

IFPAC 2013

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

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The IFPAC logo consists of the letters 'IFPAC' in a bold, italicized, red sans-serif font. The letters have a slight 3D effect with a dark shadow underneath.

IFPAC® – 2013

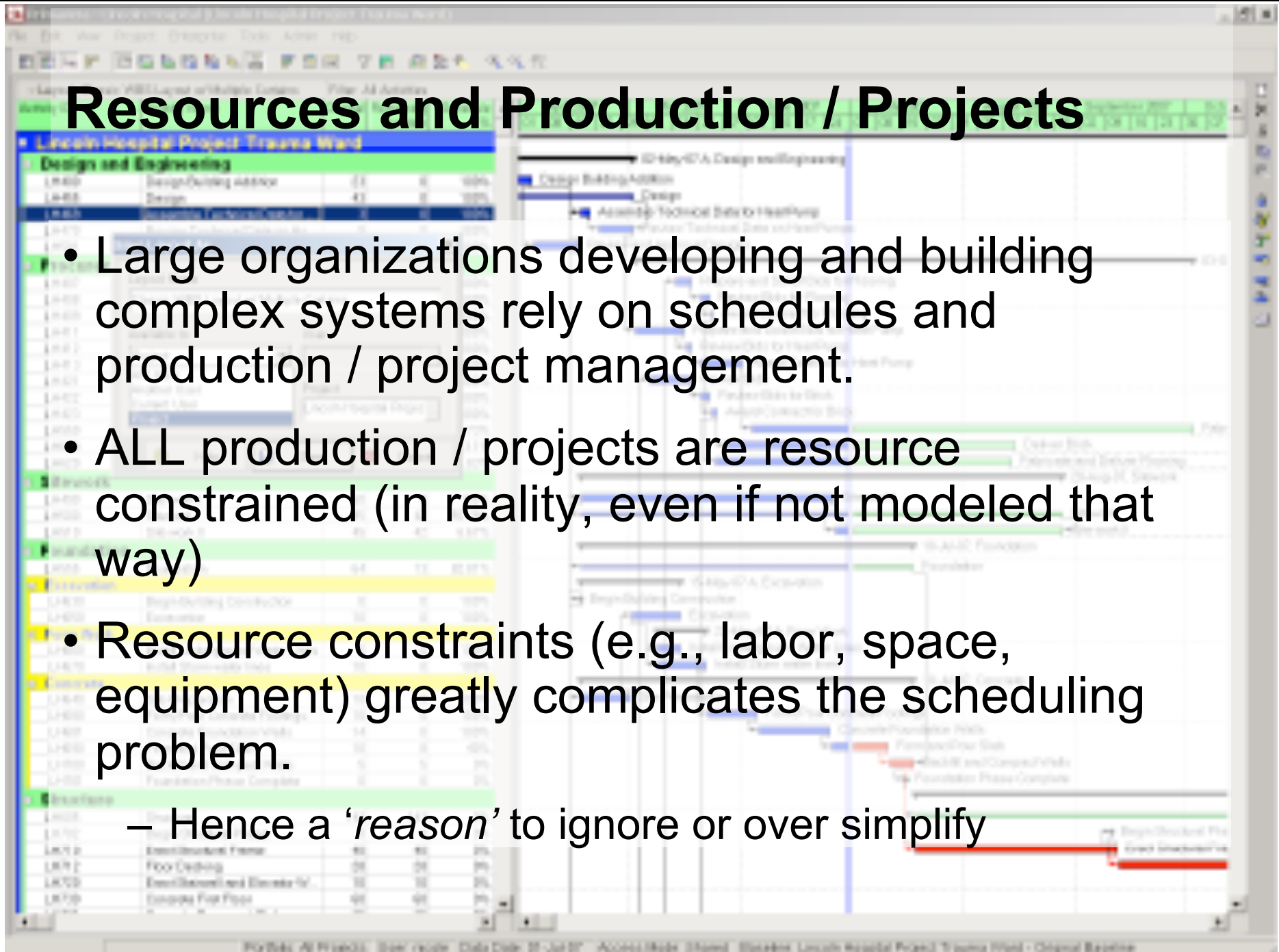
Twenty-Seventh International Forum
Process Analytical Technology

The Stottler Henke logo features the company name 'Stottler Henke' in a large, bold, blue sans-serif font. A thick blue horizontal line is positioned directly below the text.

