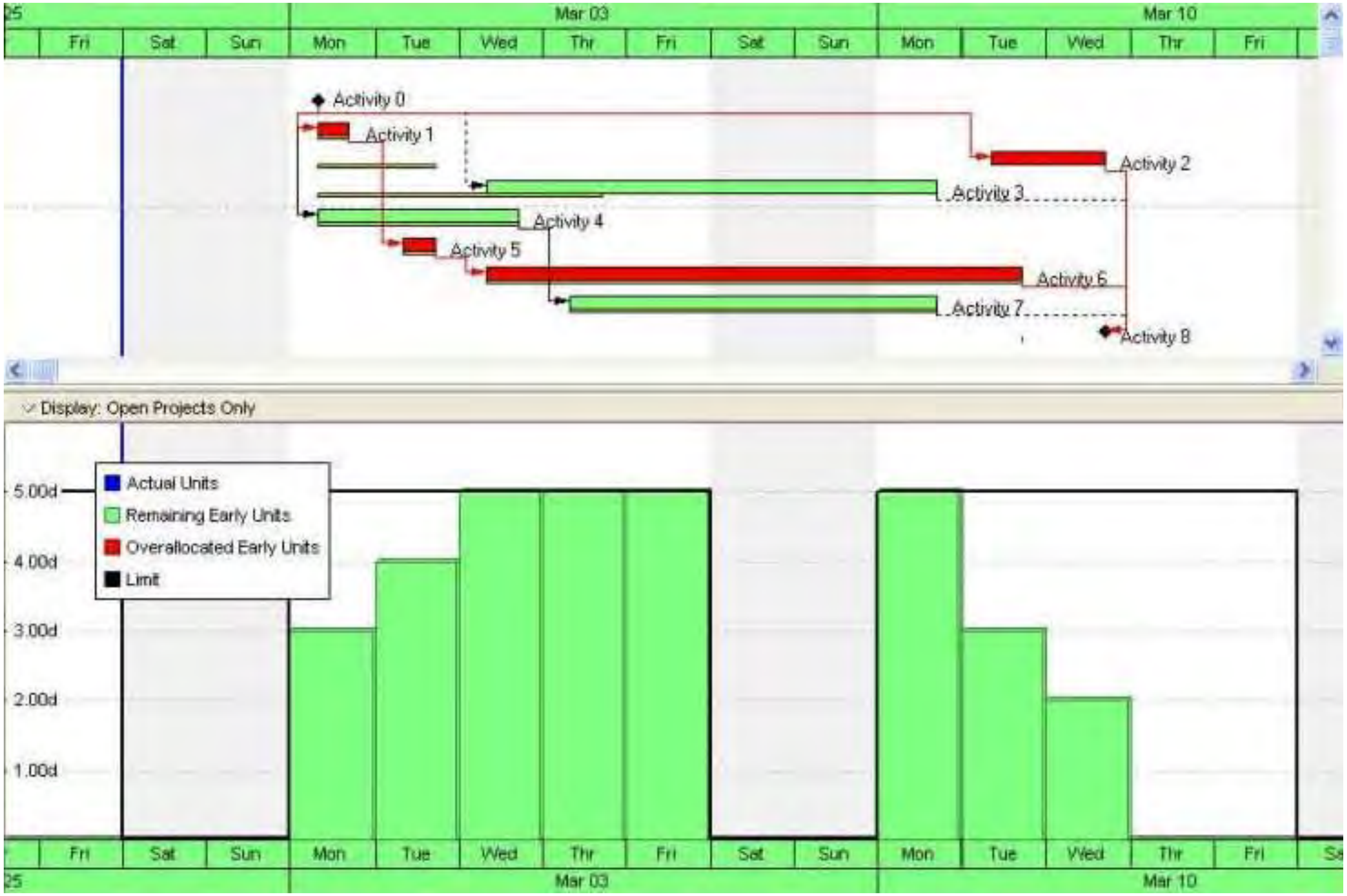
But there is a better solution …
P6 Model: Resource Leveled = 8 days



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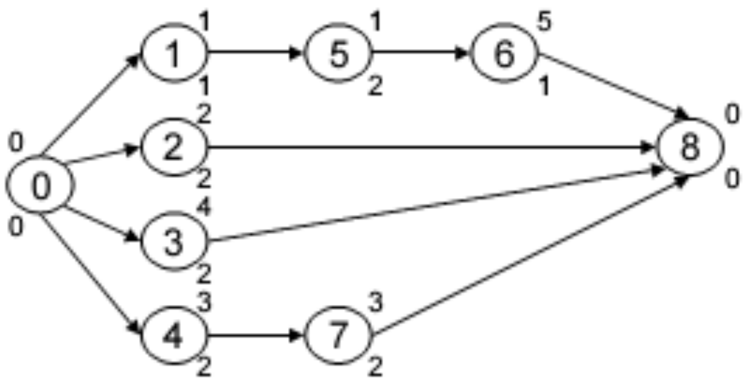
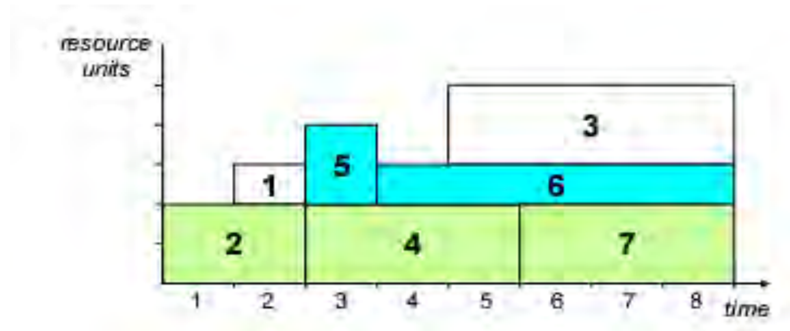
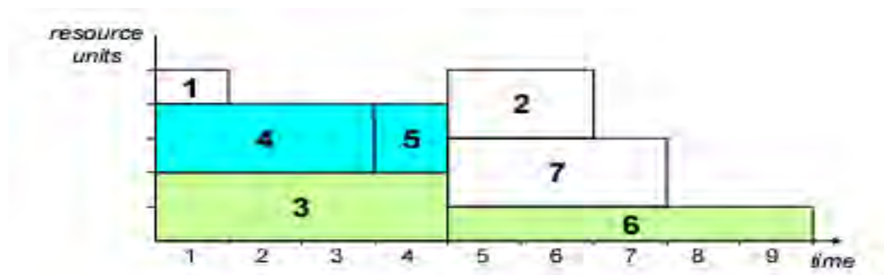
Simple?





