IFPAC 2013

Intelligent Planning & Scheduling Platform for
Lean Manufacturing and
Optimization of Changeovers

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Resources and Production / Projects

- Large organizations developing and building complex systems rely on schedules and production / project management.

- ALL production / 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 or over simplify
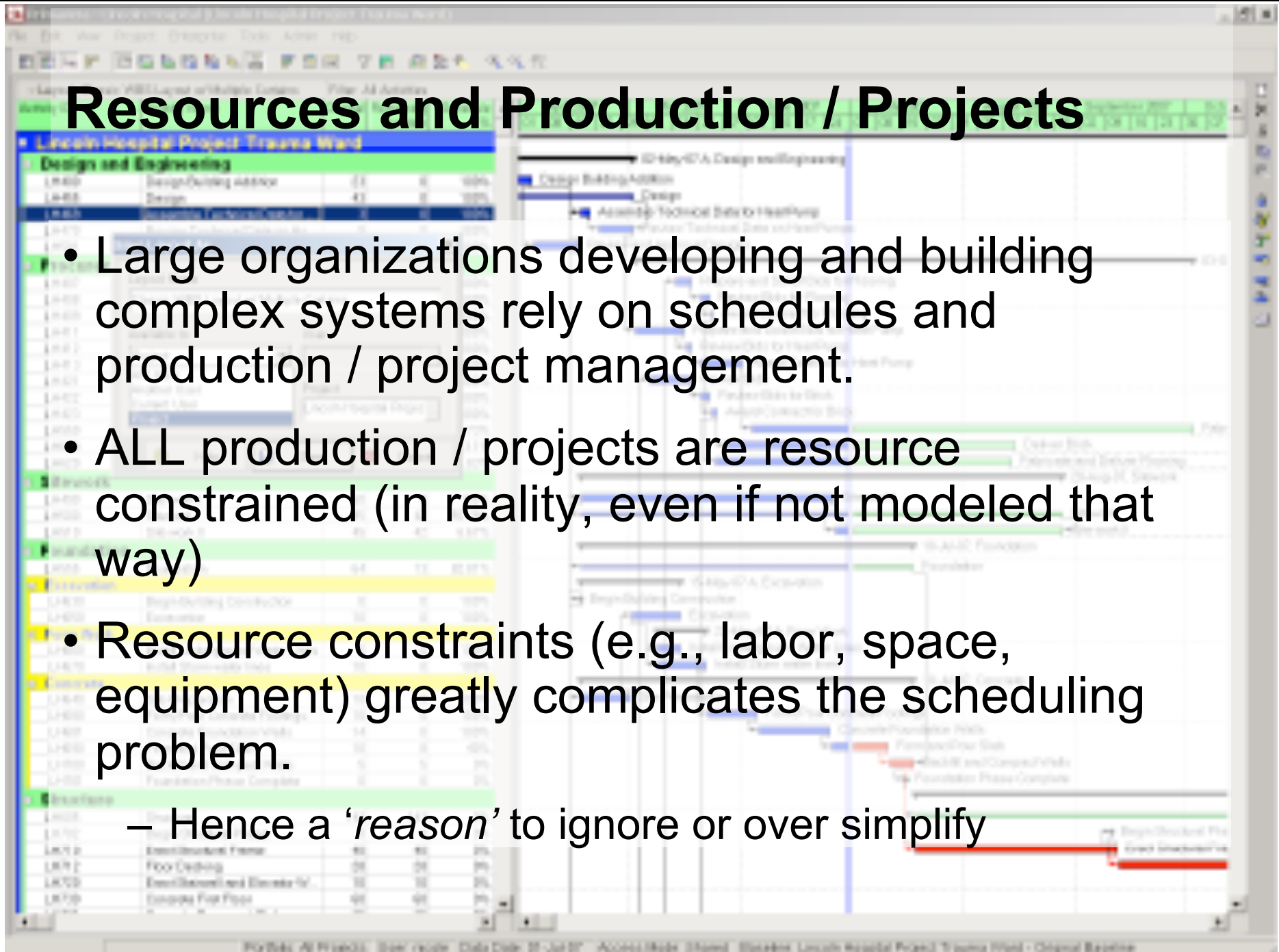
Spectrum: Production to Project

- Pure Production
  - Build exact same thing with exact same equipment and people (minimal variability)

- Pure Project
  - Unique endeavor with little direct historical precedent to provide guidance

- Pharmaceutical production with a multitude of products and/or packages of products produced with same equipment and/or people, much like a *multi-project* environment.
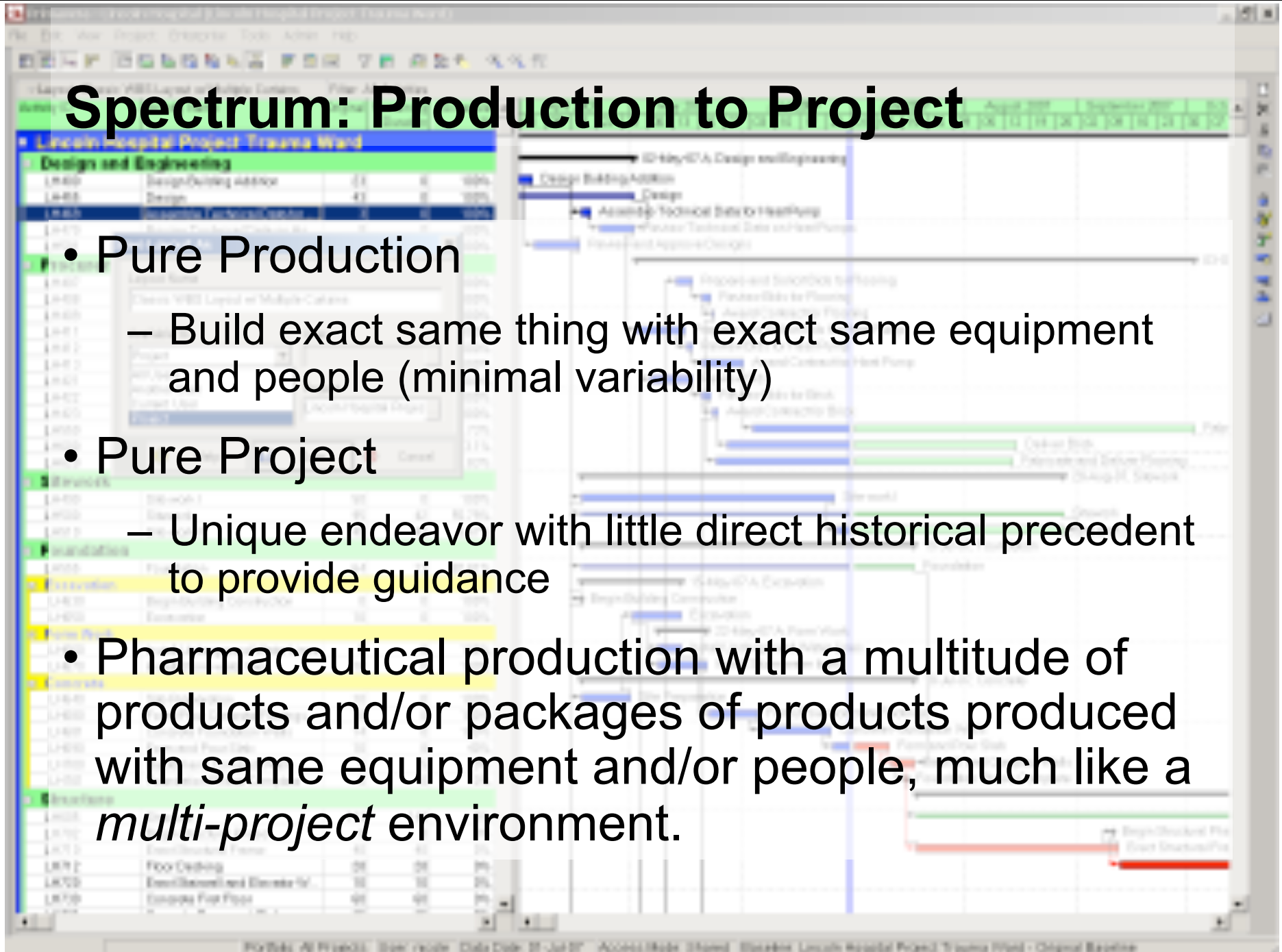
Remember Occam's Razor & Einstein

- *Numquam ponenda est pluralitas sine necessitate*

  – *Plurality must never be posited without necessity*

  – *Keep things simple*

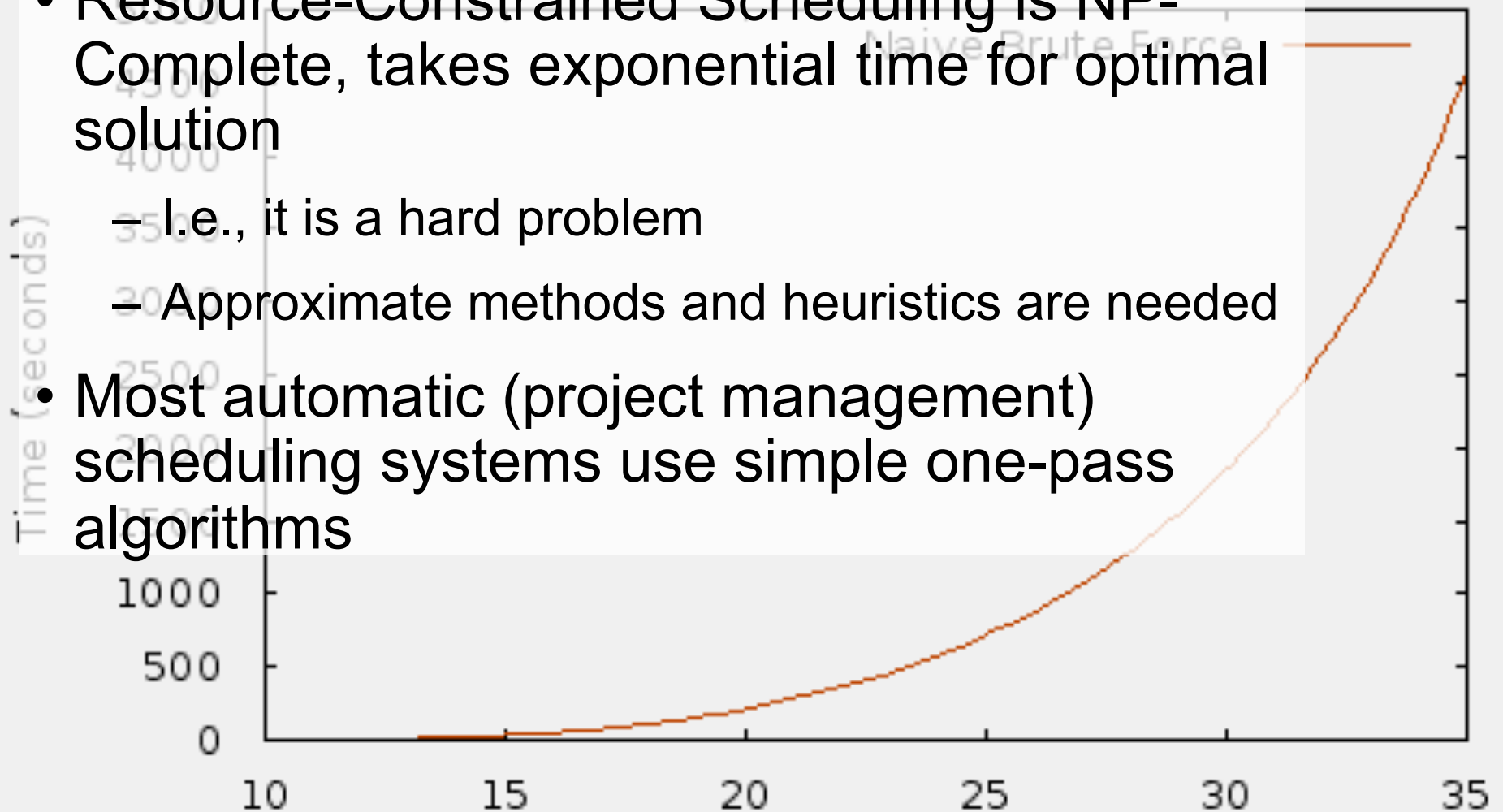- "Make everything as simple as possible, but not simpler"