Smarter Software Solutions

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

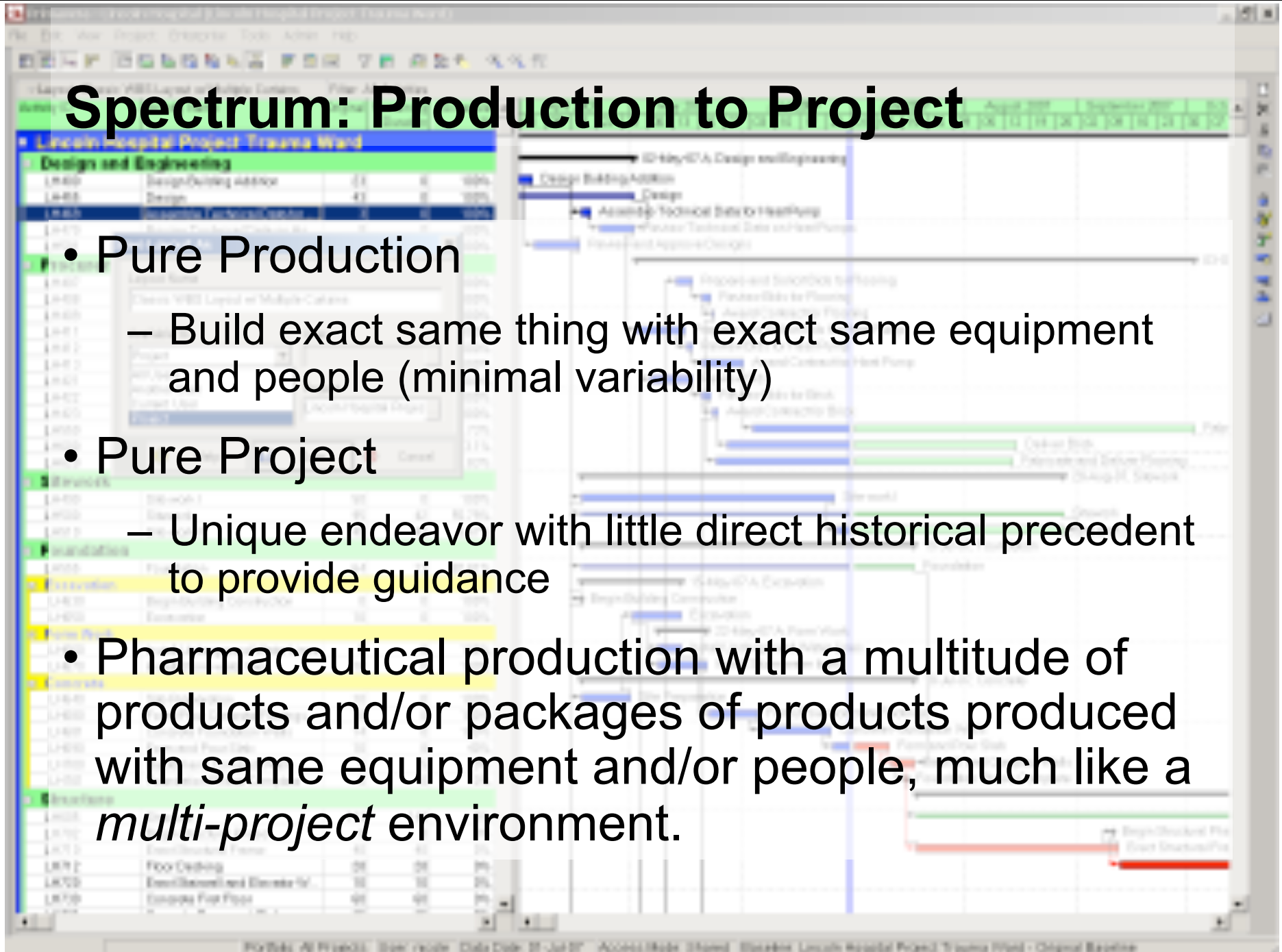
- Pure Production

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

- Pure Project

- Unique endeavor with little direct historical precedent to provide guidance

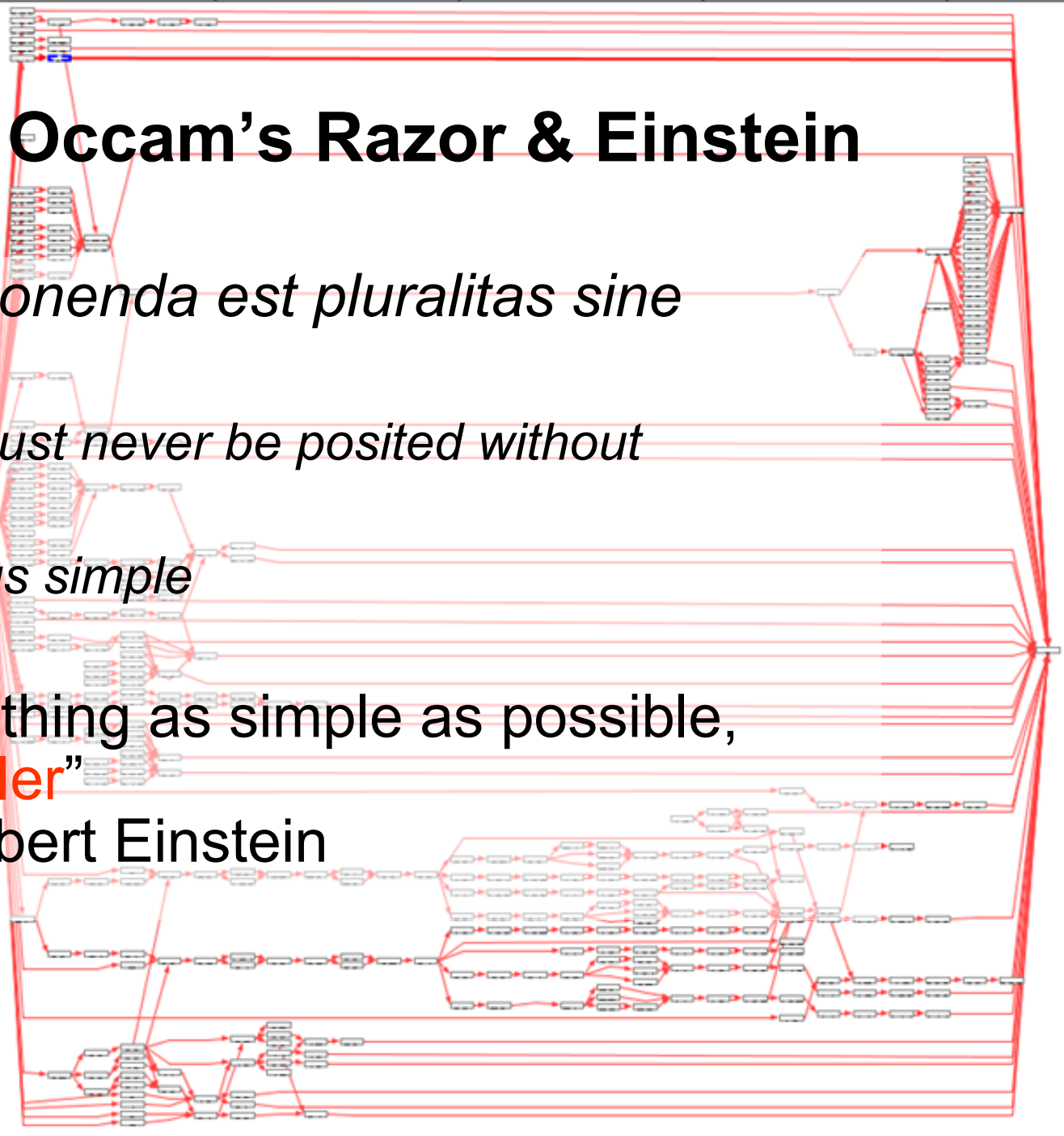
- Pharmaceutical production with a multitude of products and/or packages of products produced with same equipment and/or people, much like a *multi-project* environment.