Critical Path =
1 + 1 + 5 =7

1 resource
5 total units



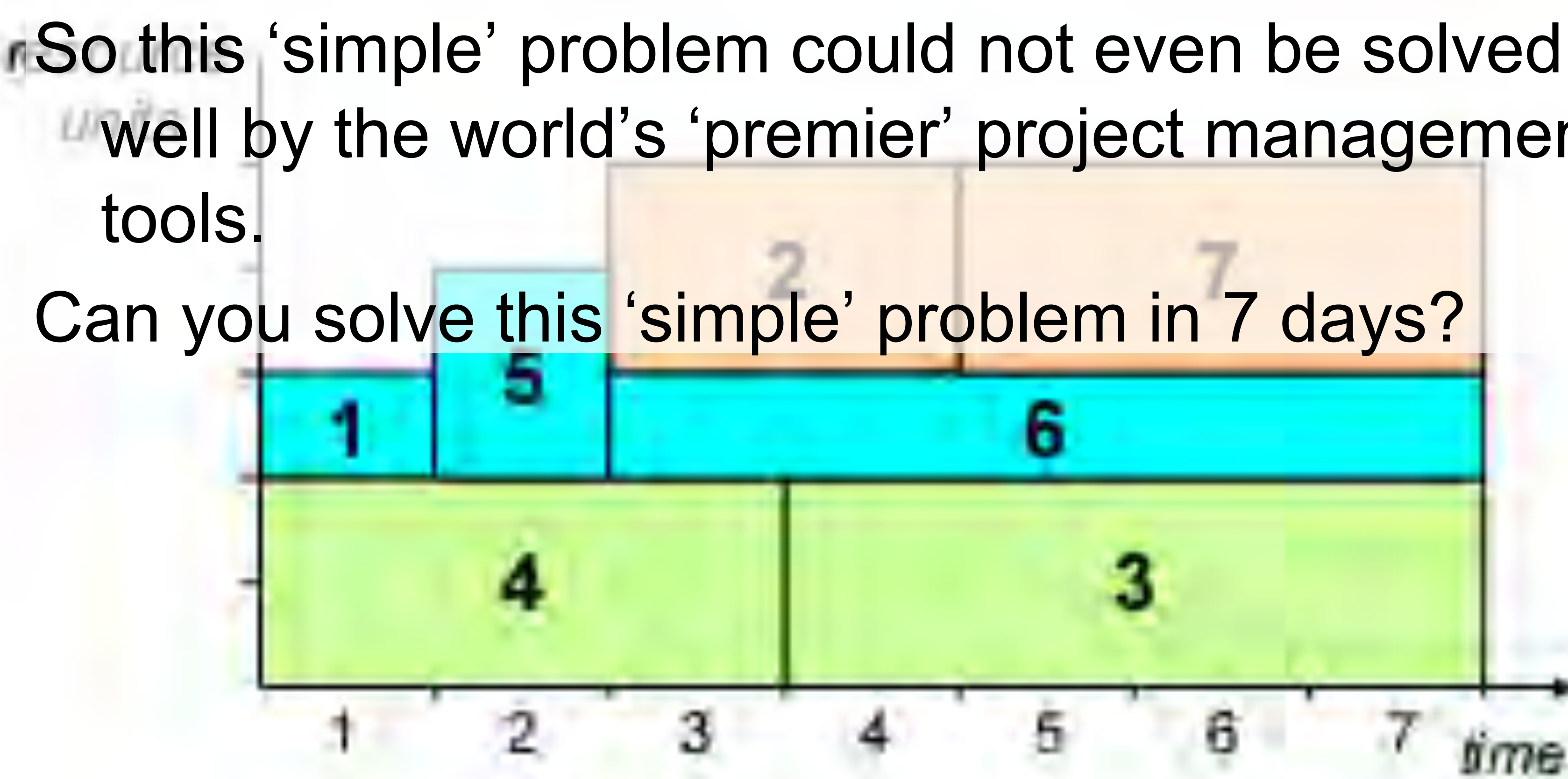
End of Story… Not quite

There is an even better solution

7 days

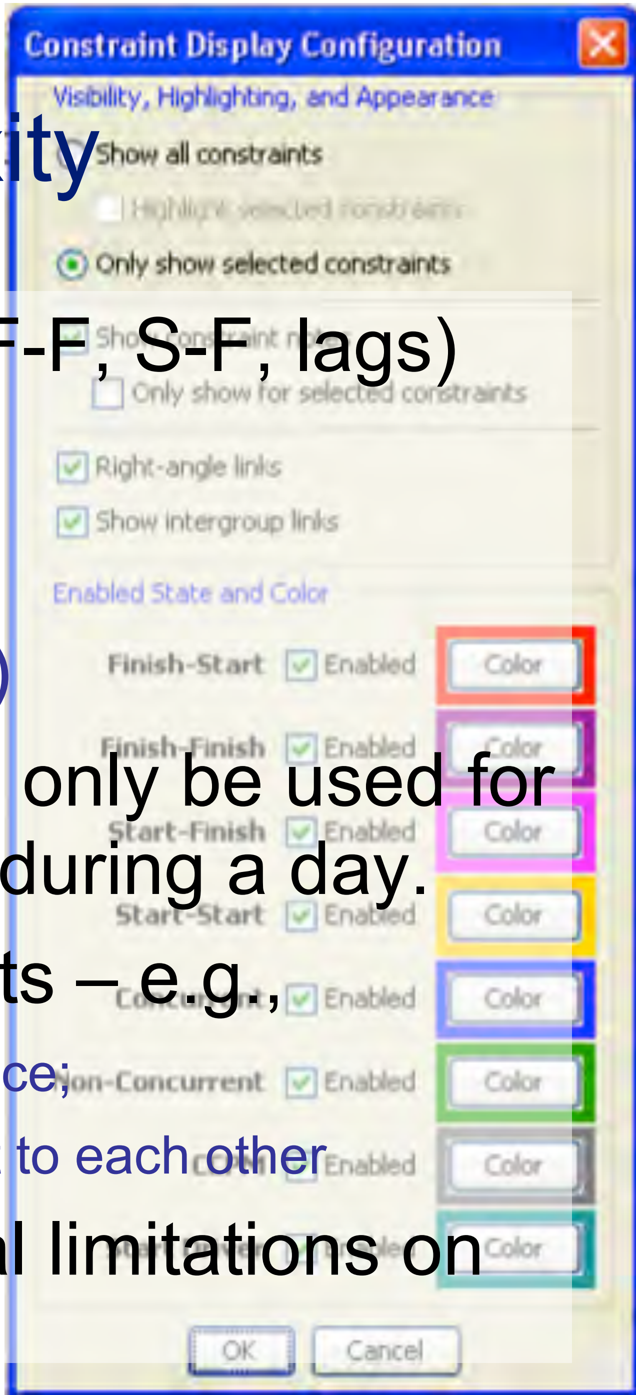
So this ‘simple’ problem could not even be solved well by the world’s ‘premier’ project management tools.

Can you solve this ‘simple’ problem in 7 days?



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

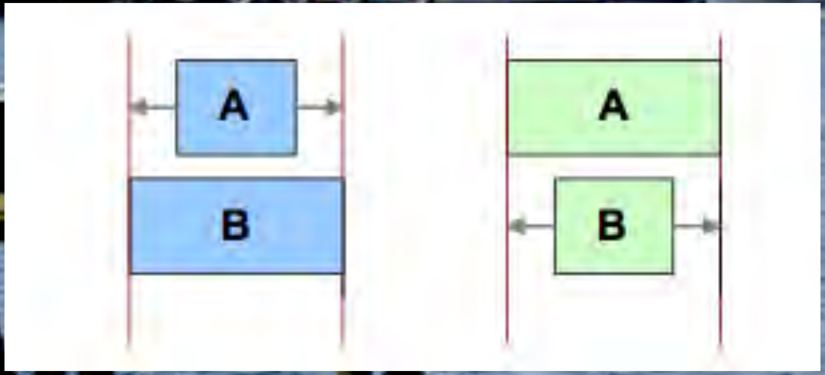
- Ingress & egress: limited
- Skills / Certifications in addition to Occupations
  - E.g., Mechanic (occupation) with 4 additional skills or certifications
- Constraints based on status/state
  - E.g., no hot work when other conditions in effect
- Shift based constraints
  - Task needs to be completed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