  Albert Einstein
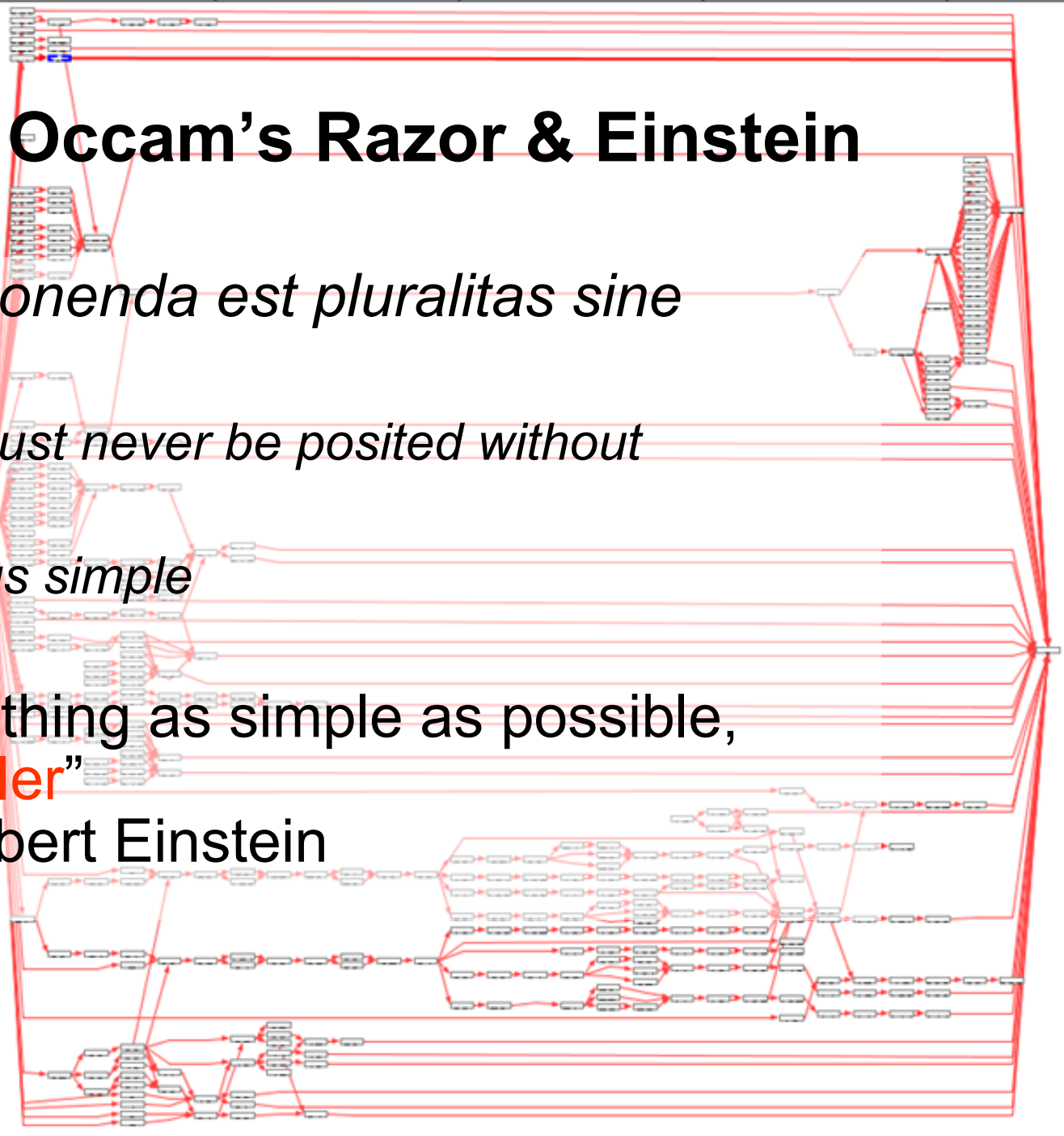
Scheduling is Difficult

- Resource-Constrained Scheduling is NP-Complete, takes exponential 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
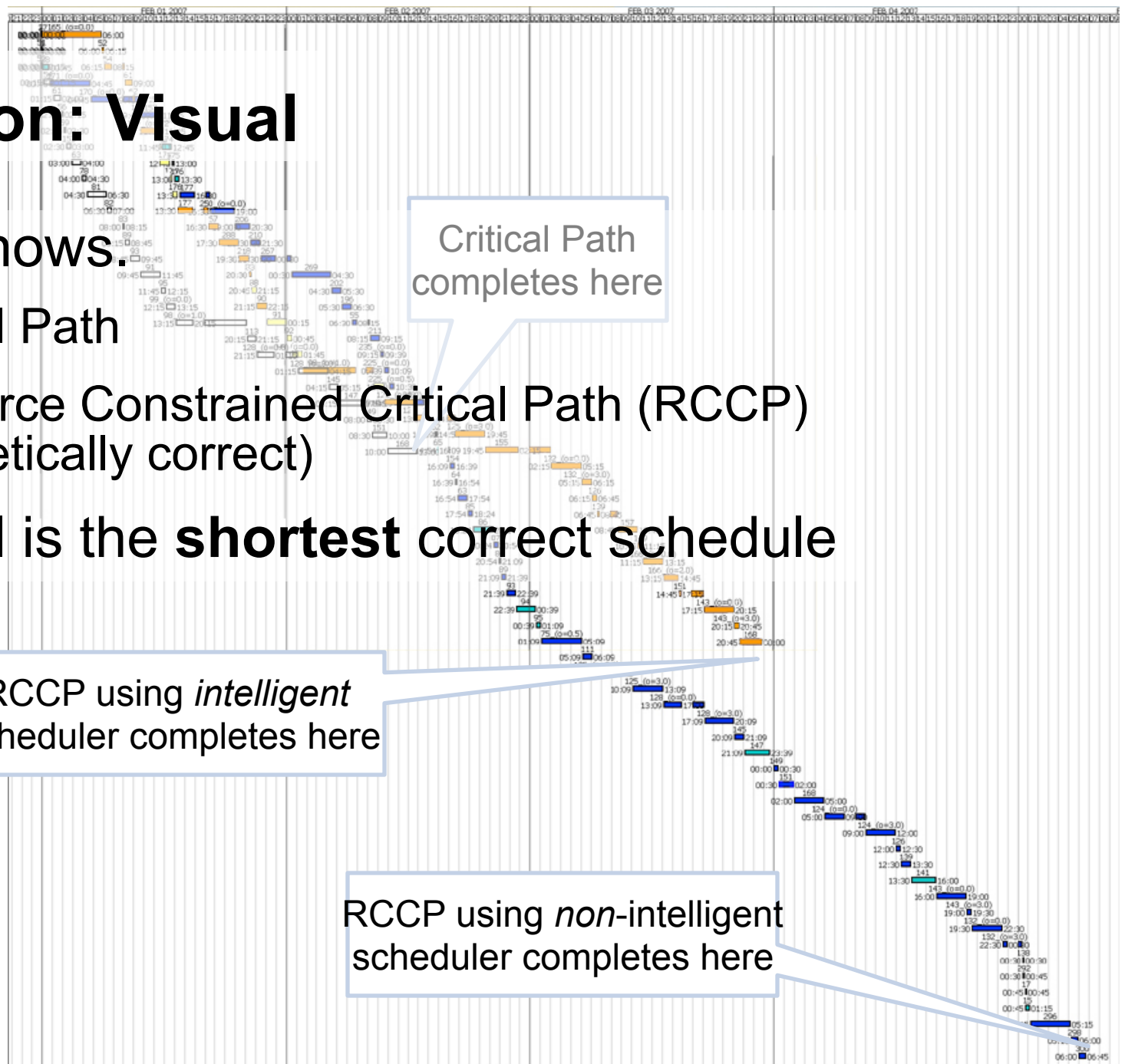
Motivation: Visual

- Figure shows.
    - Critical Path
    - Resource Constrained Critical Path (RCCP) (theoretically correct)

- The **goal** is the **shortest** correct schedule

Critical Path completes here

RCCP using *intelligent* scheduler completes here

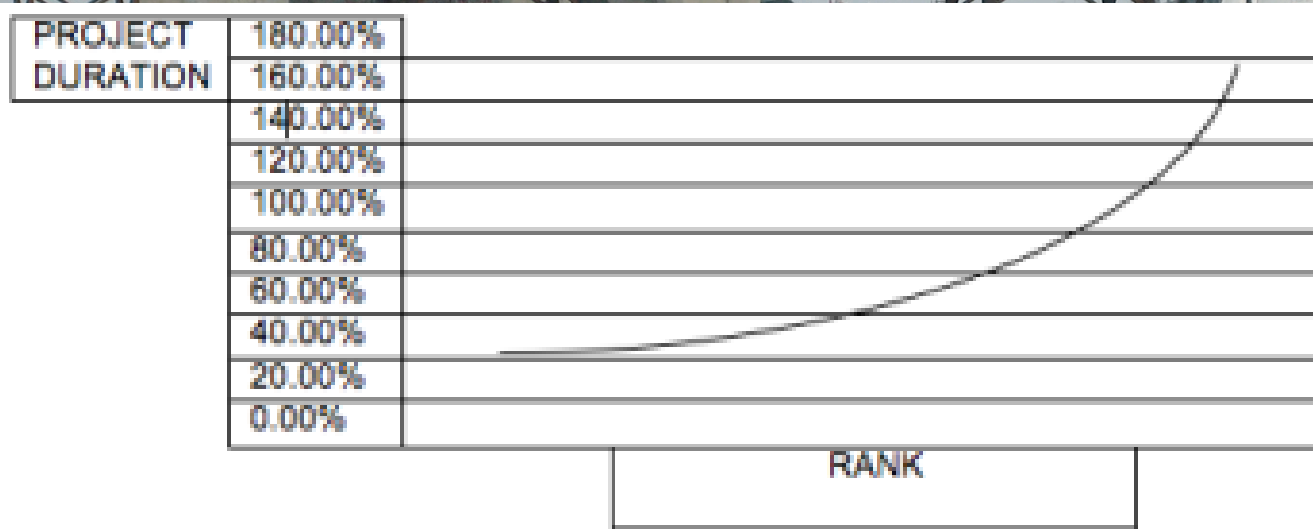RCCP using *non*-intelligent scheduler completes here

Construction Examples

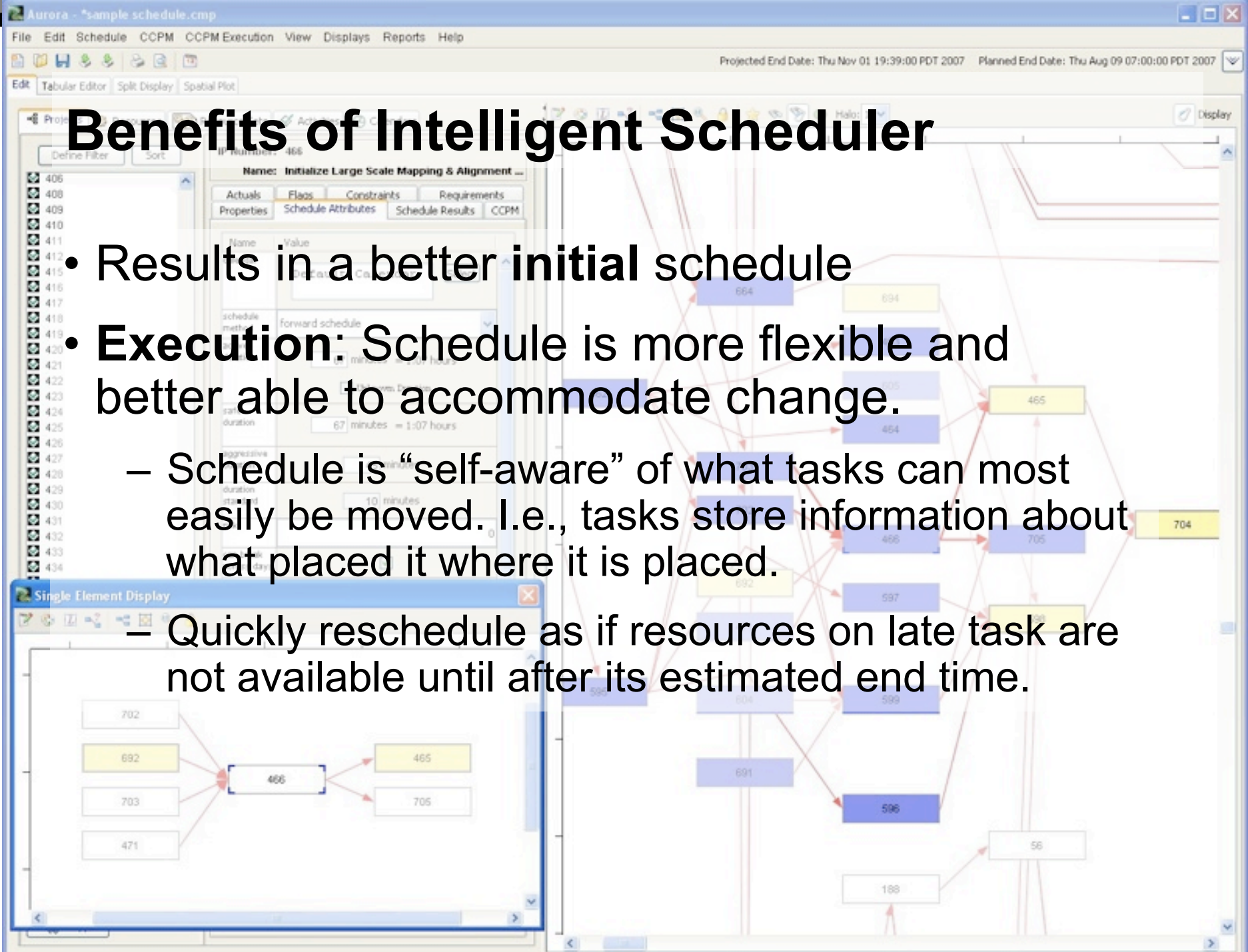## (Kastor & Sirakoulis, 2009)

Product	1st Example		2nd Example	
	Duration	Deviation from CPM (%)	Duration	Deviation from CPM (%)
Primavera P6	709	52.8	308	29.41
MS Project	744	60.34	314	31.93
Open Workbench	863	85.99	832	249.58

| PROJECT DURATION	
180.00%	
160.00%	
140.00%	
120.00%	
100.00%	
80.00%	
60.00%	
40.00%	
20.00%	
0.00%	

RANK

Benefits of Intelligent Scheduler

- Results in a better **initial** schedule

- **Execution**: Schedule is more flexible and better able to accommodate change.

  - Schedule is "self-aware" of what tasks can most easily be moved. I.e., tasks store information about what placed it where it is placed.

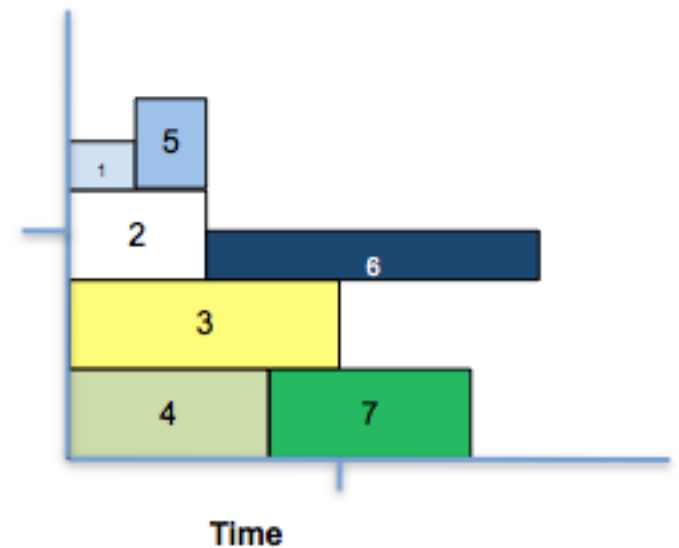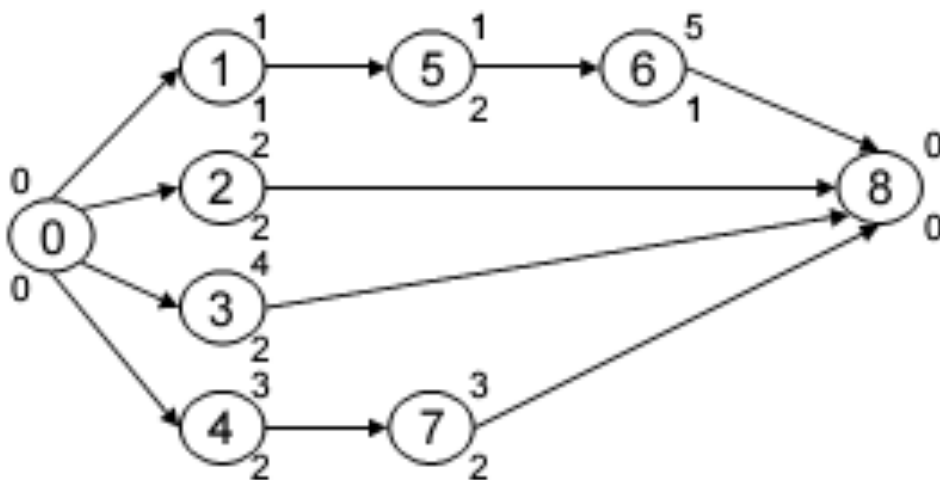 - Quickly reschedule as if resources on late task are not available until after its estimated end time.

Maybe Only for 'Big' Problems?