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



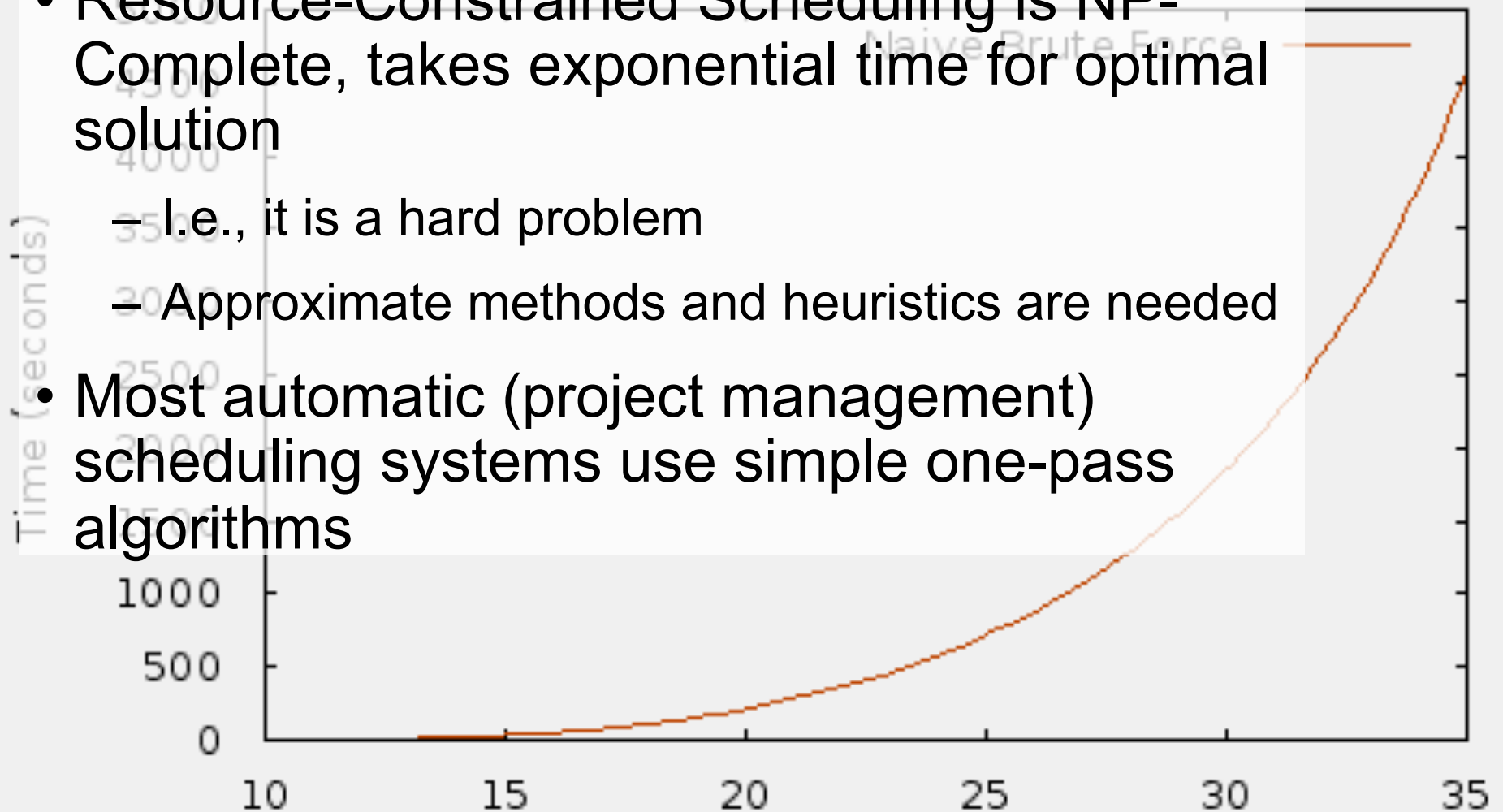
Scheduling is Difficult

- 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



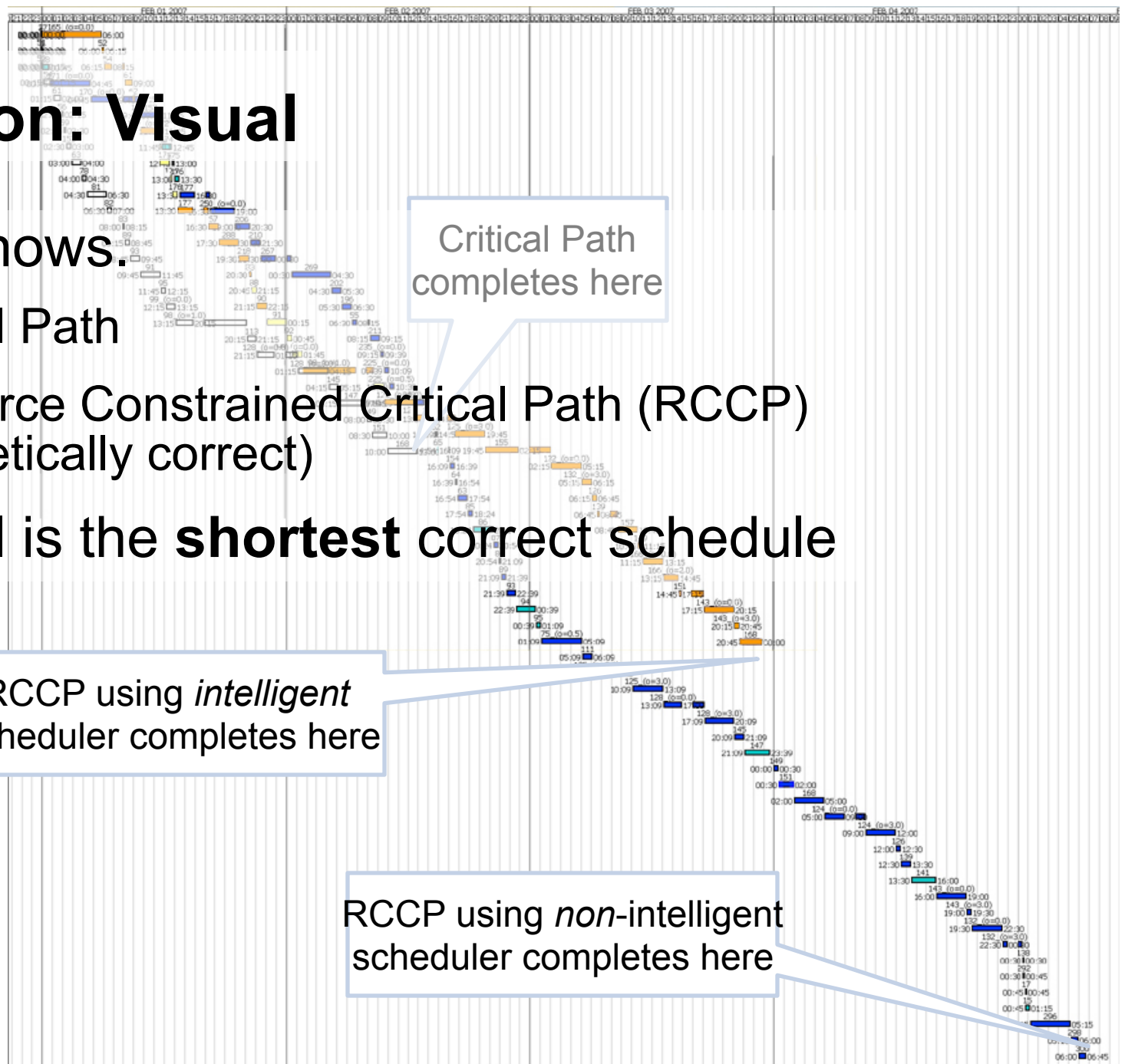
Motivation: Visual

- Figure shows.
 - Critical Path
 - Resource Constrained Critical Path (RCCP) (theoretically correct)
- The **goal** is the **shortest** correct schedule