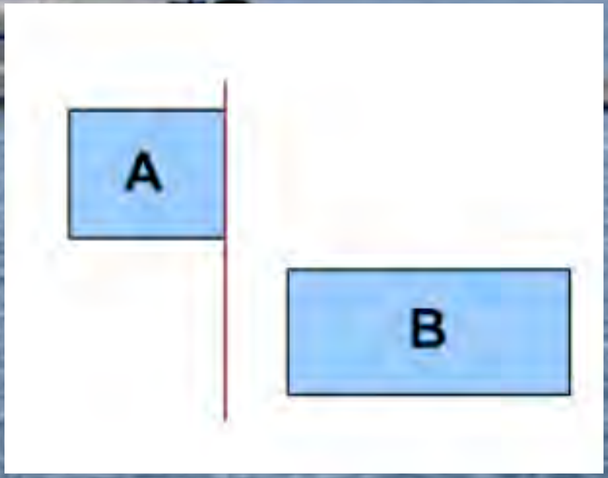
NSSF: Submarine Maintenance

- 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

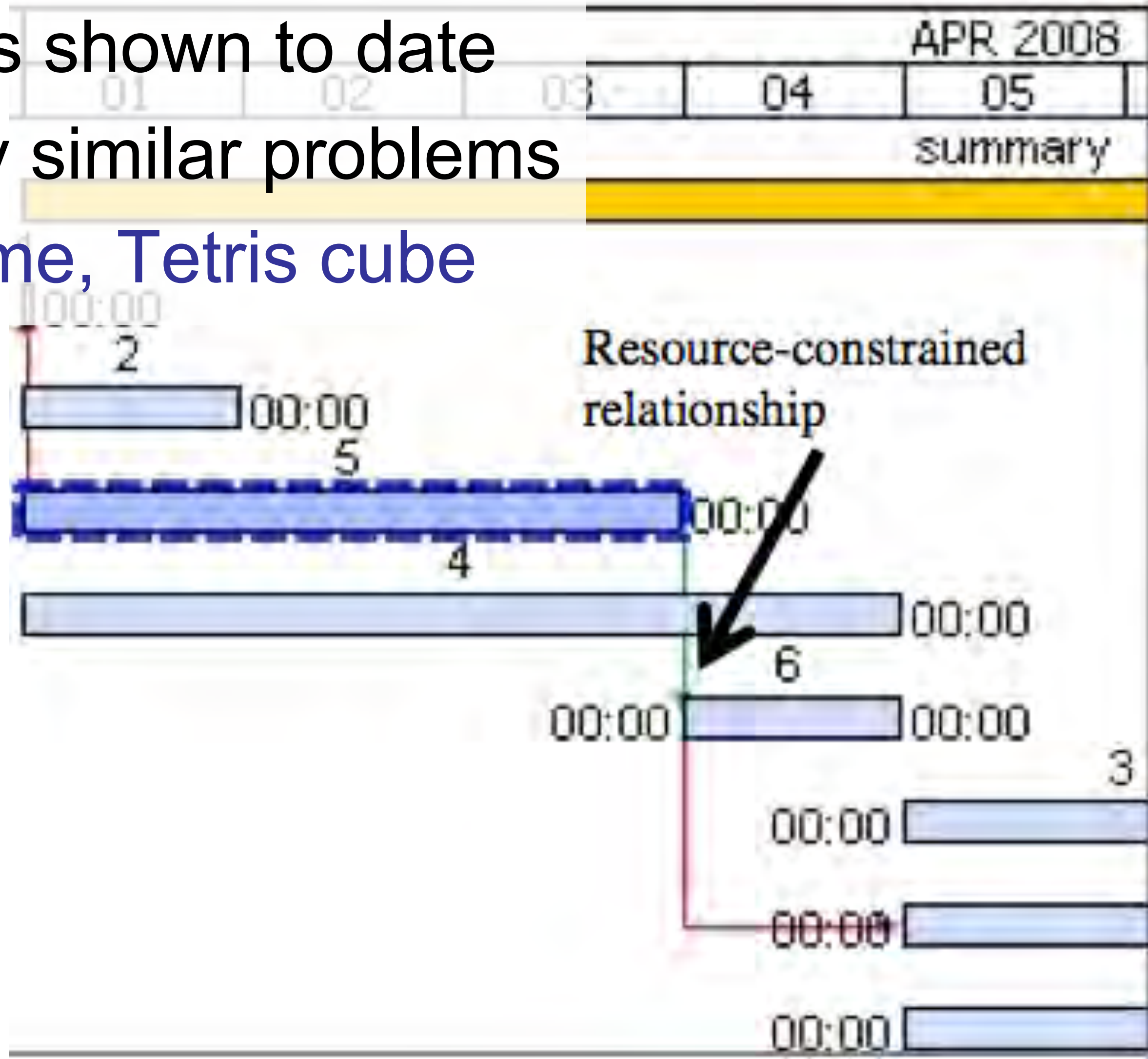
- Complex operations requires concept of concurrent & non-concurrent tasks
- Adds another layer of complexity





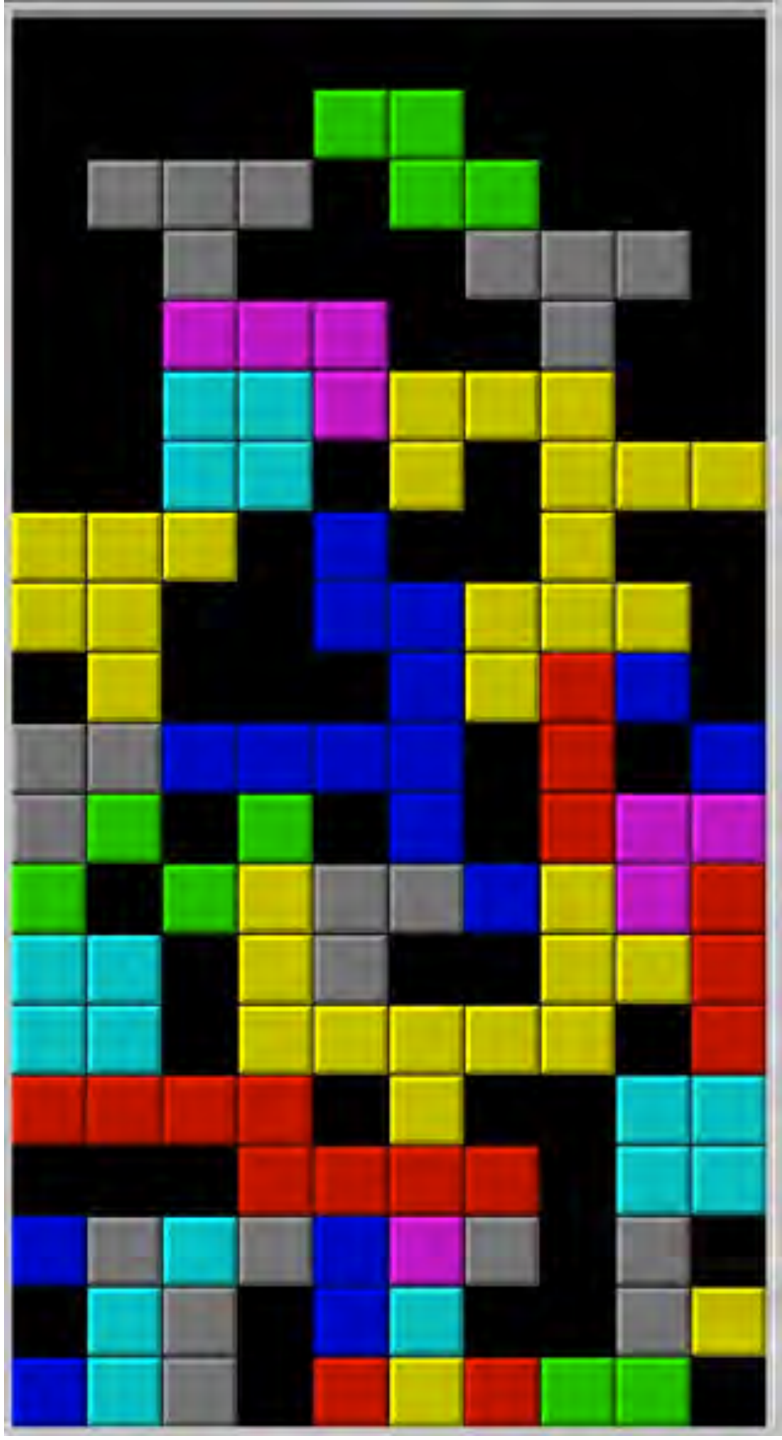
Visualizing More Complex Situations

- No good methods shown to date
- Closest way is by similar problems
  - E.g., Tetris game, Tetris cube



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 www.FreeTretris.org for yourself.