- Let's look at a toy problem …
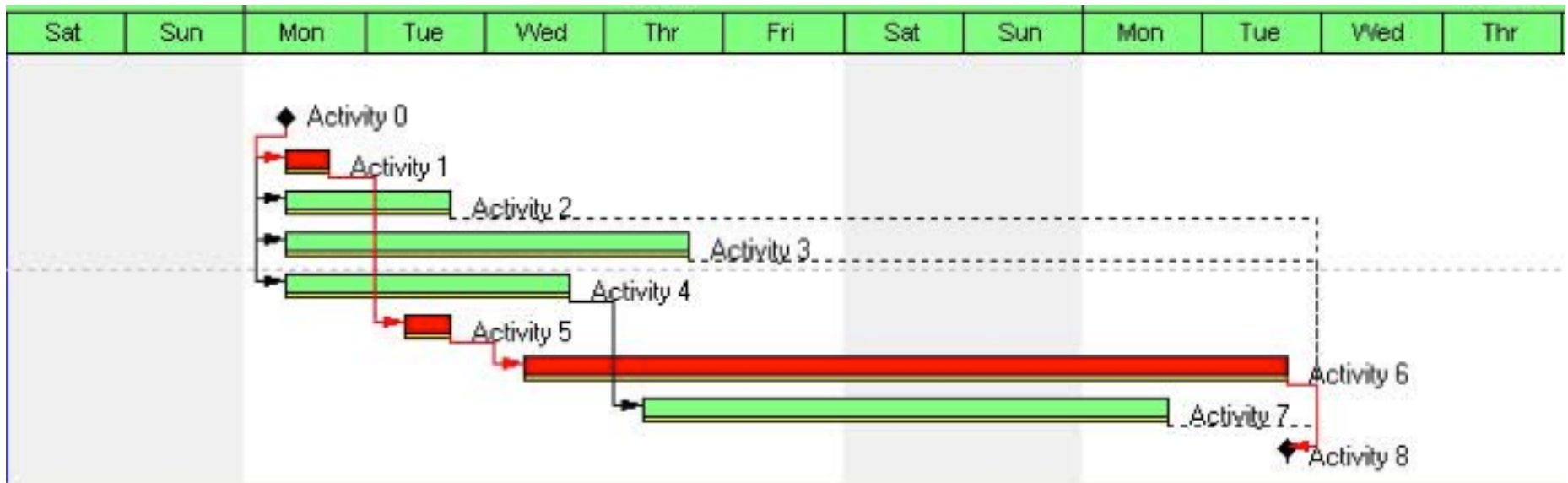- 'Simple' problem with only 7 real tasks and 2 milestones.
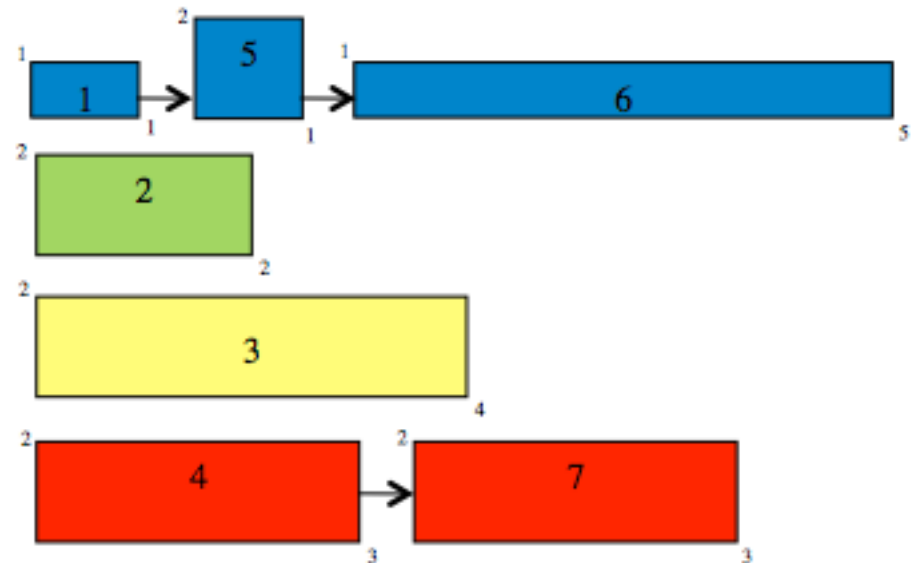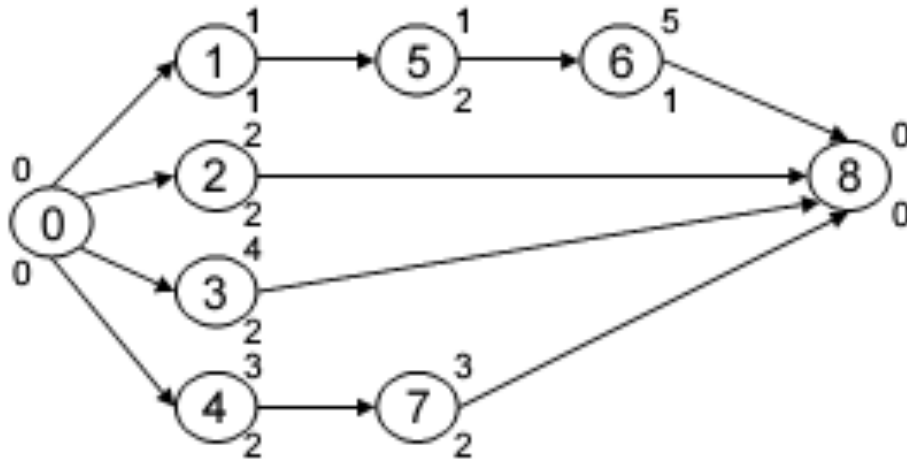
Critical Path of Network

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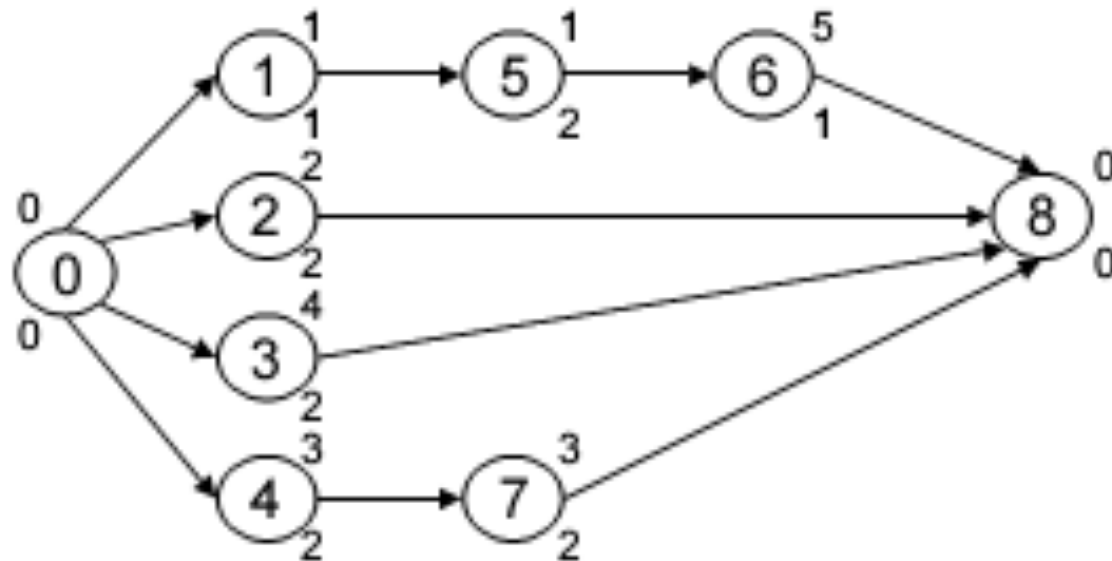   – Find longest path = 1 + 1 + 5 = 7
- So Critical Path is 7 days

Gantt Chart of Critical Path

- Note: Sat/Sun are not workdays

Set Resource Pool to 5

- Only one type of resource to keep 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

	❶	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	
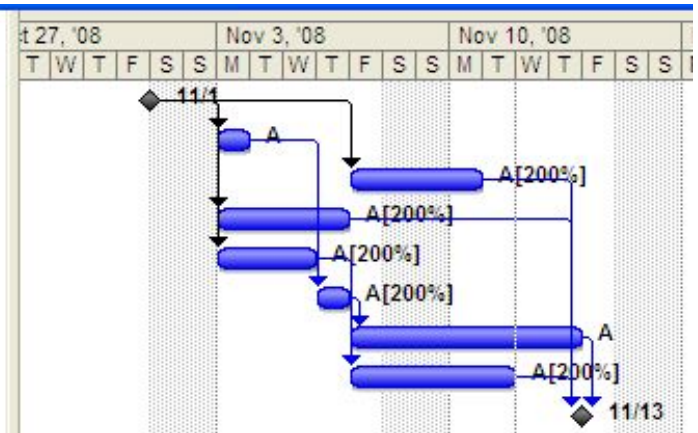
Resource Units
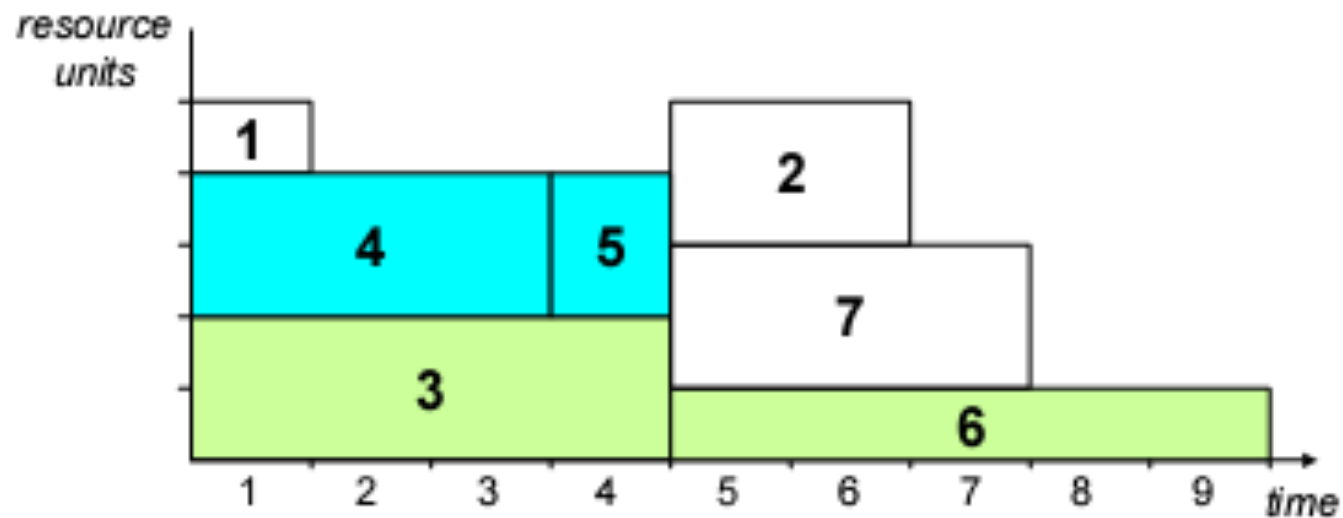
Resource Units

5

1

2

6

3

4

7

Time

Time
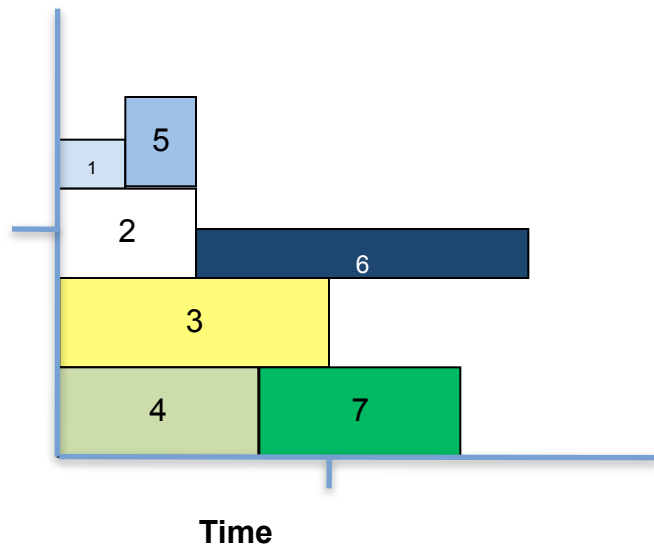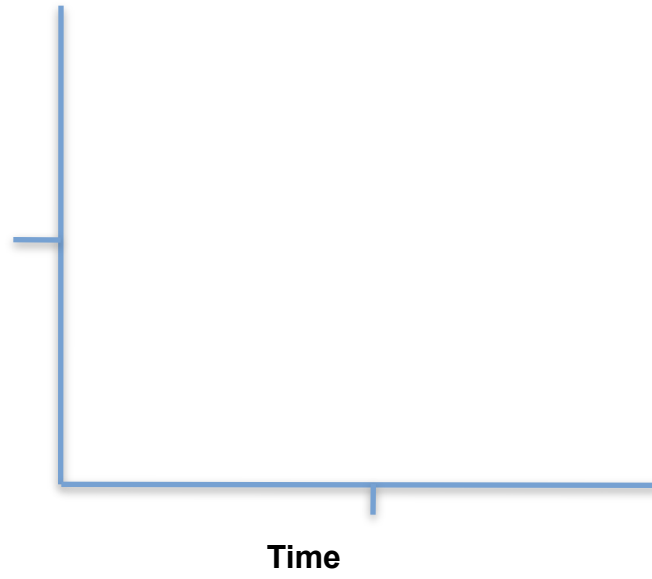
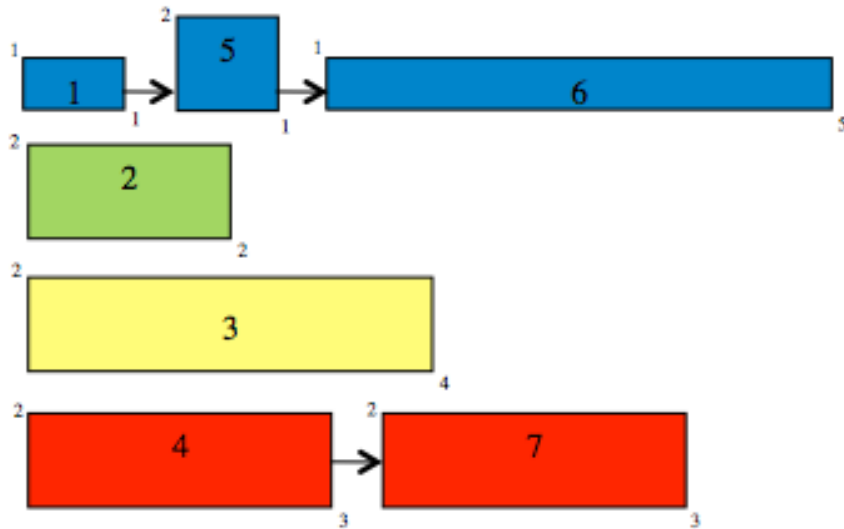# Simple Enough, Right?