RCCP using *intelligent* scheduler completes here

RCCP using *non-intelligent* scheduler completes here

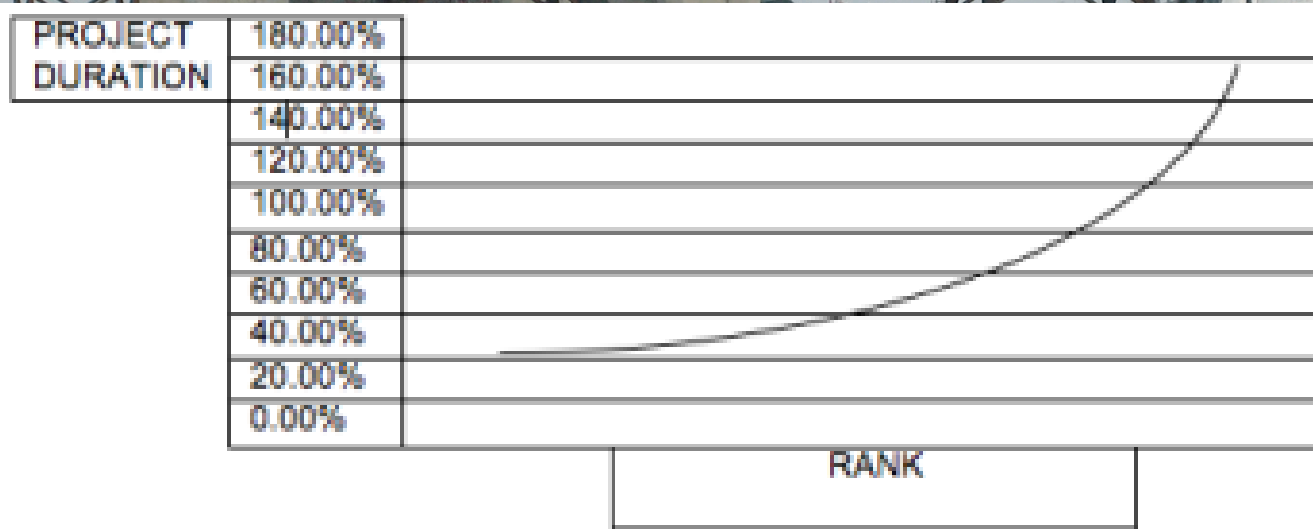
Critical Path completes here

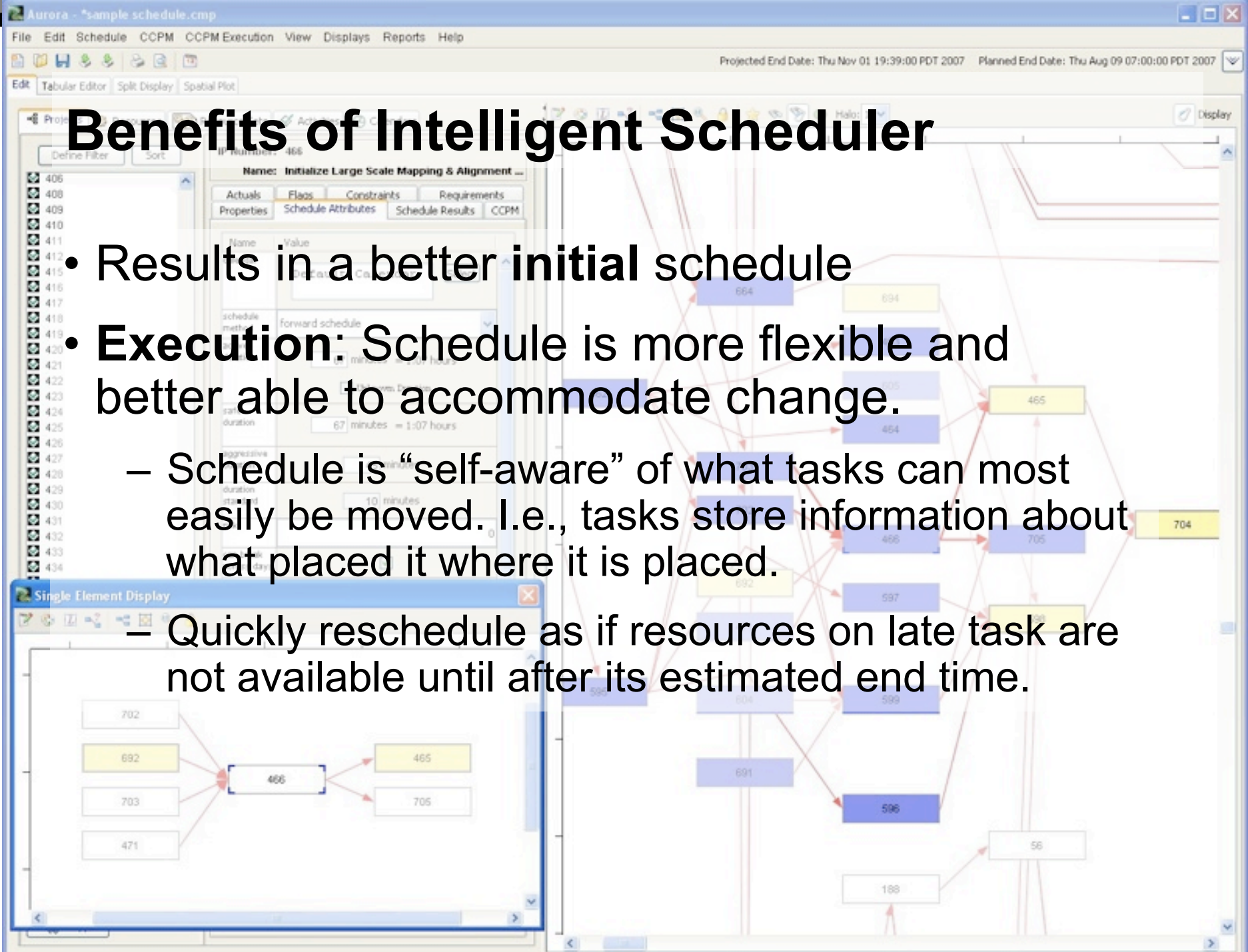


Construction Examples

(Kastor & Sirakoulis, 2009)

Product	1st Example Duration	Deviation from CPM (%)	2 nd Example 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



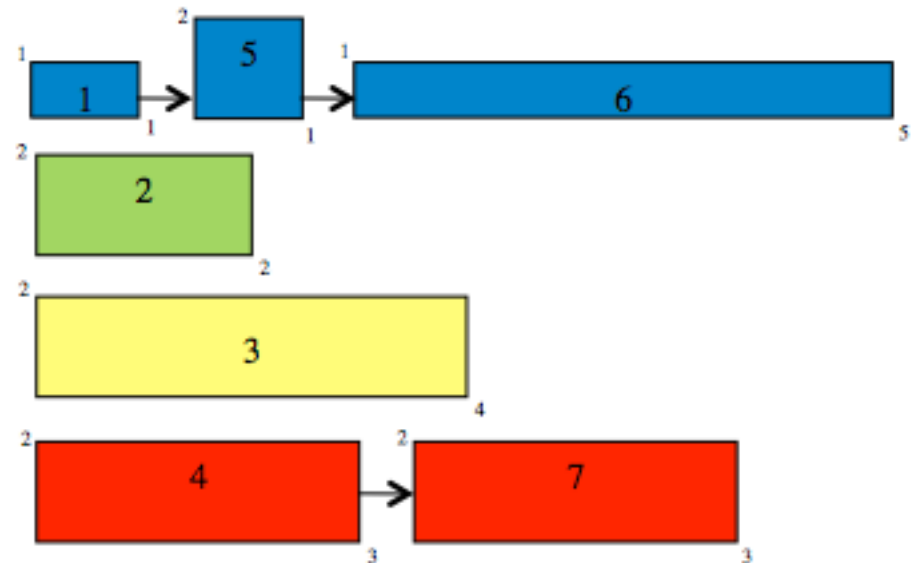
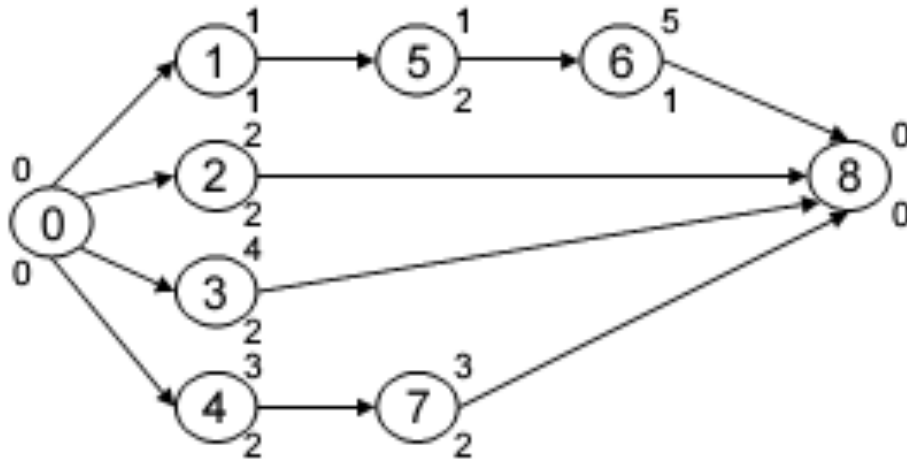


Benefits of Intelligent Scheduler

- 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.