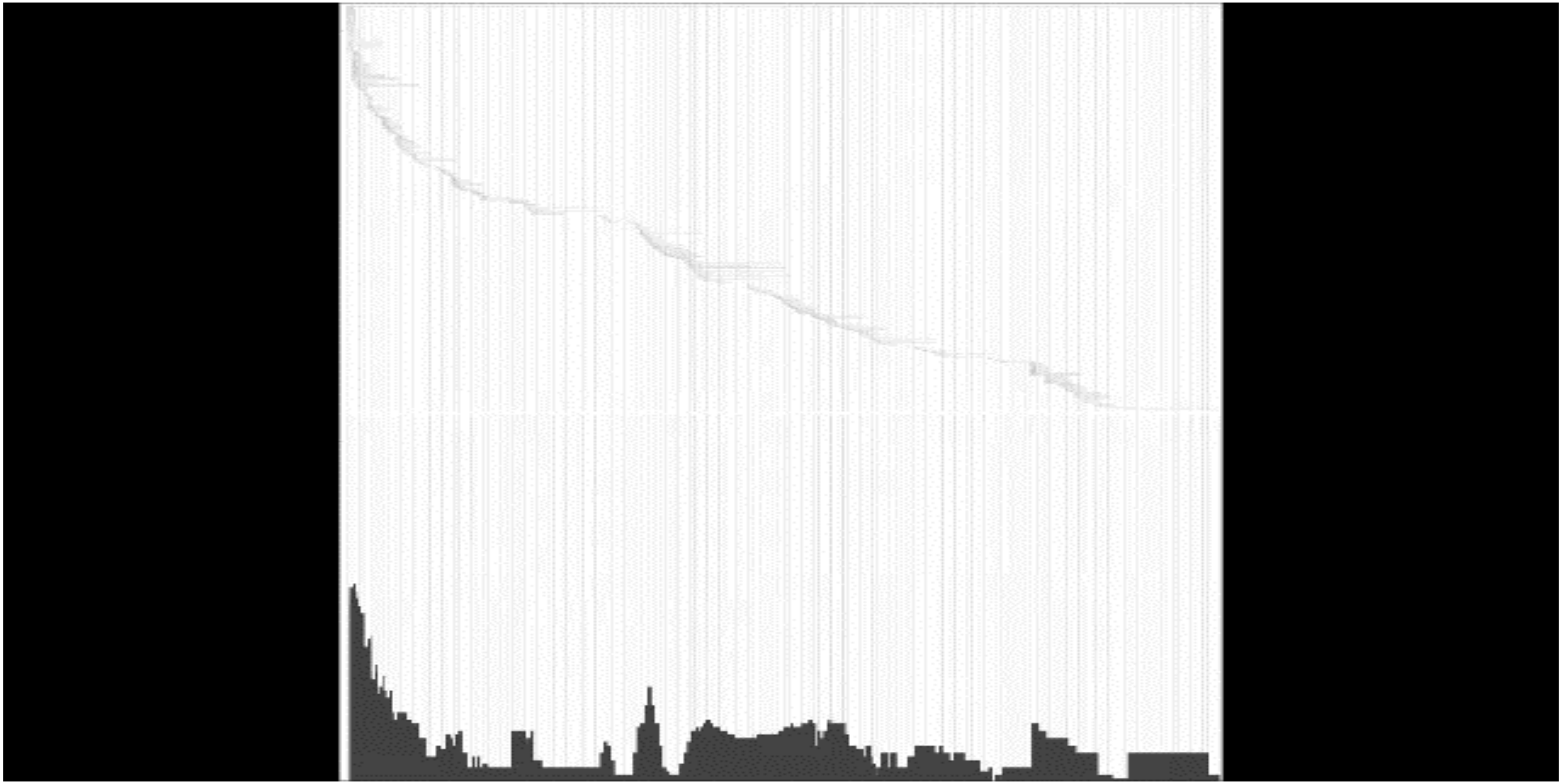


Tetris Cube

- 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

MS Project results (beginning of animation) VS. Aurora results (END)



Refinery Turnaround Leveraging Intelligent Scheduling Technology

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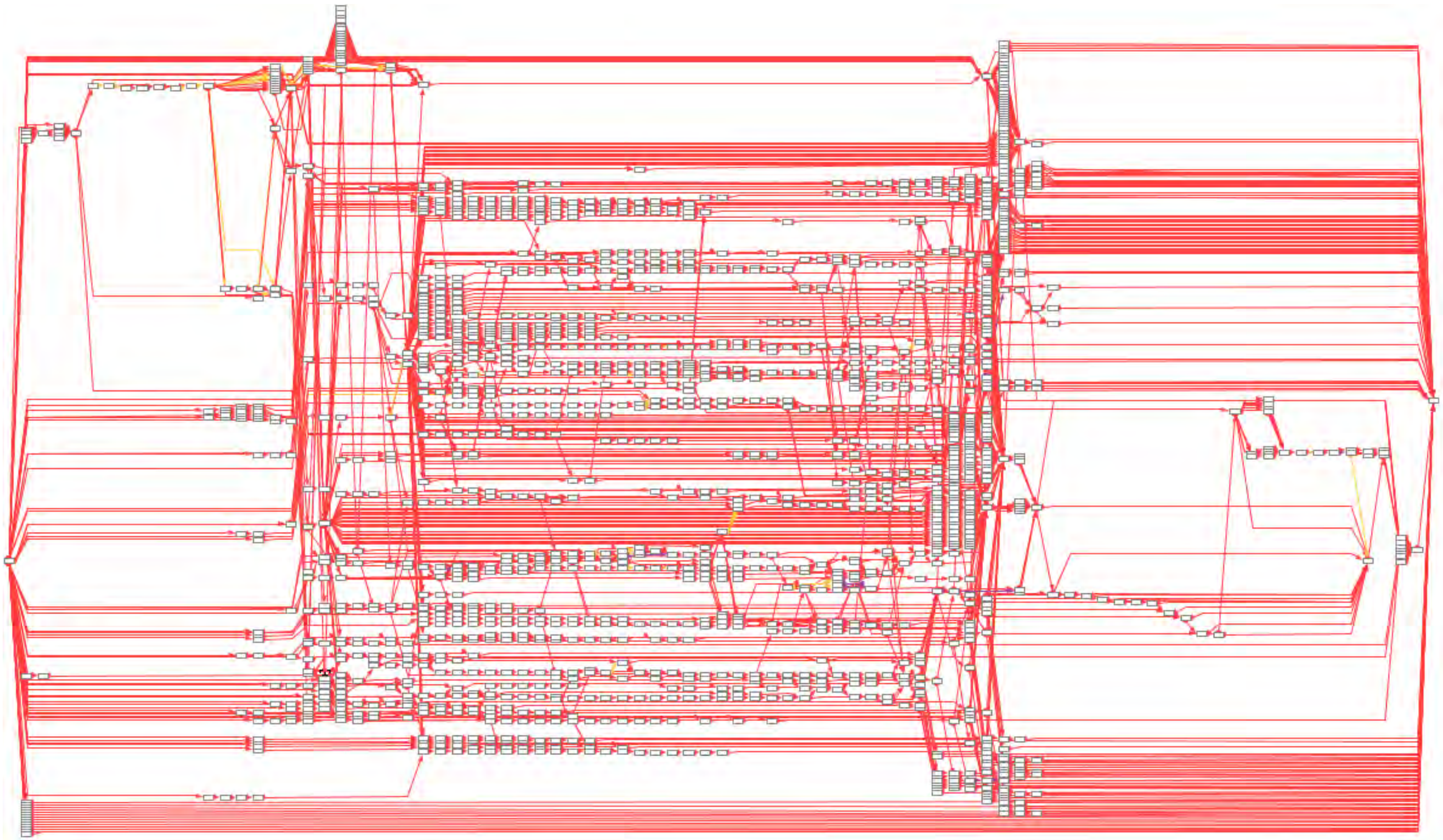
Turnaround Project Network 2,500+ Tasks