- Another view of the solution
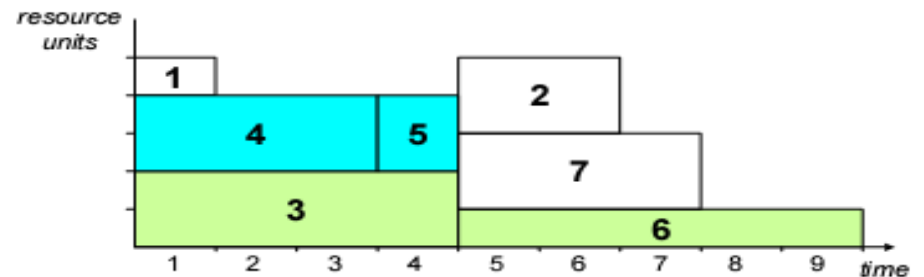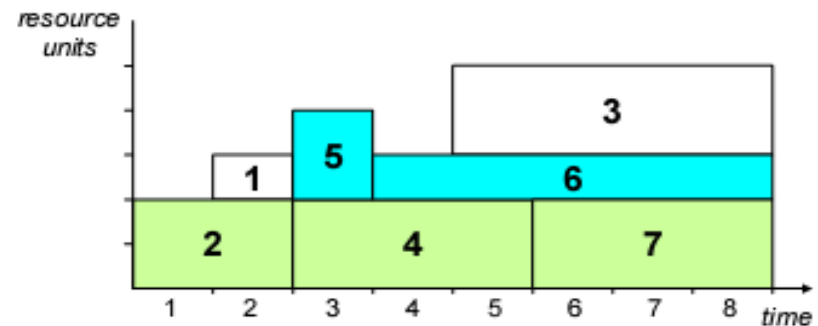
But there is a better solution …
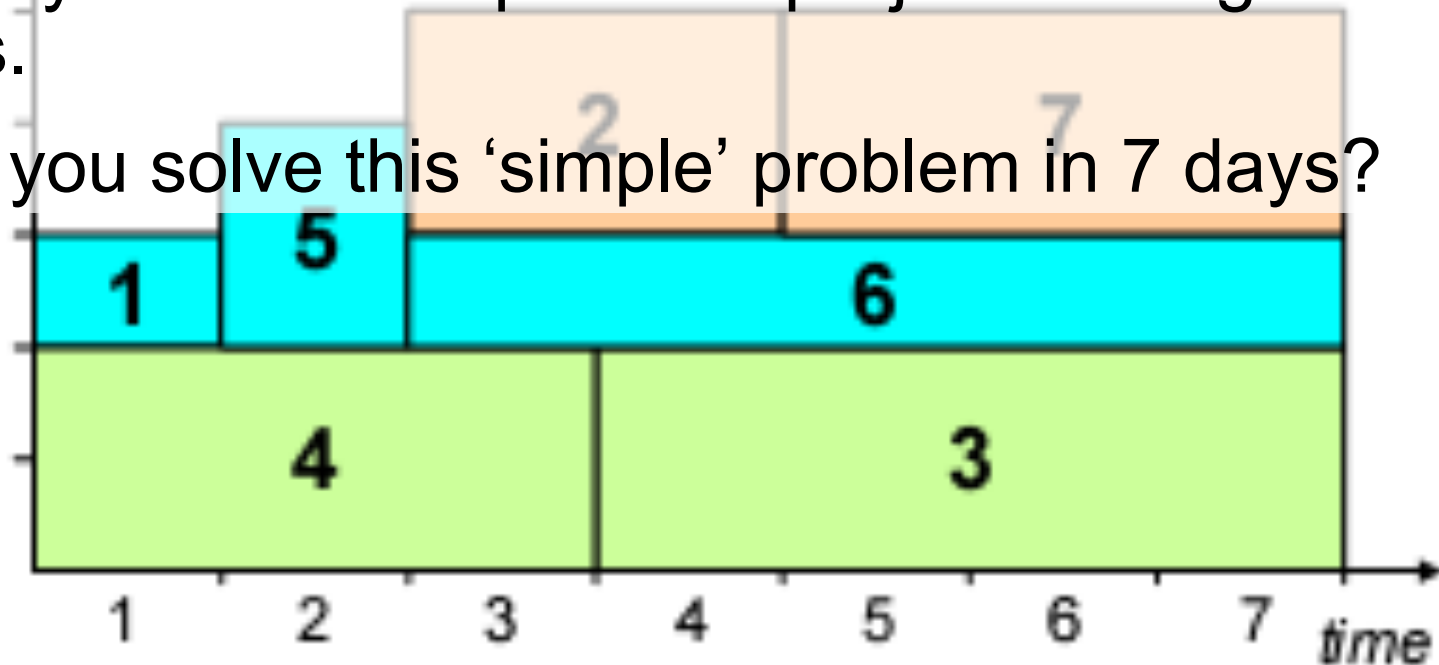# Primavera: Resource Leveled = 8 days

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.
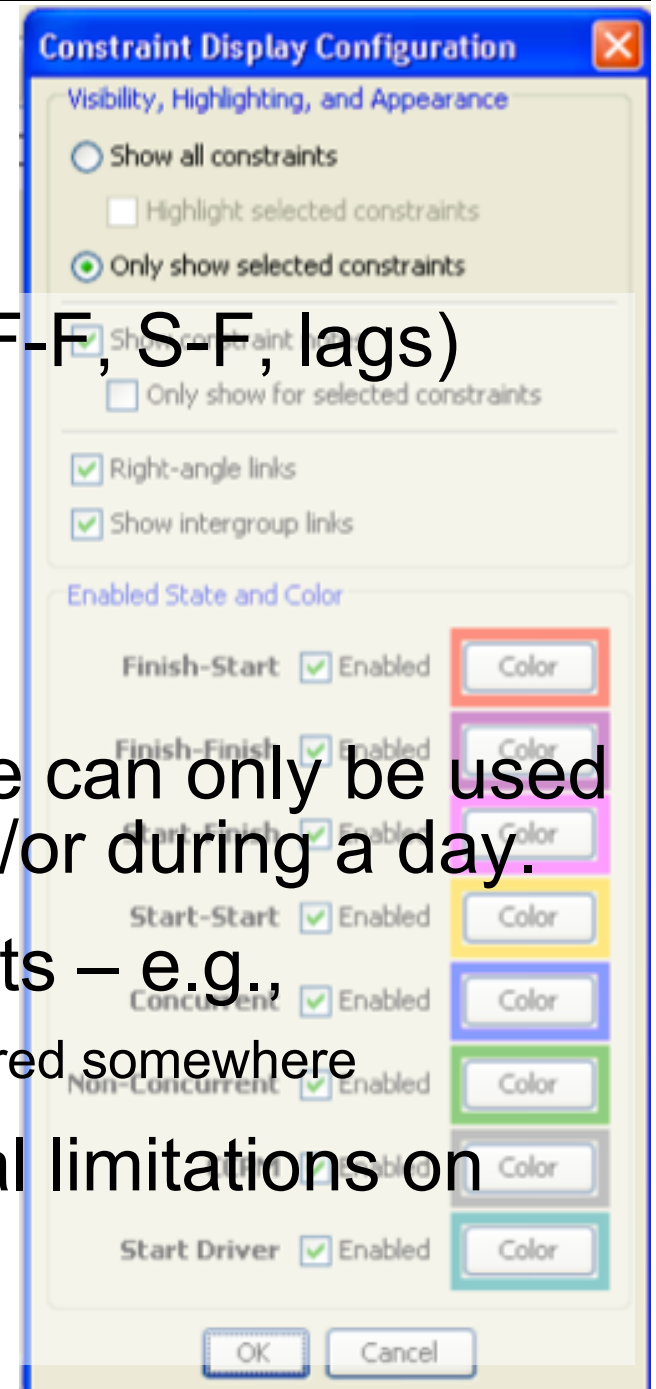
- Can you solve this 'simple' problem in 7 days?

Critical Resource

- A resource is critical if the project duration would be shorter if more of that resource were available

- Both MS Project & Primavera – **incorrectly** determined the resource to be a *critical resource*
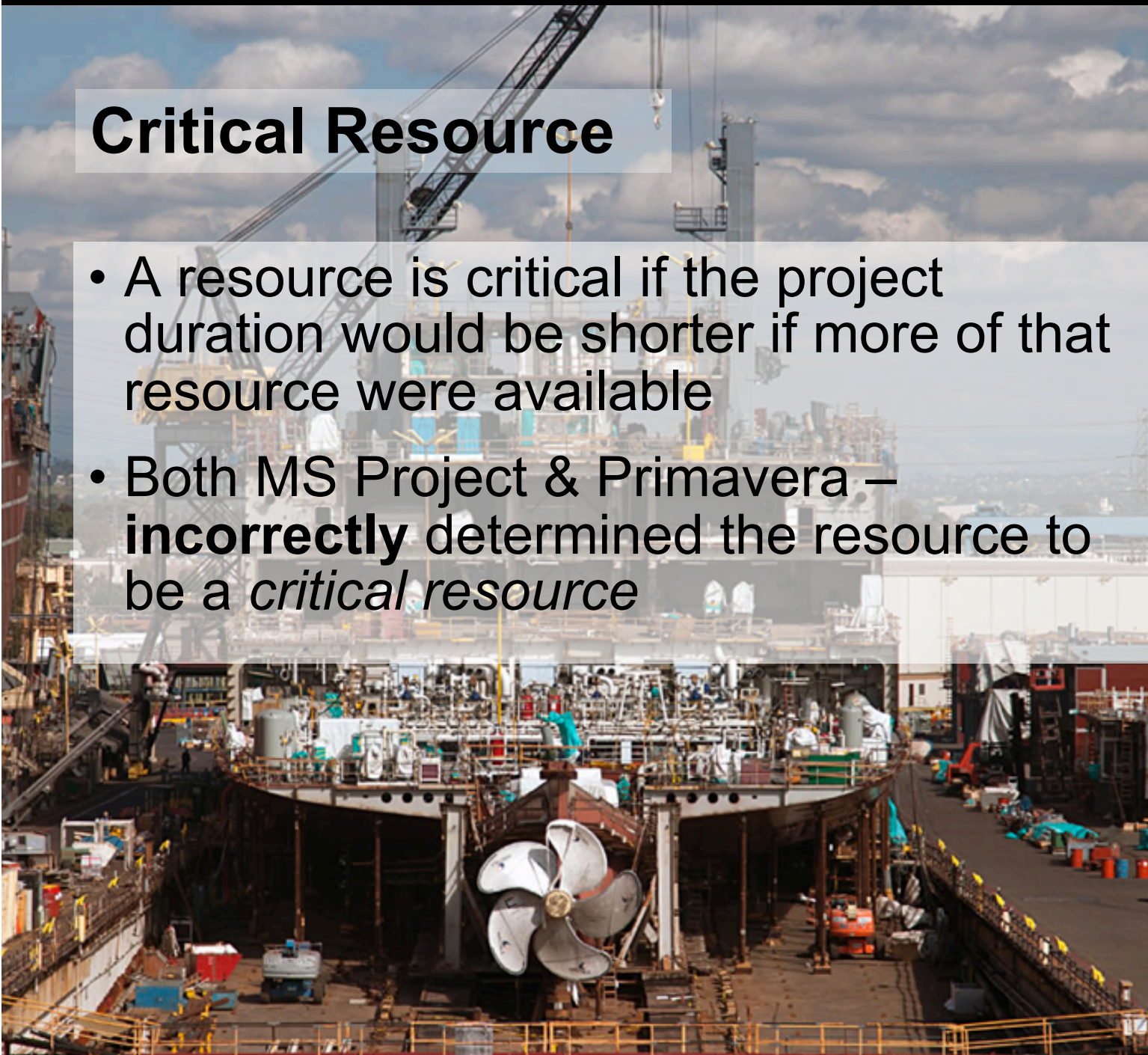
Constraints Add Complexity

- Technical constraints (E.g., F-S, F-F, S-F, lags)

- Resource constraints

  - Labor constraints

  - Equipment, Tools, Machines

- Usage constraints – e.g., machine can only be used for so many hours continuously &/or during a day.

- Spatial / physical space constraints – e.g.,

  - Material used by machines need to be stored somewhere

- Ergonomic constraints – individual limitations on work conditions

Constraint Display Configuration ✕

Visibility, Highlighting, and Appearance

○ Show all constraints

☐ Highlight selected constraints

⦿ Only show selected constraints

☑ Show constraint lags

☐ Only show for selected constraints

☑ Right-angle links

☑ Show intergroup links

Enabled State and Color

Finish-Start ☑ Enabled [Color]

Finish-Finish ☑ Enabled [Color]

Start-Finish ☑ Enabled [Color]

Start-Start ☑ Enabled [Color]

Concurrent ☑ Enabled [Color]

Non-Concurrent ☑ Enabled [Color]

☑ [Color]

Start Driver ☑ Enabled [Color]

[OK] [Cancel]

Visualizing More Complex Situations

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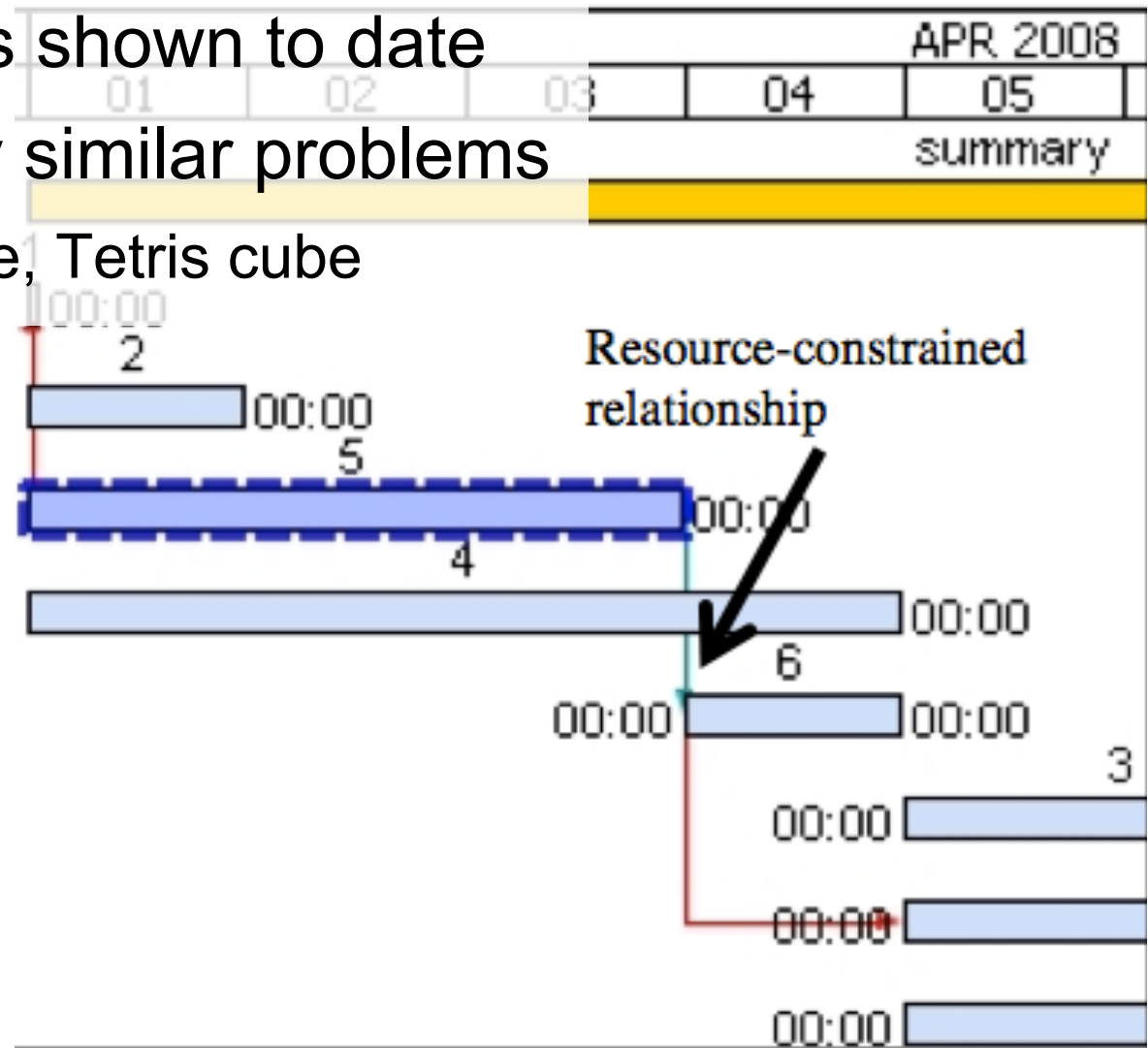
Tetris