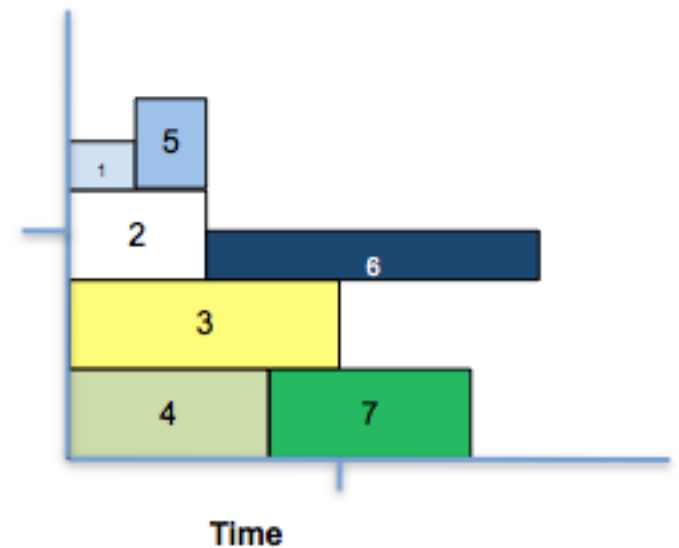
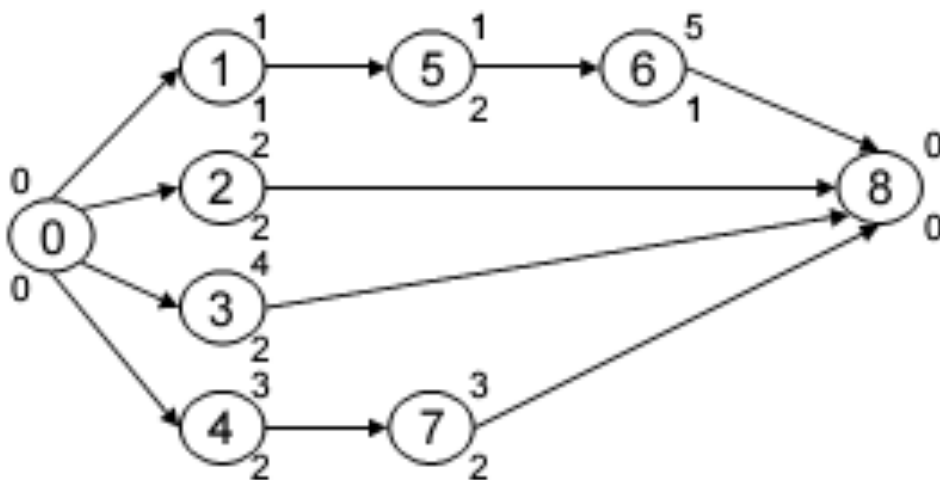
Maybe Only for 'Big' Problems?

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



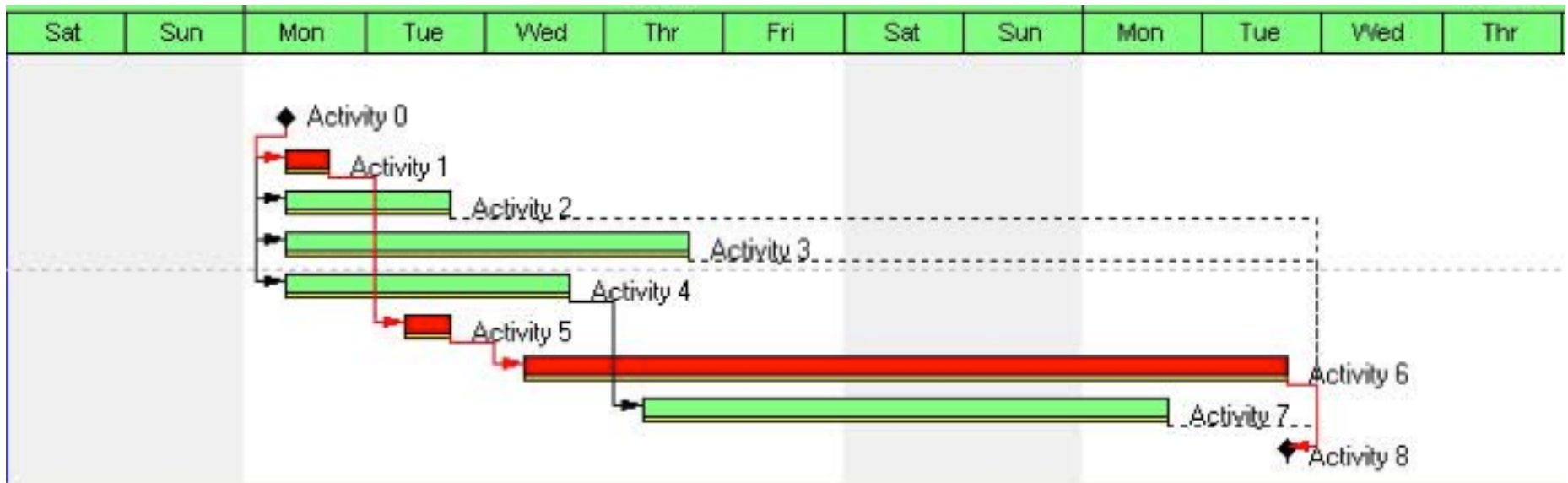
Critical Path of Network

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



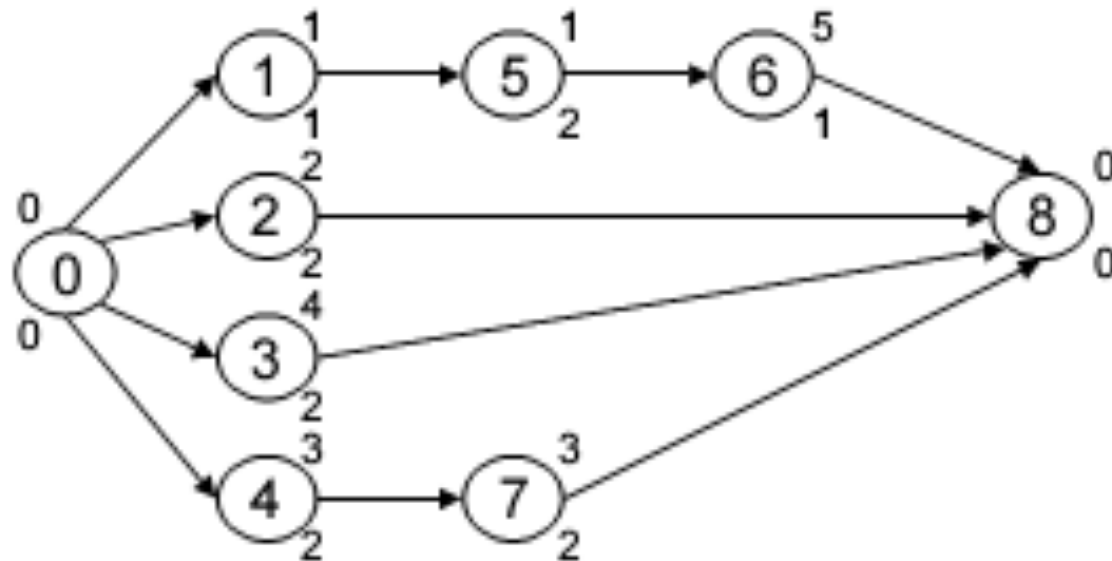
Gantt Chart of Critical Path

- Note: Sat/Sun are not workdays



Set Resource Pool to 5

- Only one type of resource to keep the problem 'simple'