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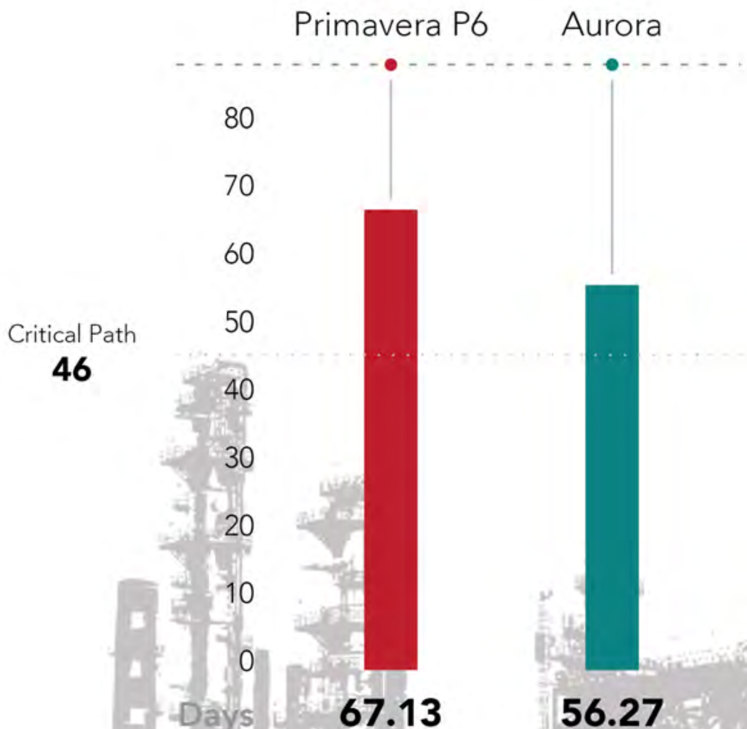
Results: 2,500+ Turnaround