- 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

- Video showing

- Try www.FreeTretris.org for yourself.
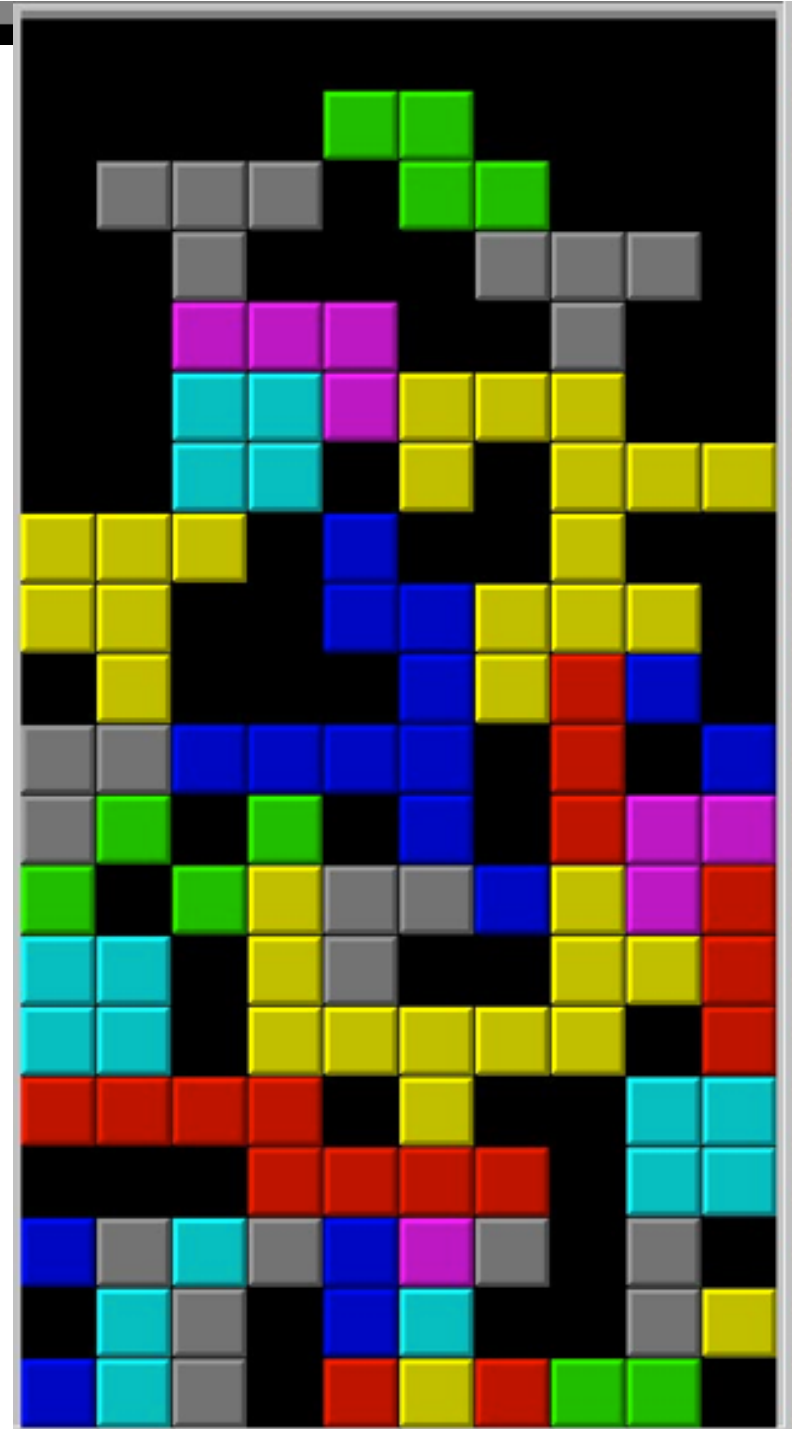
Tetris Cube

- 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
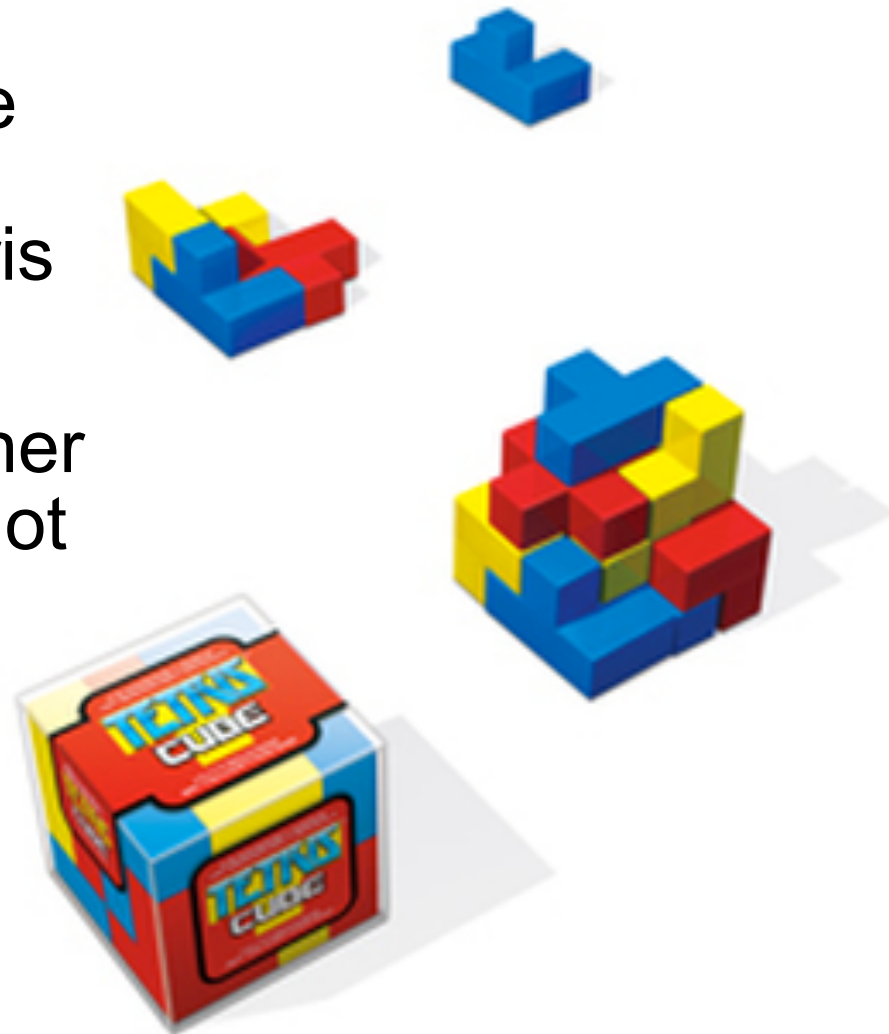
Aurora: Intelligent Scheduling

- ## Default & Customized Scheduling
  - Multiple-pass intelligent resource-constrained scheduling
    - Leverages the best of academic mathematical algorithms
    - Proprietary enhancements from our expertise / experience
  - Scheduler will investigate different resource allocations before it begins scheduling.

- ## Scheduling Heuristics
  - To find a high-quality schedule in a reasonable amount of run time, necessary to use a battery of heuristics.
  - Some heuristics general to all domains & some are domain specific.

Refinery Turnaround Leveraging Intelligent Scheduling Technology
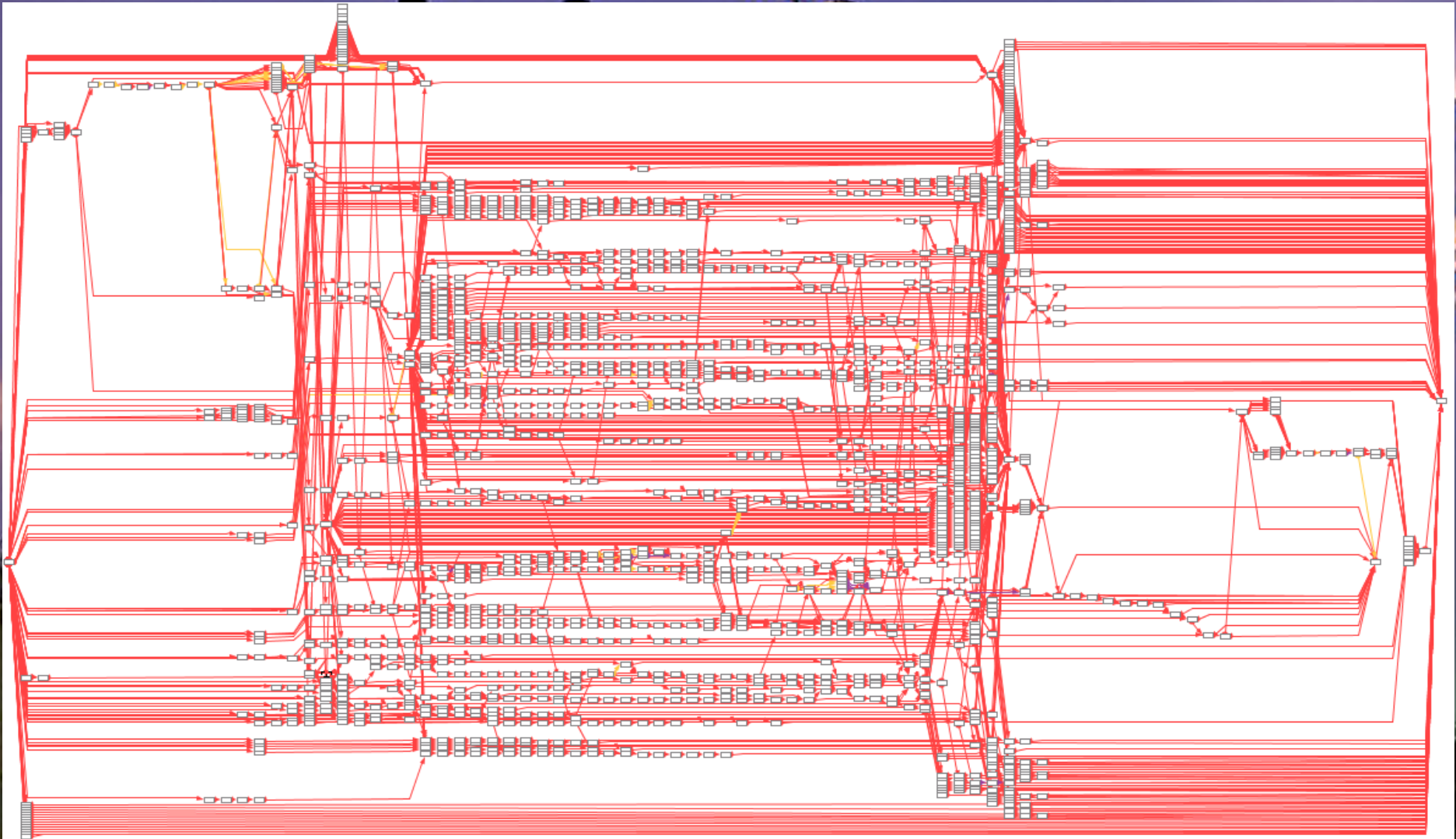
Results: 2,500+ Tasks

- Primavera P6   **67.125** days
  – Performed by 3rd party
- Aurora   **56.27** days
- Primavera P6 **19.3% longer** than Aurora
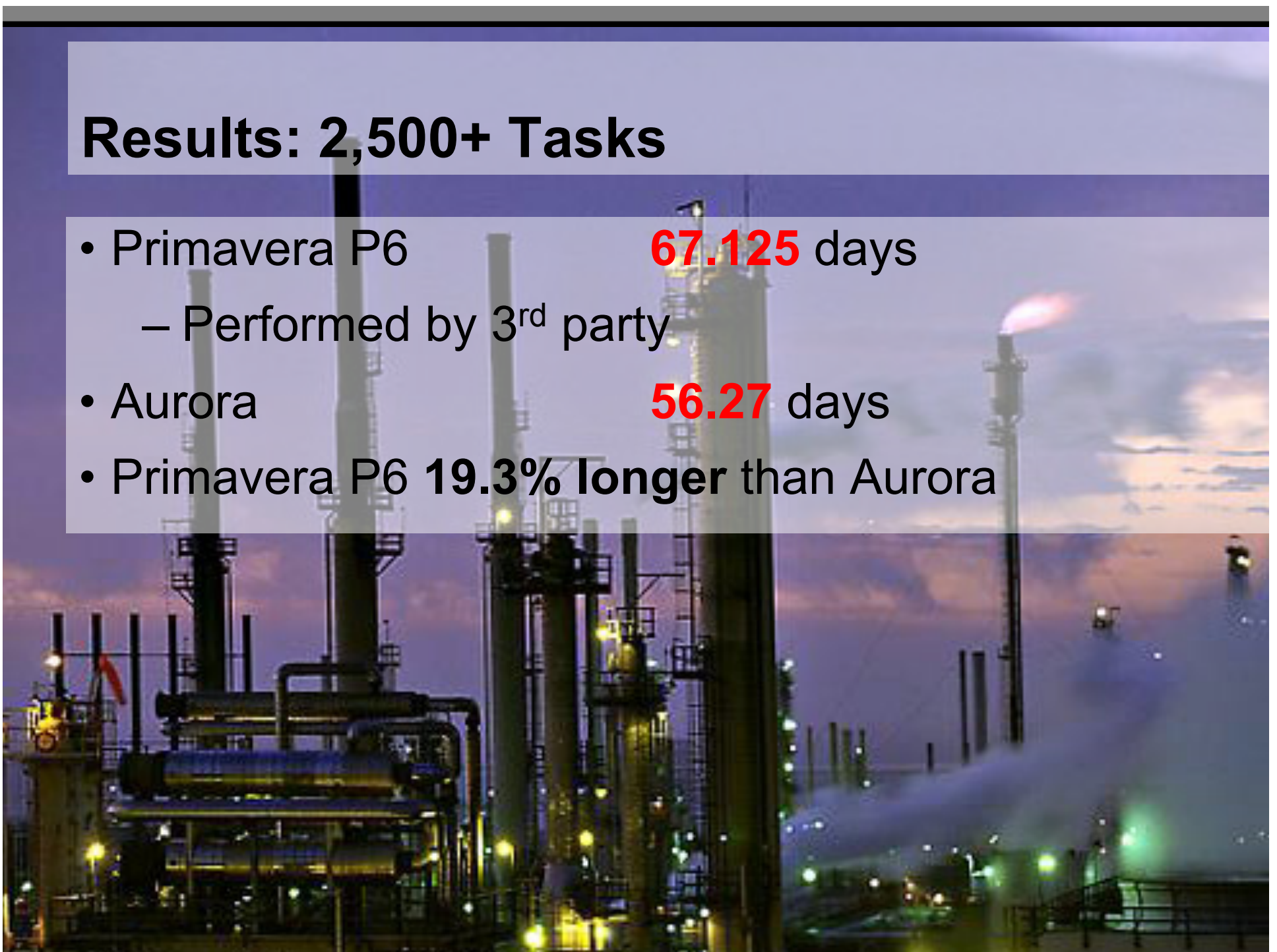
Aerospace Application: 300 Task Example