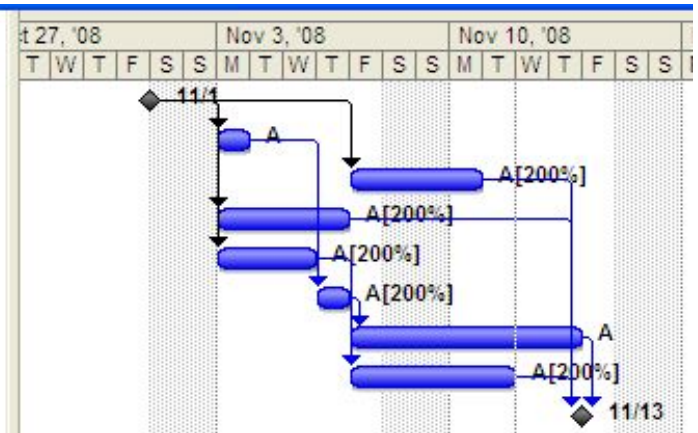
Gantt Chart Showing the Critical Path & Histogram

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



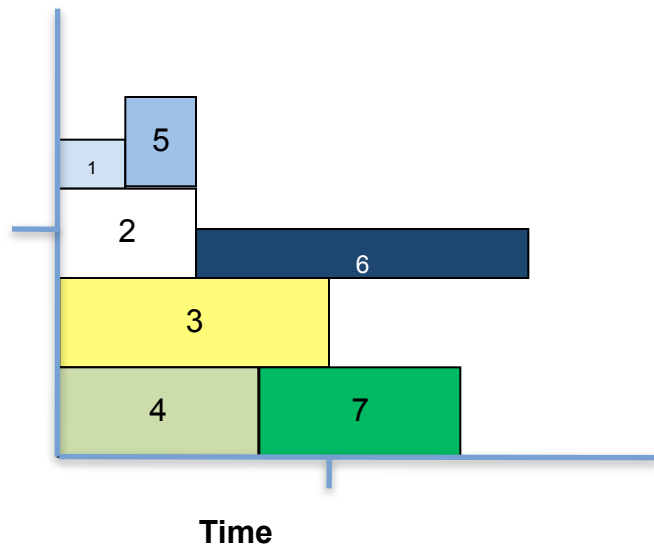
Resource-Leveled in MS Project = 9 days

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

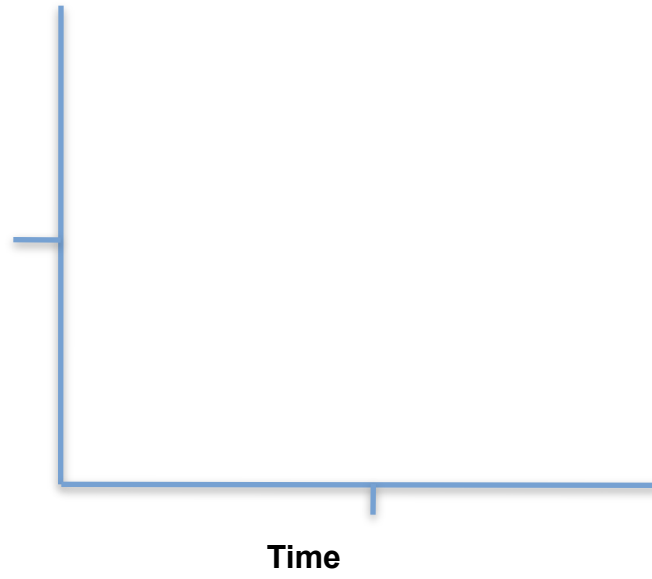




Resource Units

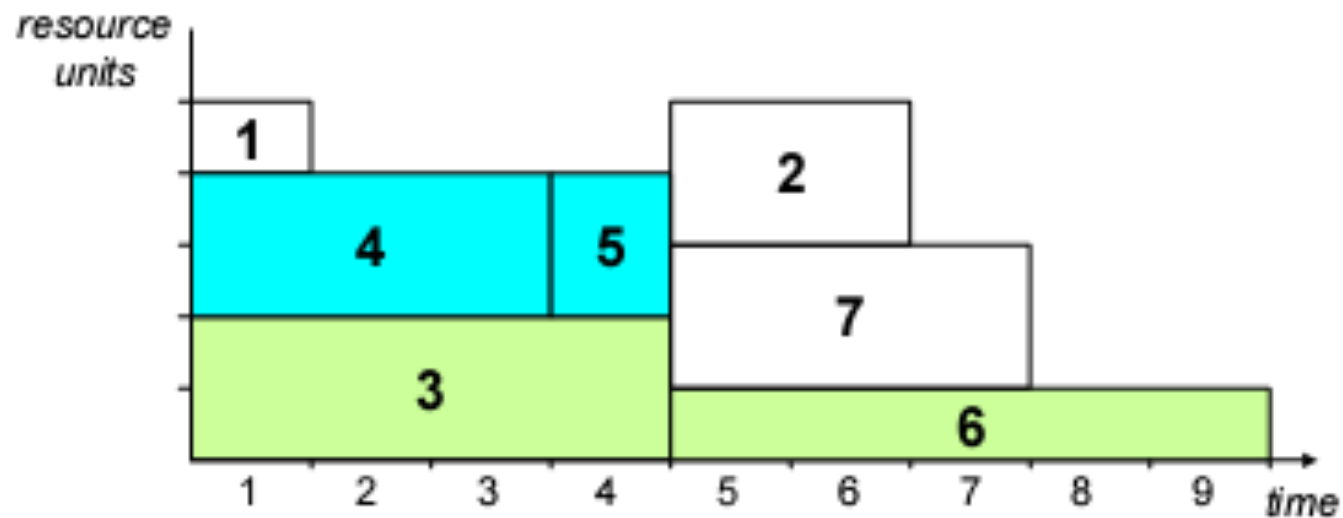


Resource Units



Simple Enough, Right?

- Another view of the solution

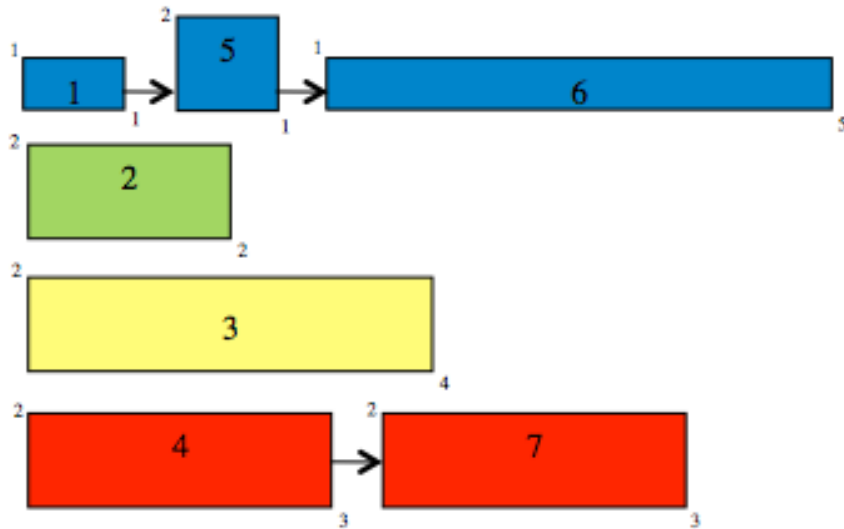


But there is a better solution ...