- 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
2500+ TASKS



Aurora saves over

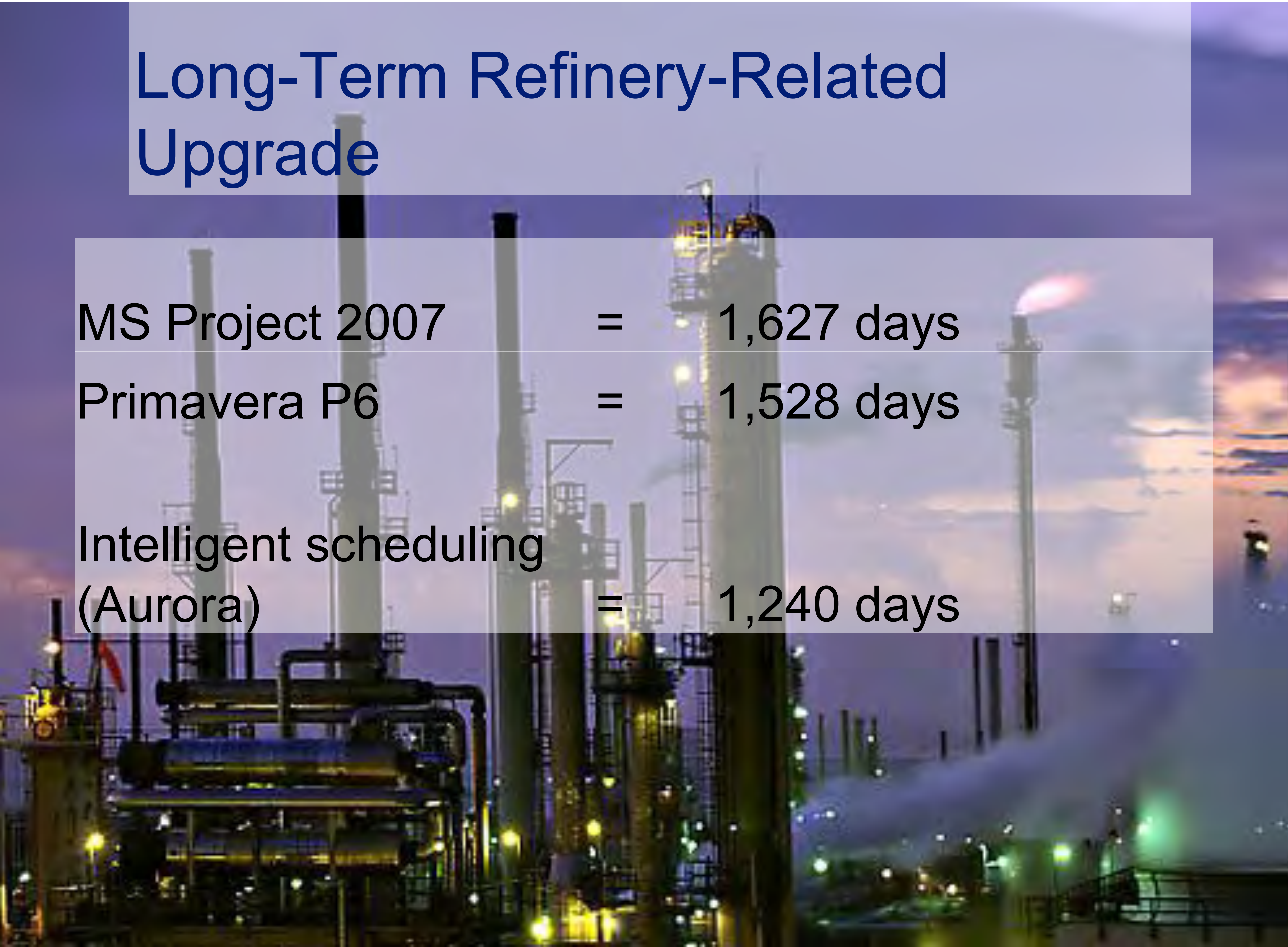
10

days versus Primavera P6

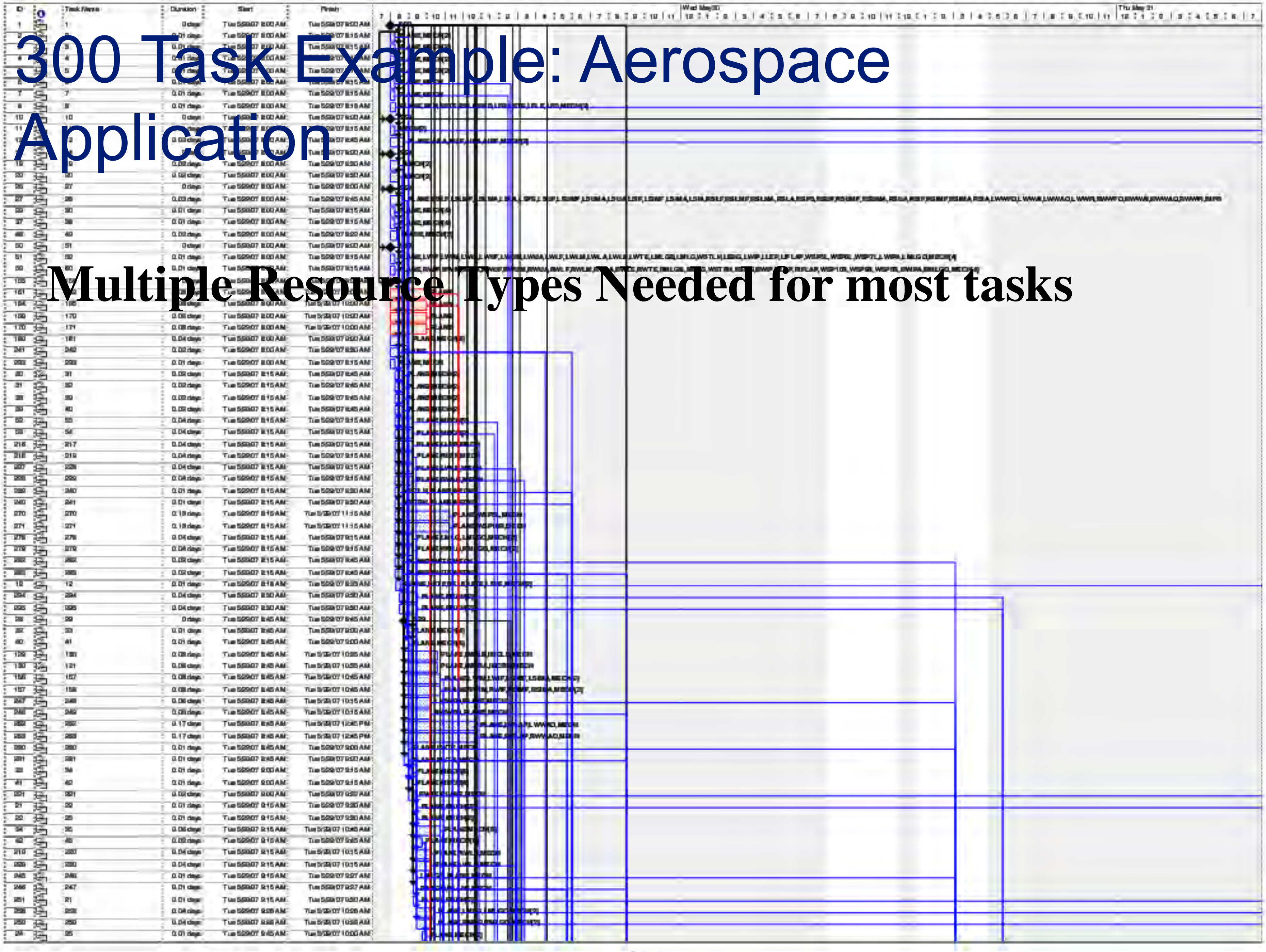
All tests done by third party

Long-Term Refinery-Related Upgrade

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

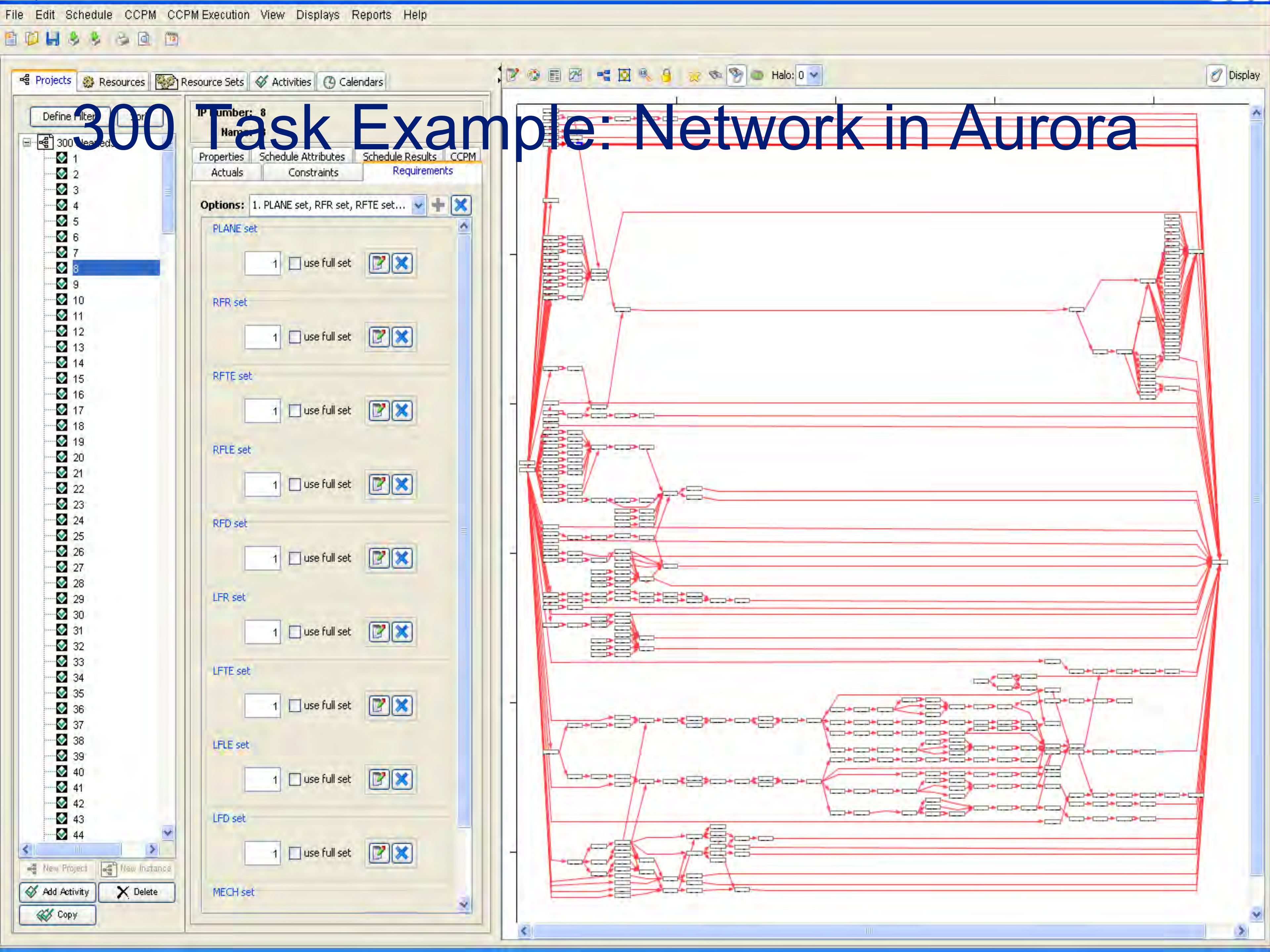


300 Task Example: Aerospace Application



Multiple Resource Types Needed for most tasks

300 Task Example: Network in Aurora



Scheduling results – Aerospace model

- 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

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