Results: 300 Task Example

- MS Project 2007   **145.6** days

- Primavera P6   **115** days
  - Performed by 3rd party

- Aurora   **102.5** days
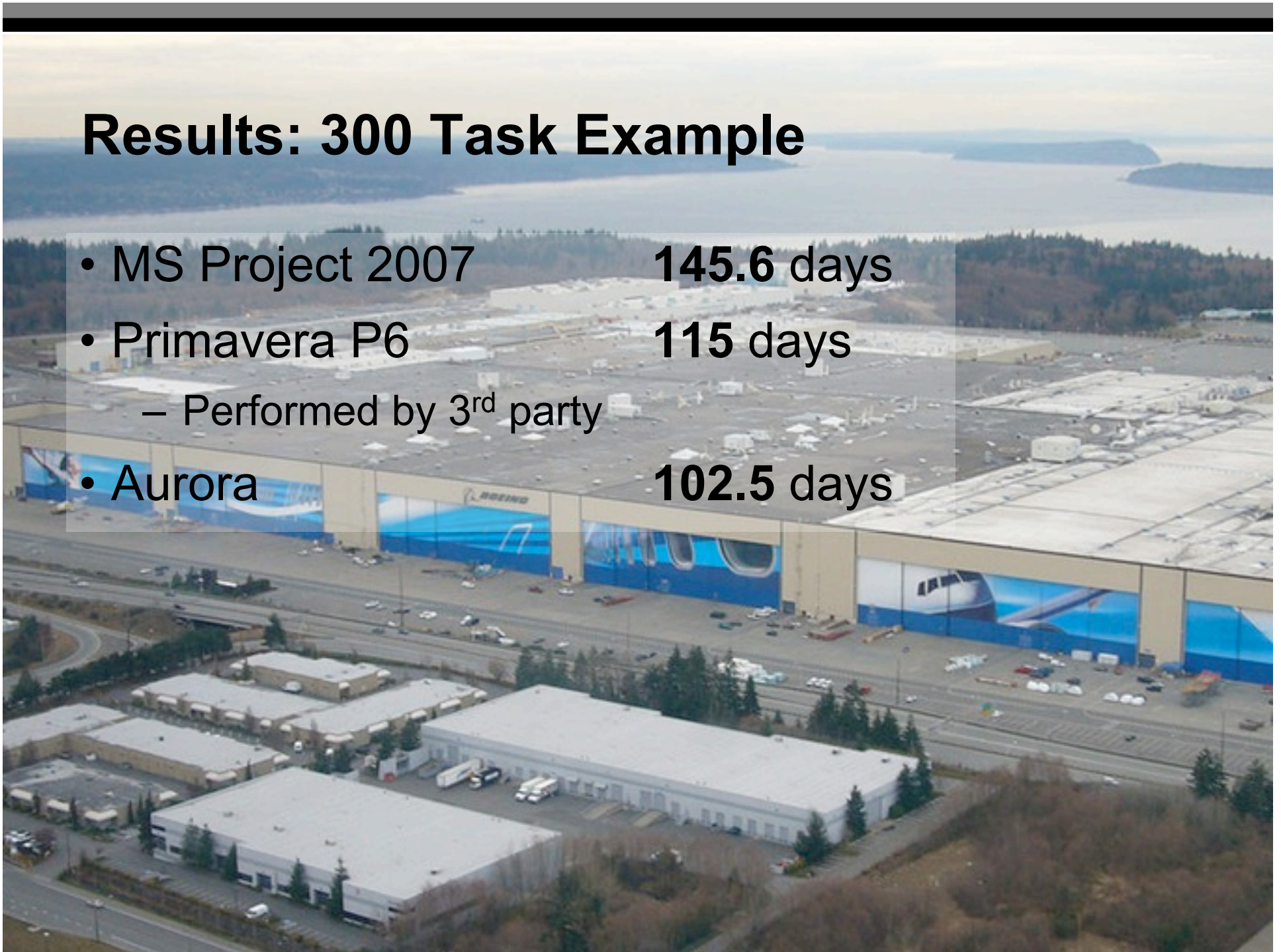
Aurora Applications: Diverse Samples

- Boeing Aircraft Assembly (replaced 20 year, in-house Timepiece product)

- Learjet Multi-Phase Assembly Scheduling

- Medical Resident Scheduling

- NASA Space Station Processing Facility (SSPF) floor space and resources

- Satellite to Ground Station Scheduling

- Submarine Maintenance

- Optimize Test Vehicle Scheduling & Determine Vehicles Required

In every domain, Aurora has surpassed all existing scheduling systems

Intelligent Scheduling Application to Pharma

- Production / Packaging Optimization

Summary

Production Data

→ Stottler Henke's Aurora

→ Production Schedule
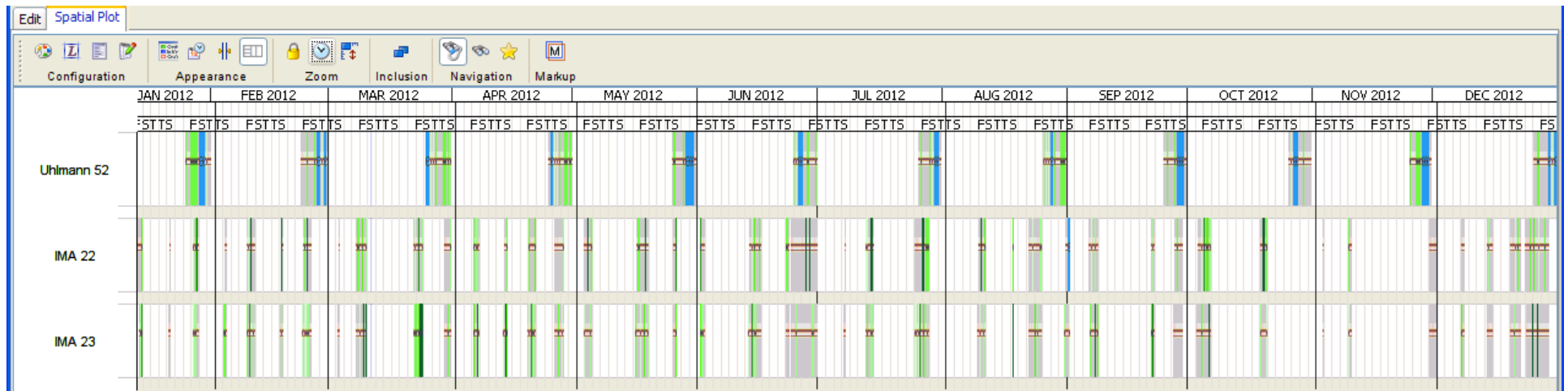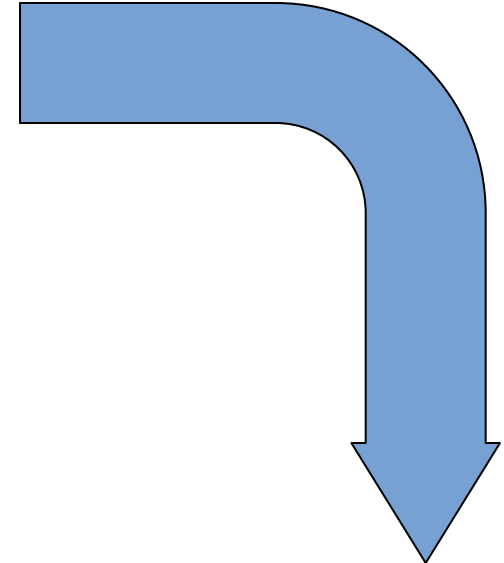
Graphical Differences: Setup vs Production
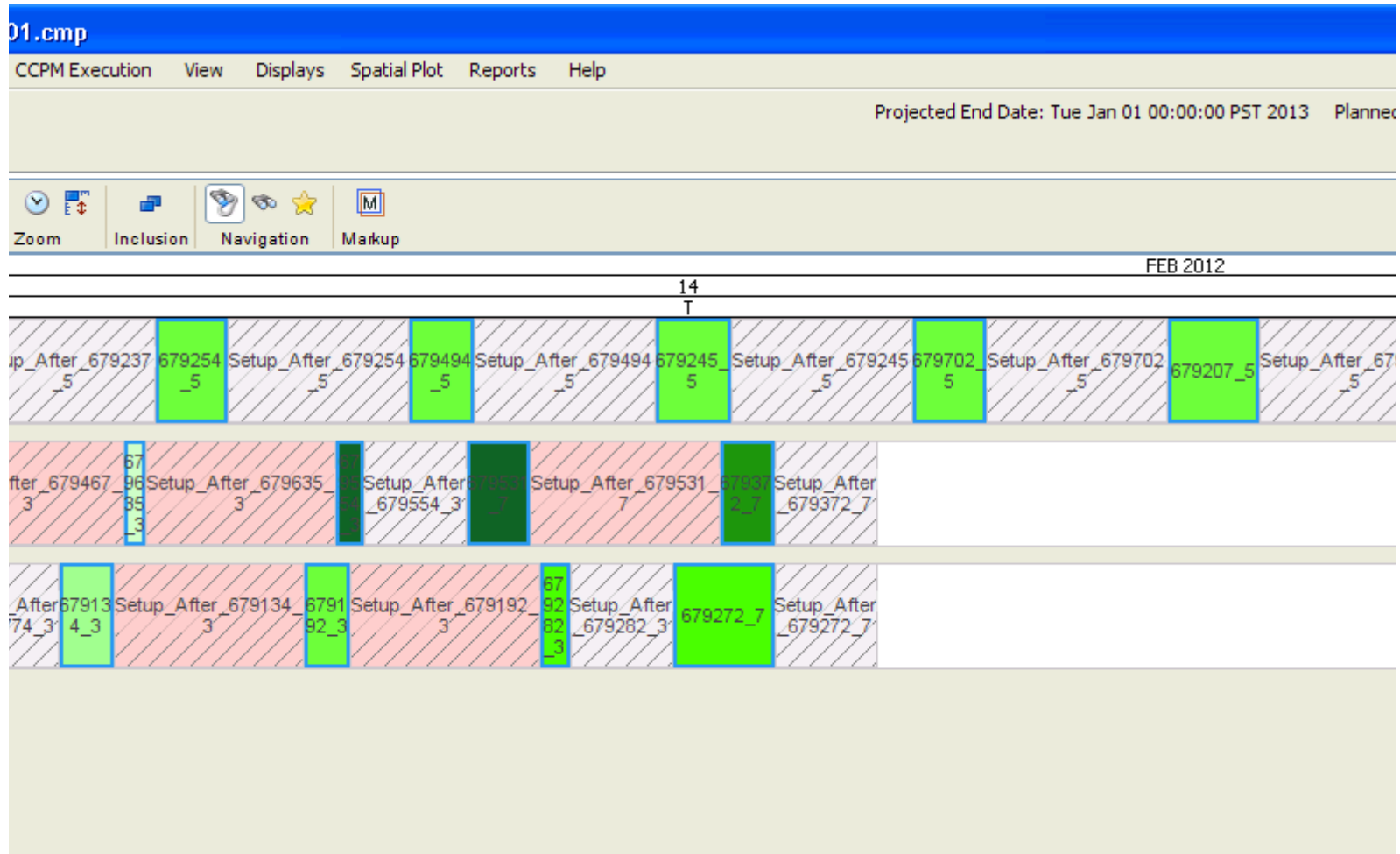
What-If Capabilities