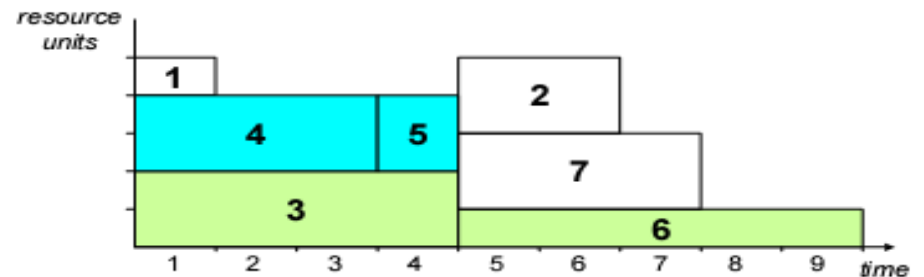
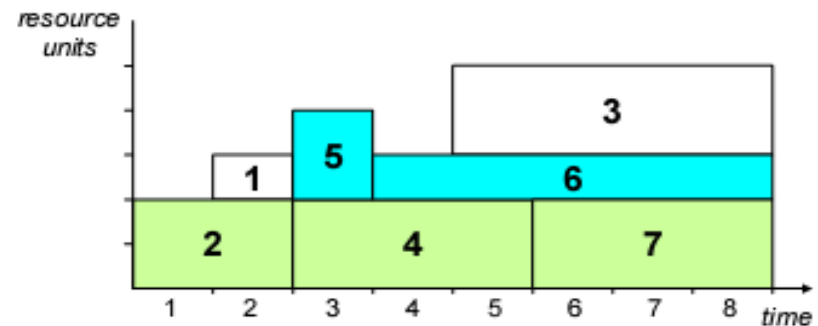
Primavera: Resource Leveled = 8 days



Simple?

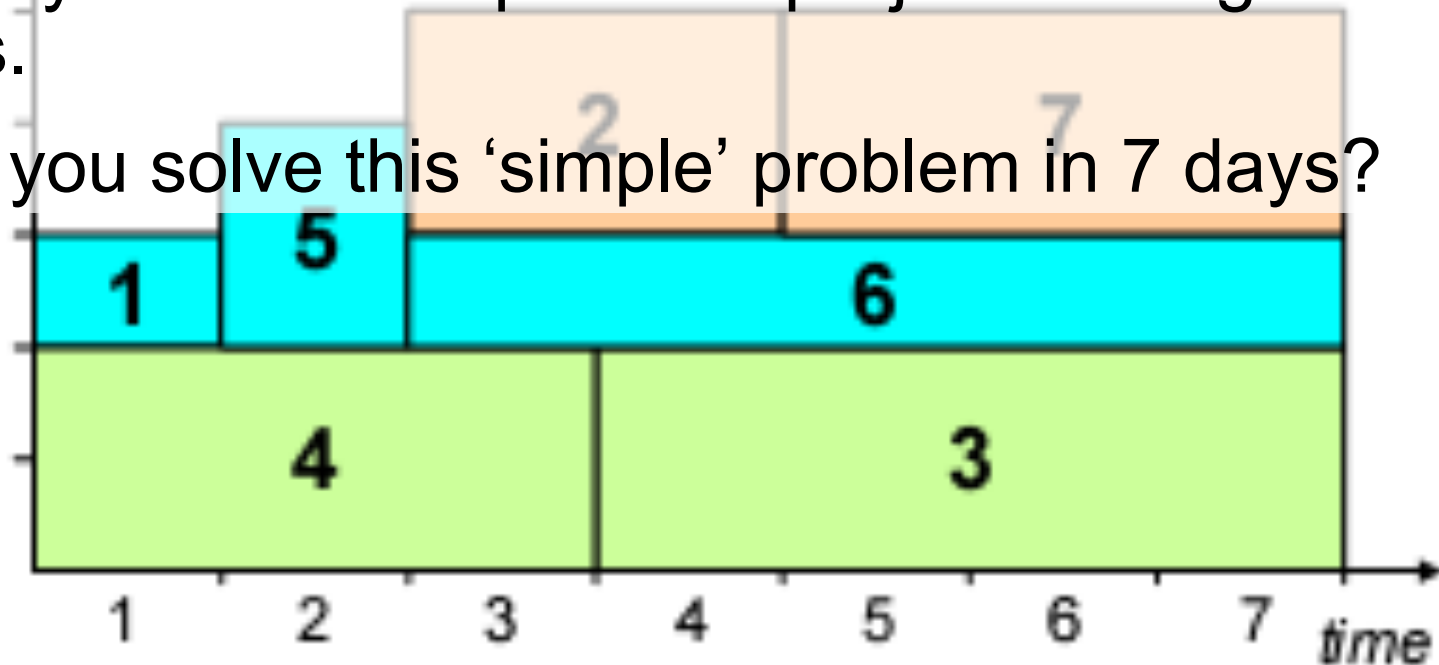


- Critical Path =
 $1 + 1 + 5 = 7$
- 1 resource
5 total units



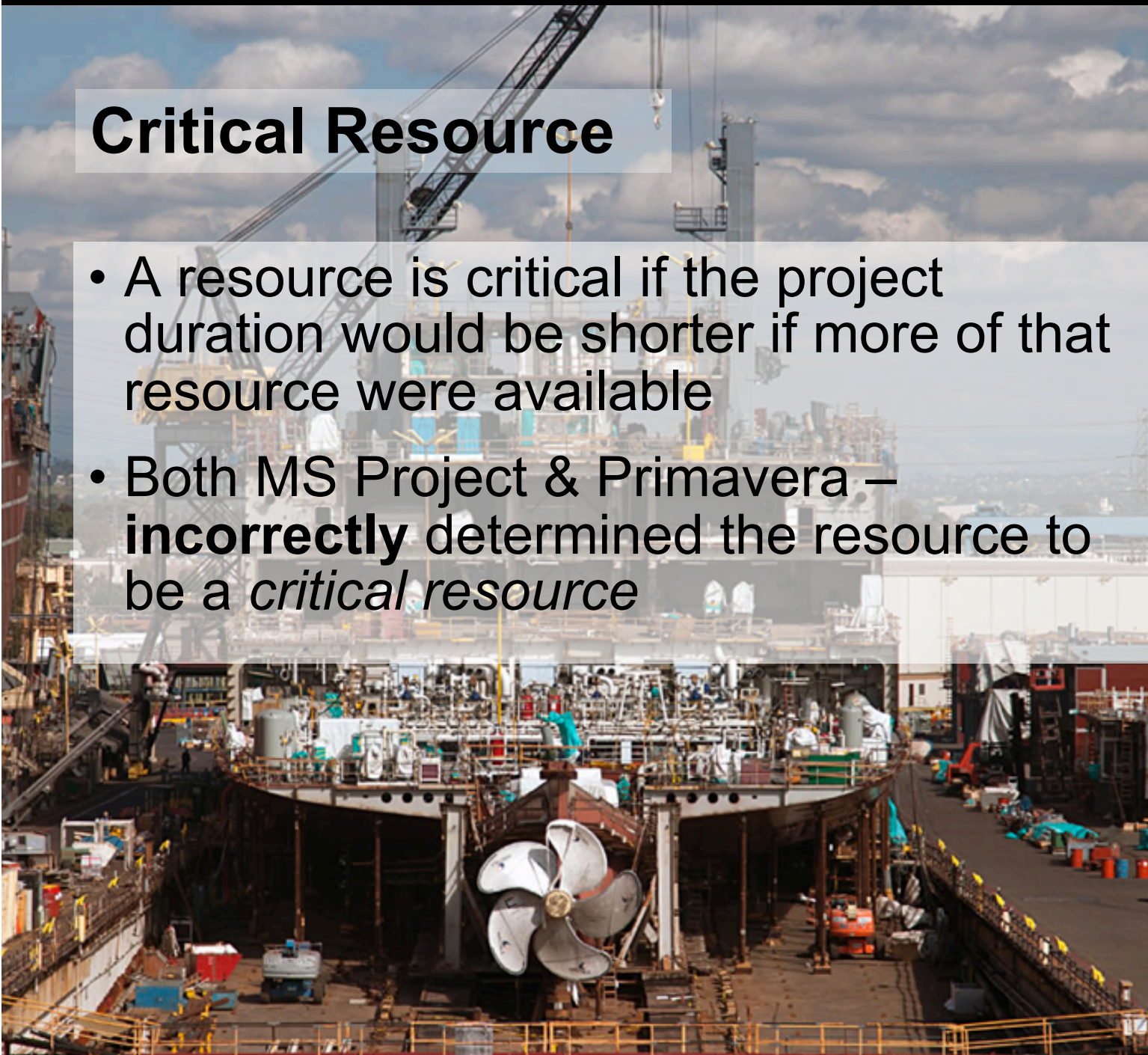
End of Story... Not quite

- 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?