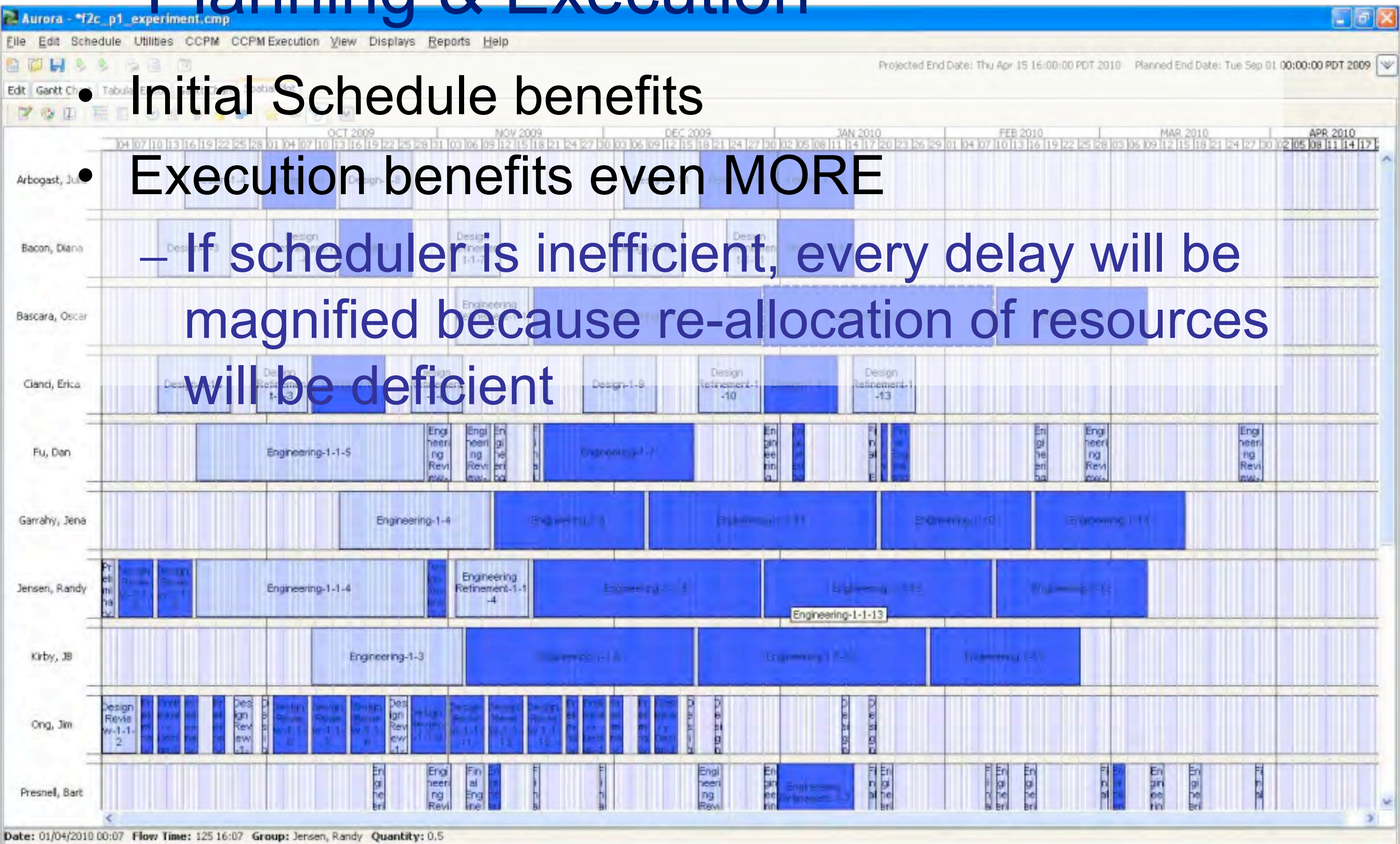
- High degree of variation - it depends a lot on the shape of the problem

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.

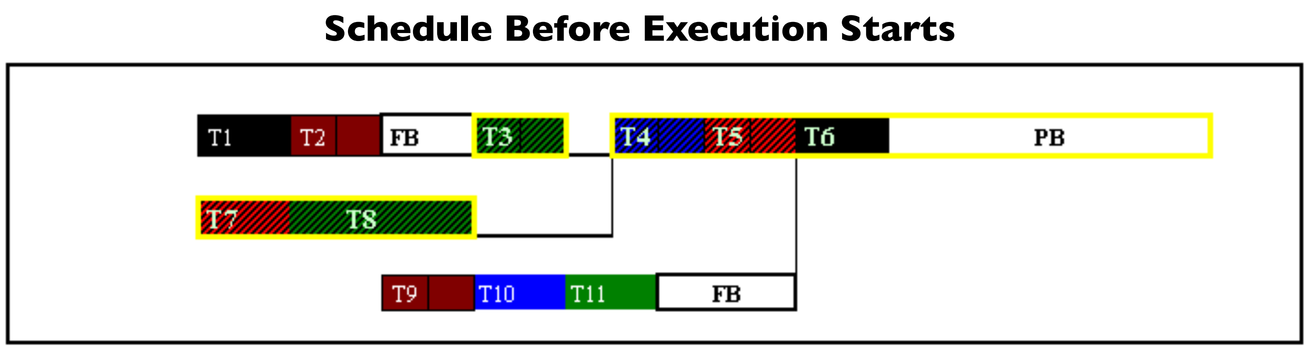
Analogy: Chess

- 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

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

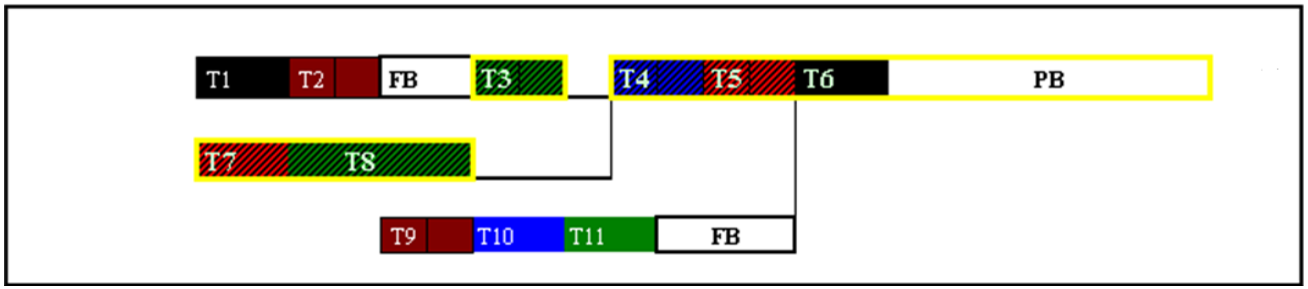
Critical Chain in Execution (view in slide show mode to see animations)

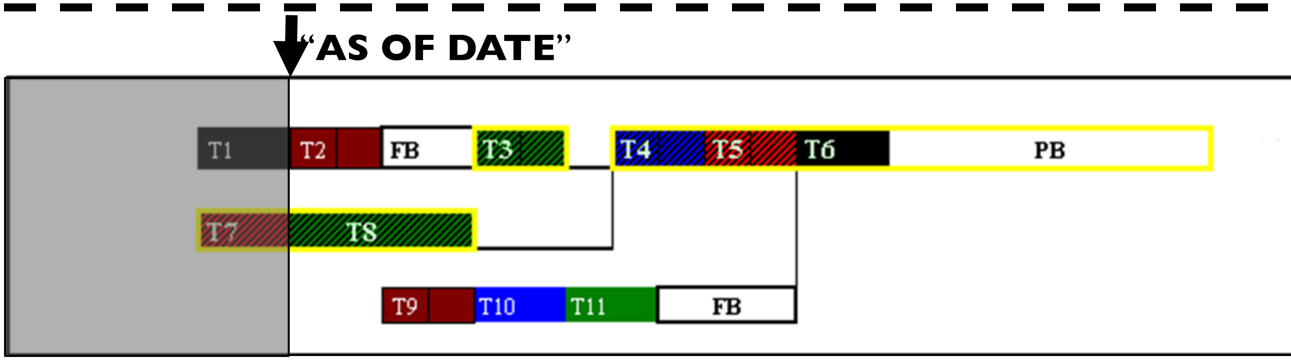


Report *remaining duration*, not % complete

Critical Chain in Execution(view in slide show mode to see animations)