- The user can manually add/remove machines or change calendars to see the effect on the schedule.
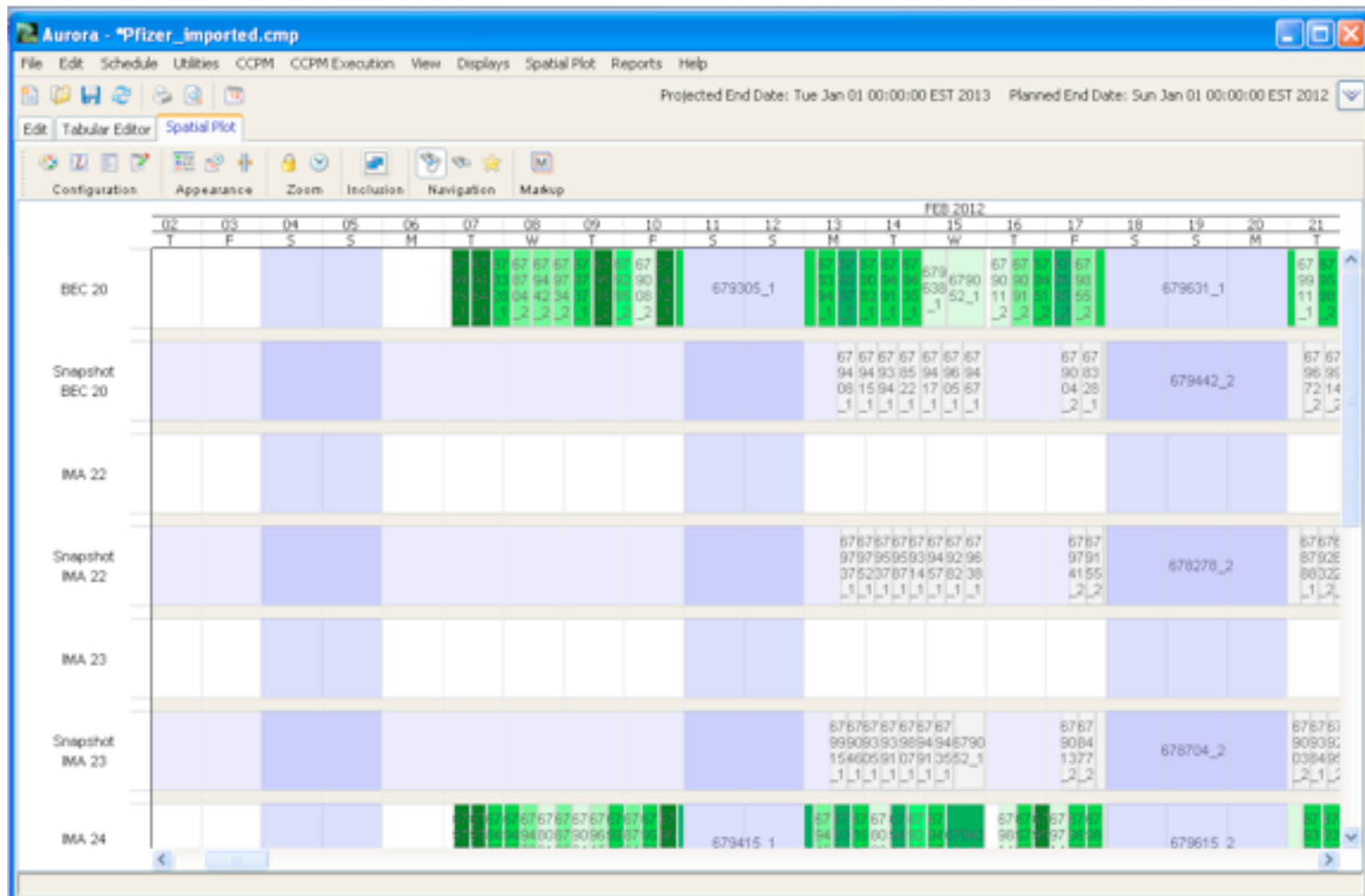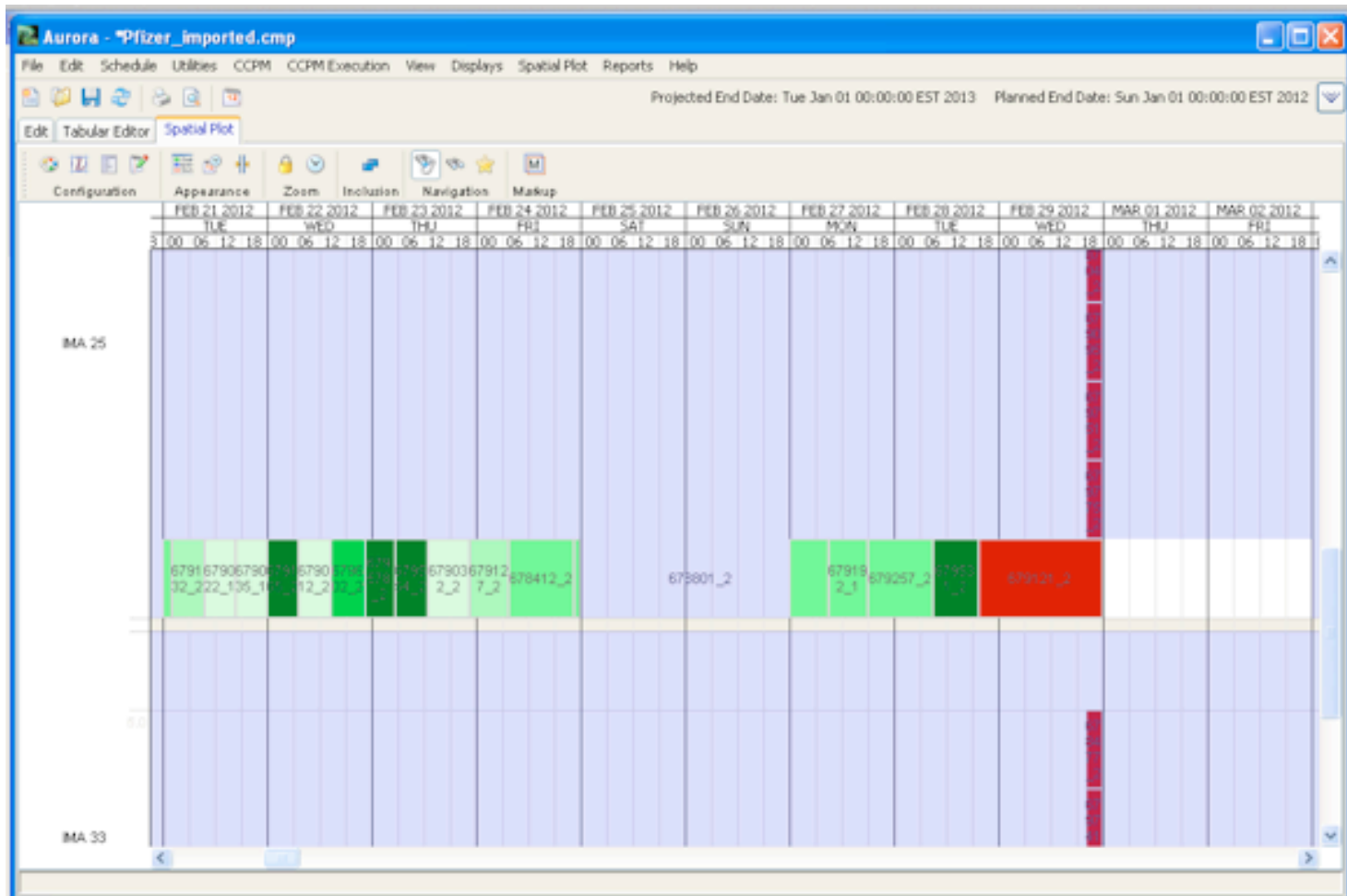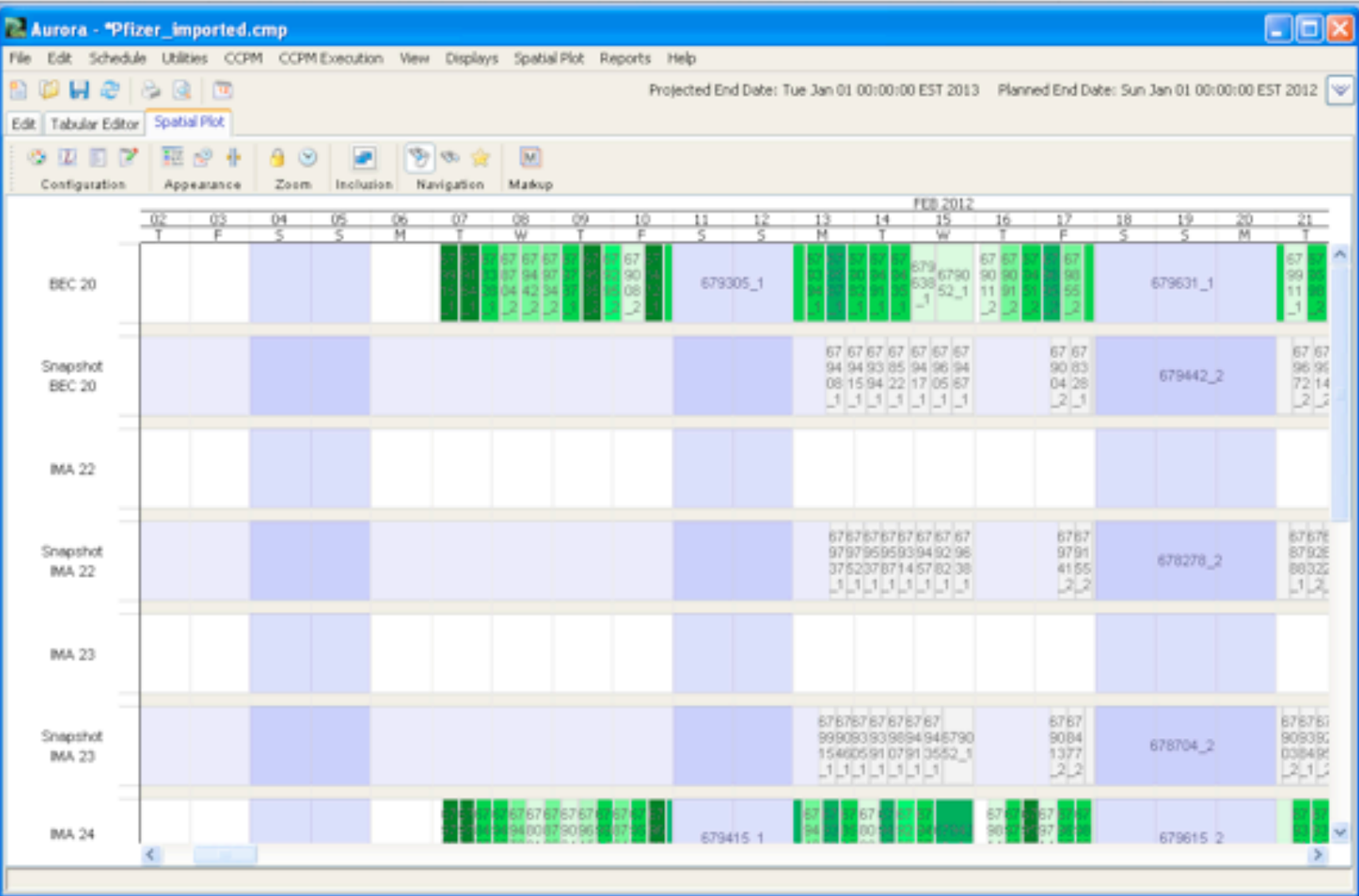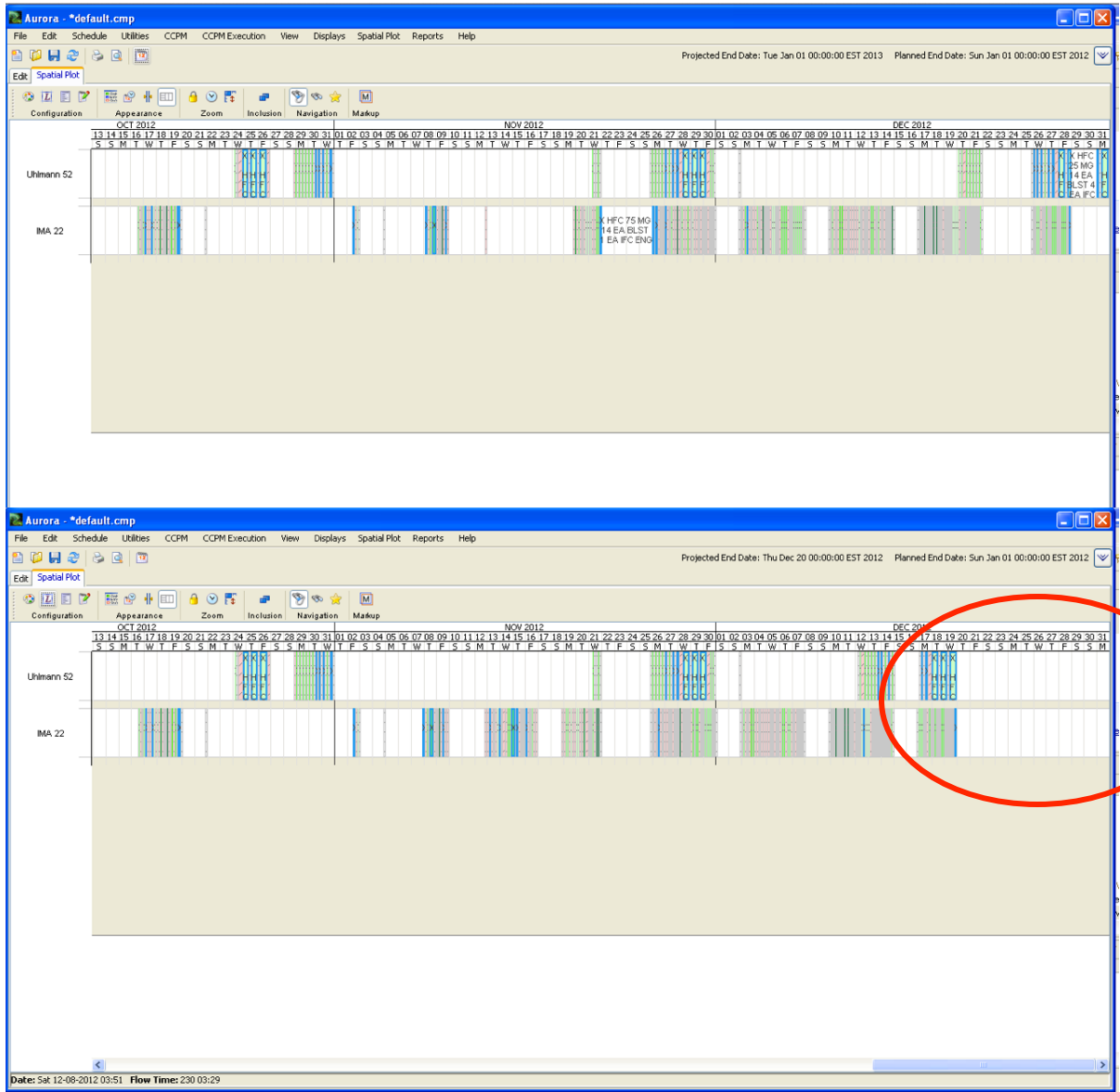
What-If: Same Demand 3 vs 2 Lines
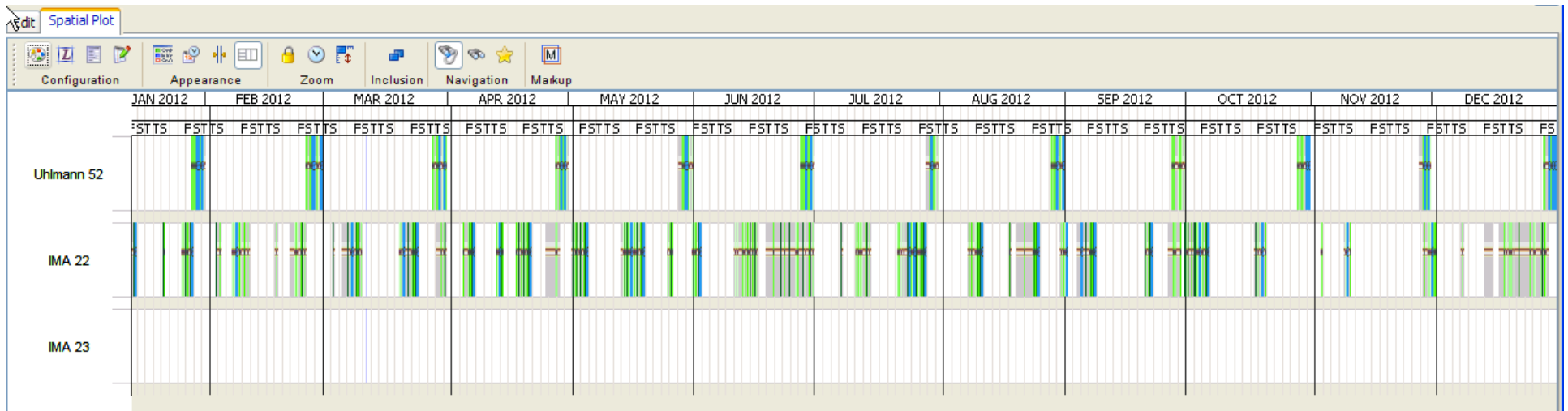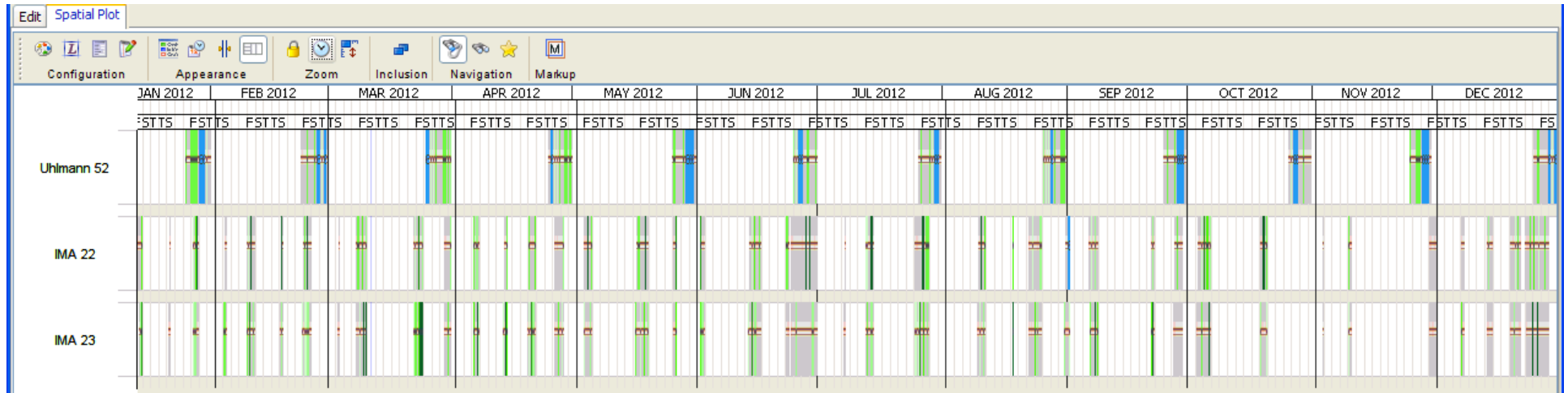
Conflicts