Schedule Before Execution Starts

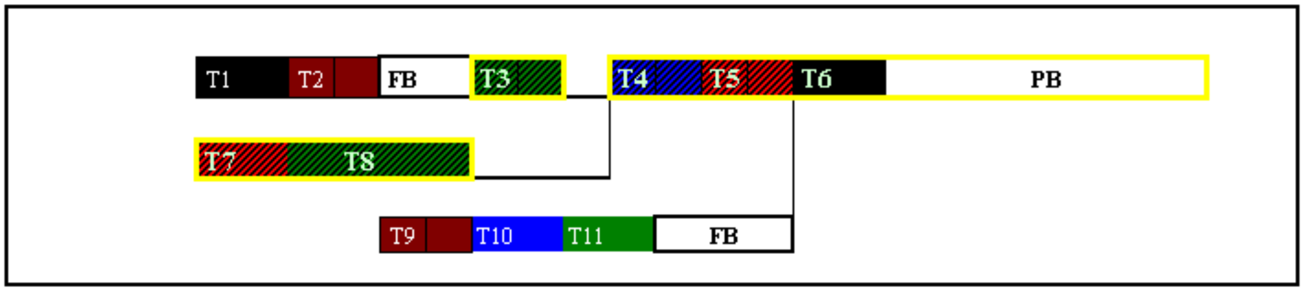




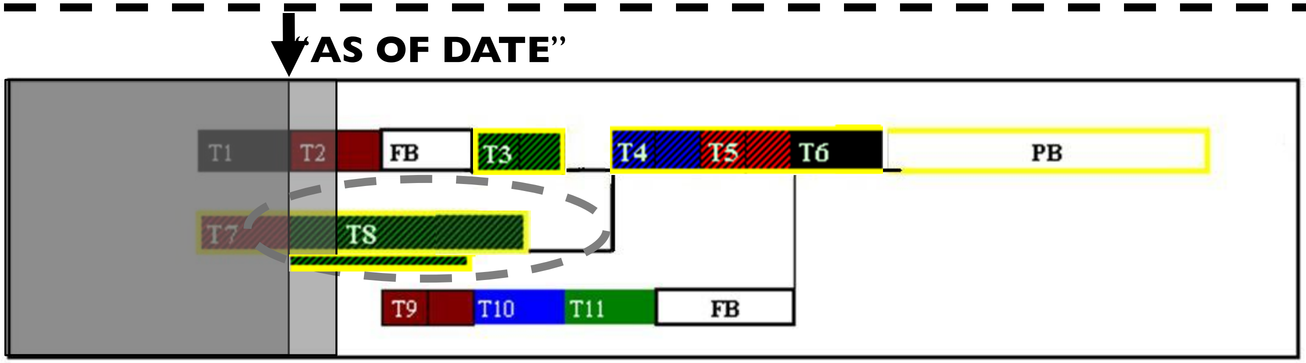
- T1 & T7 finish on time

Critical Chain in Execution (view in slide show mode to see animations)

Schedule Before Execution Starts



"AS OF DATE"

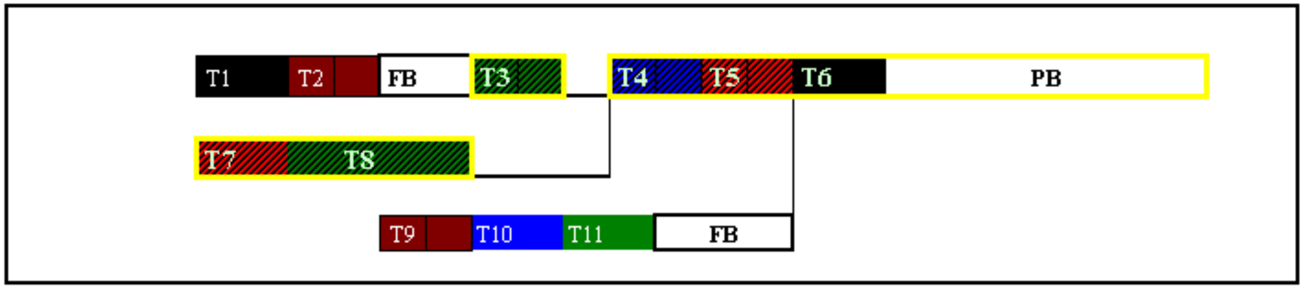


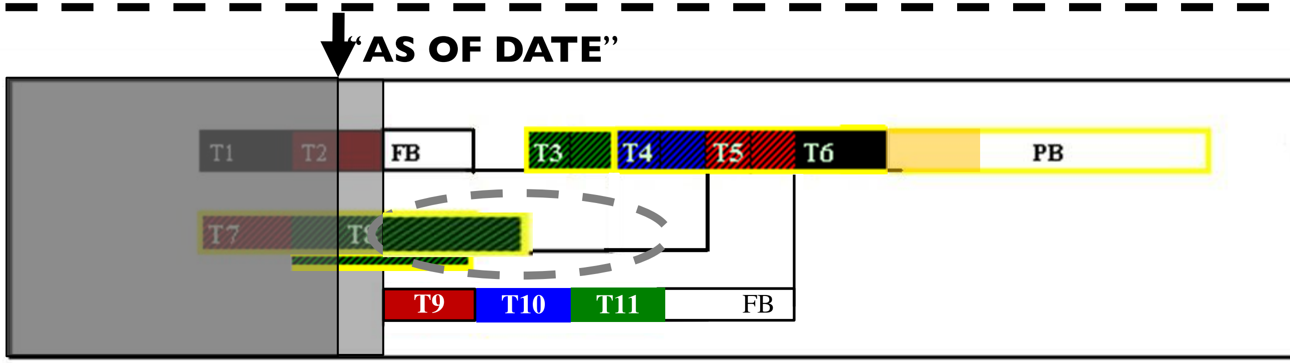
- T8 experiences increase in Scope or Delay
- First portion of delay absorbed by gap between T3 & T4

= Original T8 duration

Critical Chain in Execution (view in slide show mode to see animations)

Schedule Before Execution Starts





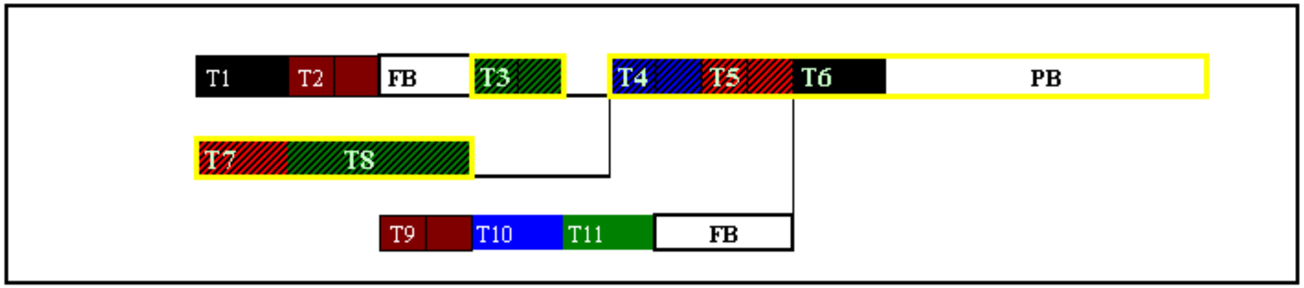
- Rest of delay impacts the project buffer
- T11 also affected due to resource constraint
- E.g., So as of the "As of Date" project may be → 7% Complete with 30% Buffer Consumed

= Original T8 duration

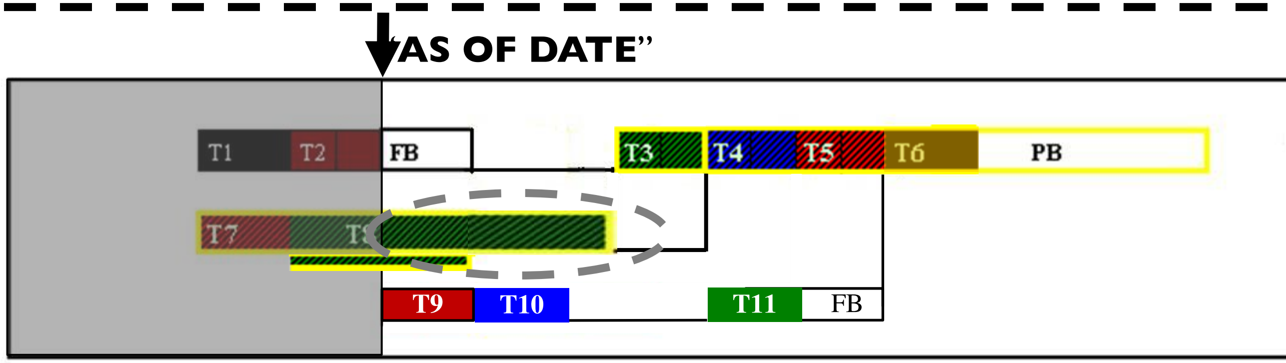
= project buffer impact

Critical Chain in Execution (view in slide show mode to see animations)

Schedule Before Execution Starts



"AS OF DATE"



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Our Engagement Model