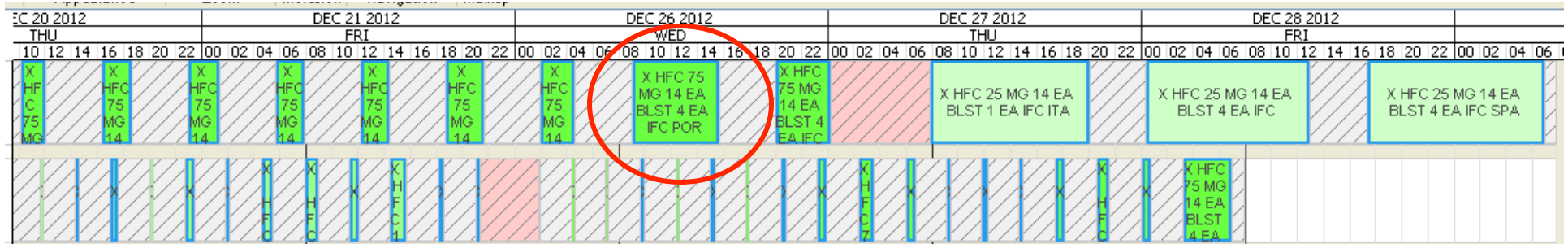- Conflicts will occur if there are not enough lines / machines
  - Conflicts shown in red

Removing Capacity Without Causing Conflicts
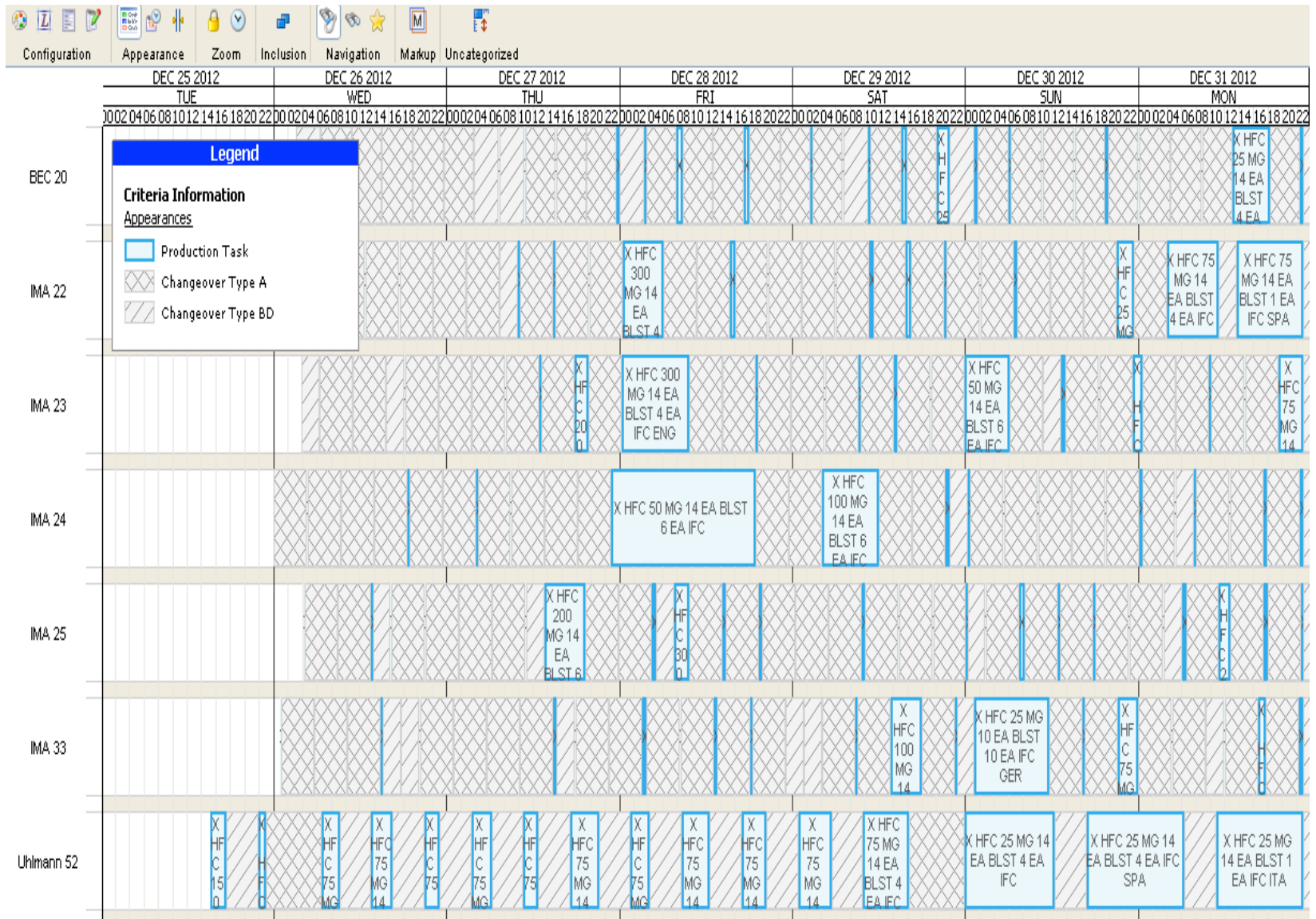
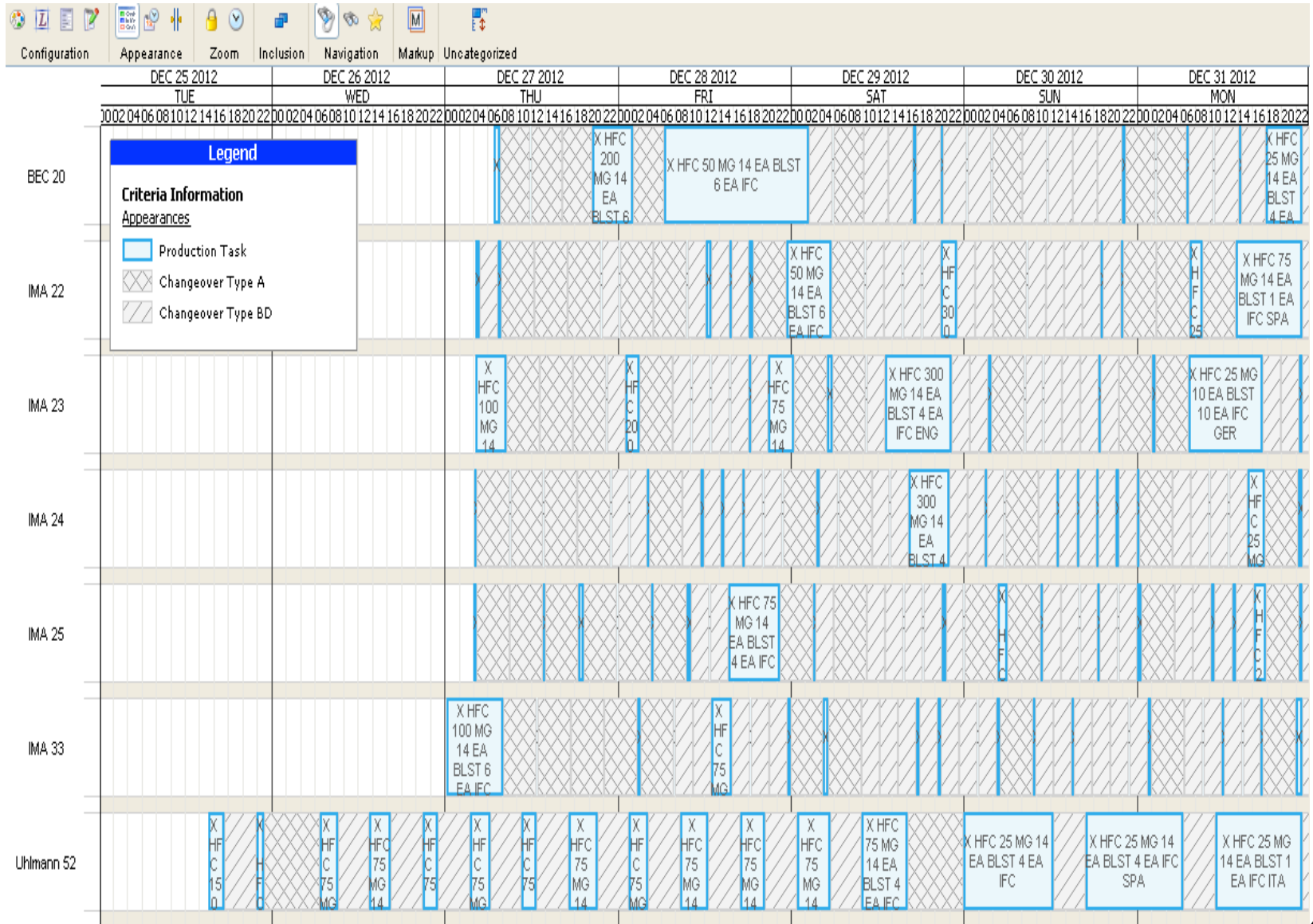# What-if: End of Year Shutdown

What-if: Demand Increase
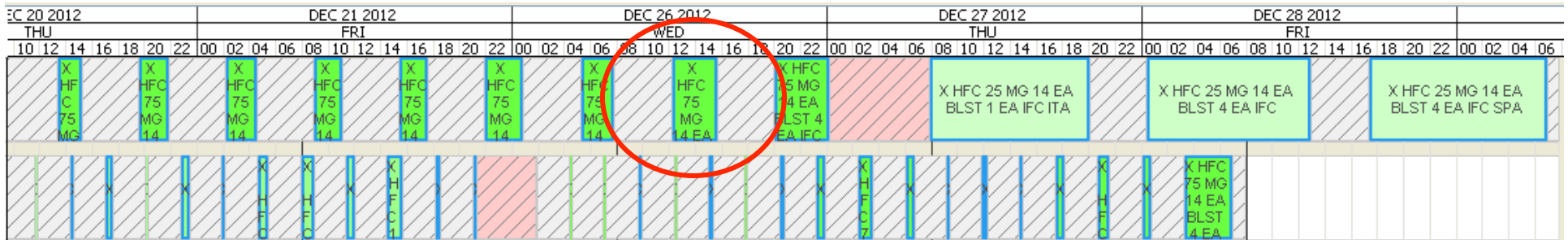
Optimizations ….

- Minimize the Changeover times,

- While ordering tasks in such a way as to minimize carrying costs, and other metrics.
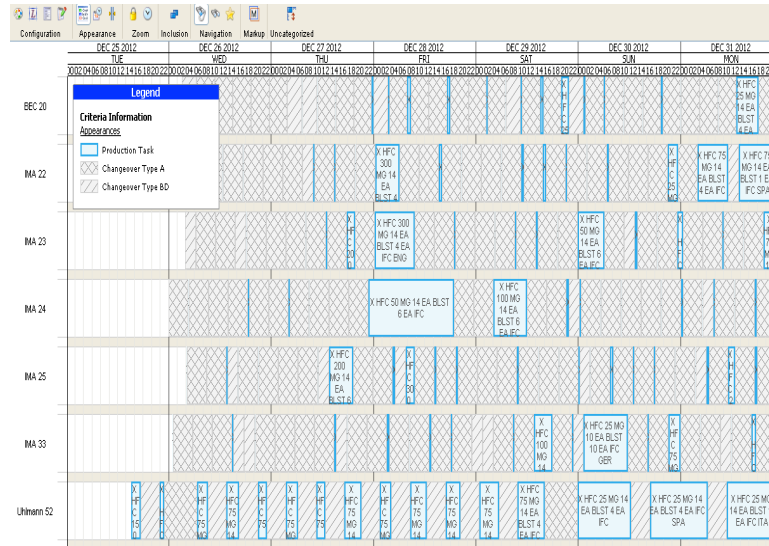
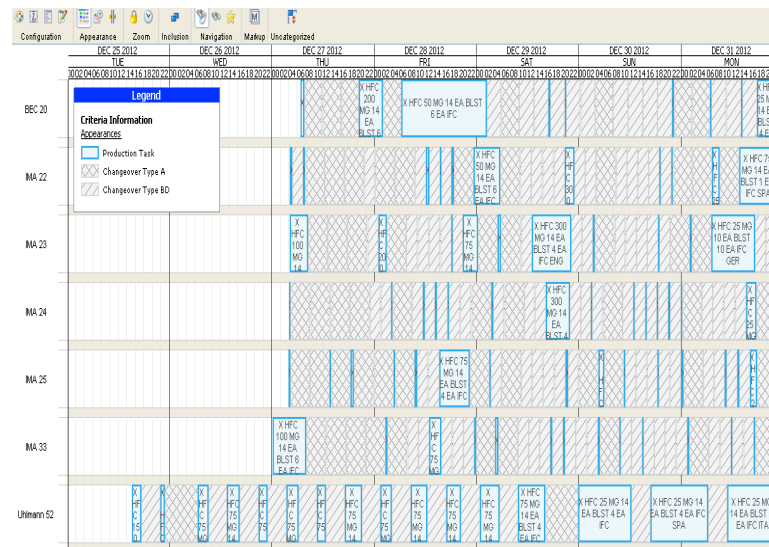# WithOUT Optimization

With Optimization

Production Optimization (changeover)

Without

optimization

With

optimization

What-Ifs: Various Can be Performed

- Change the demand for different SKUs
  - Due to inventory & expiration dates
- Change the working time of machines
- Change carrying costs
- Change changeover properties
- Make changes in external data or in Aurora
- Update production schedule after changes in a matter of minutes

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
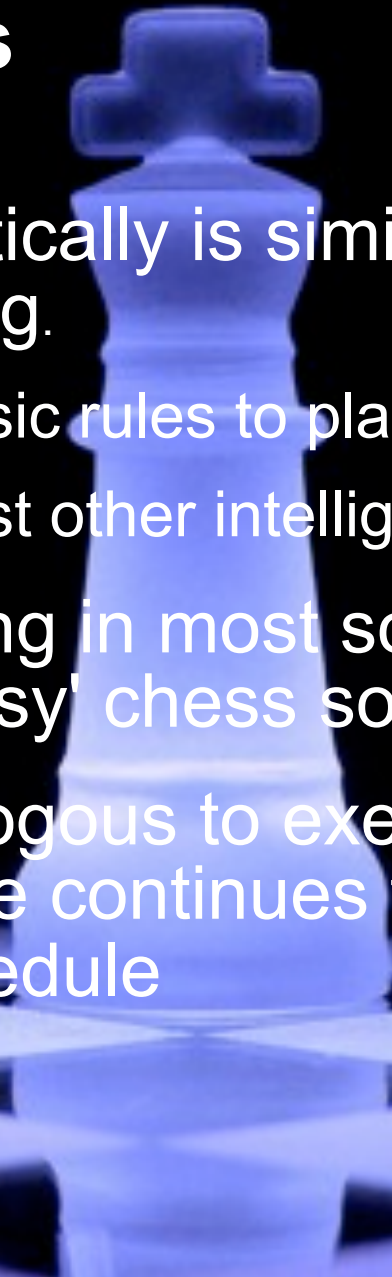
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