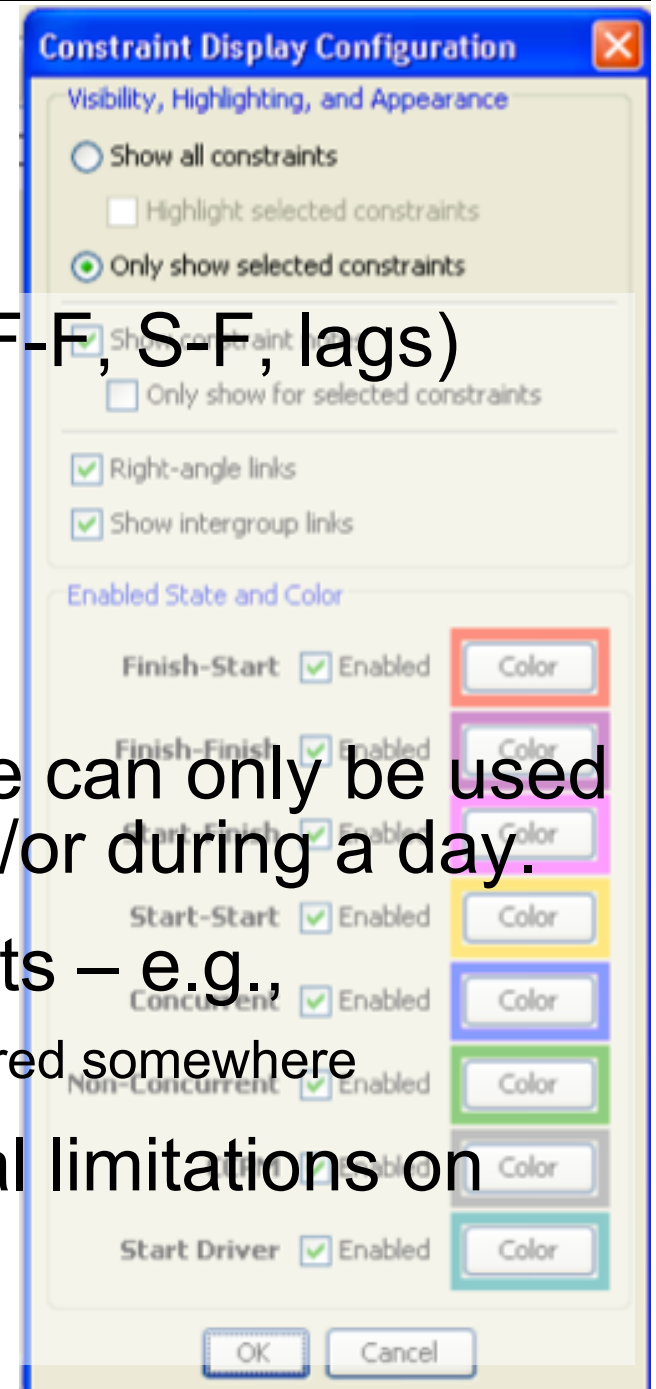
Critical Resource

- 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*



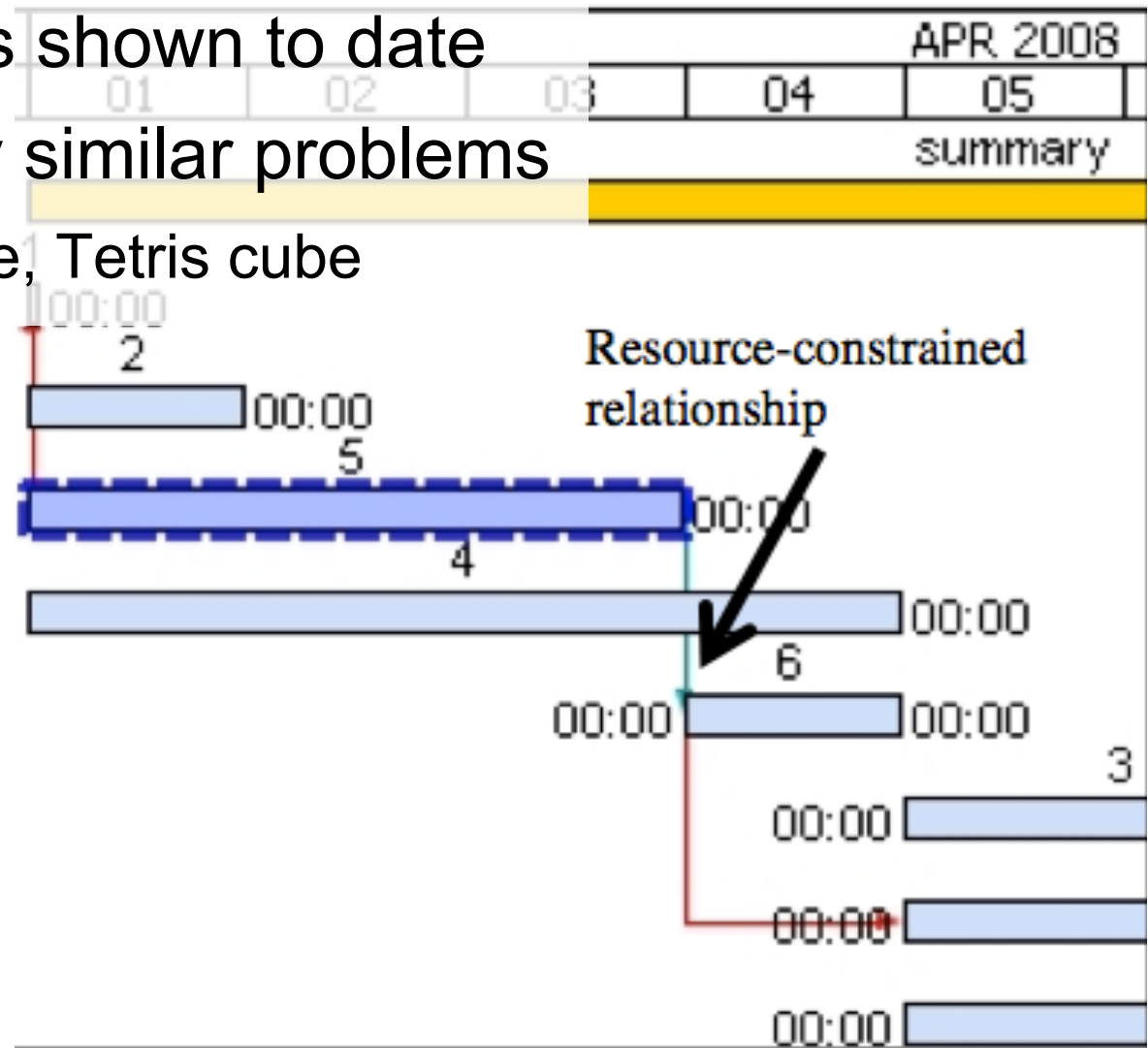
Constraints Add Complexity

- 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



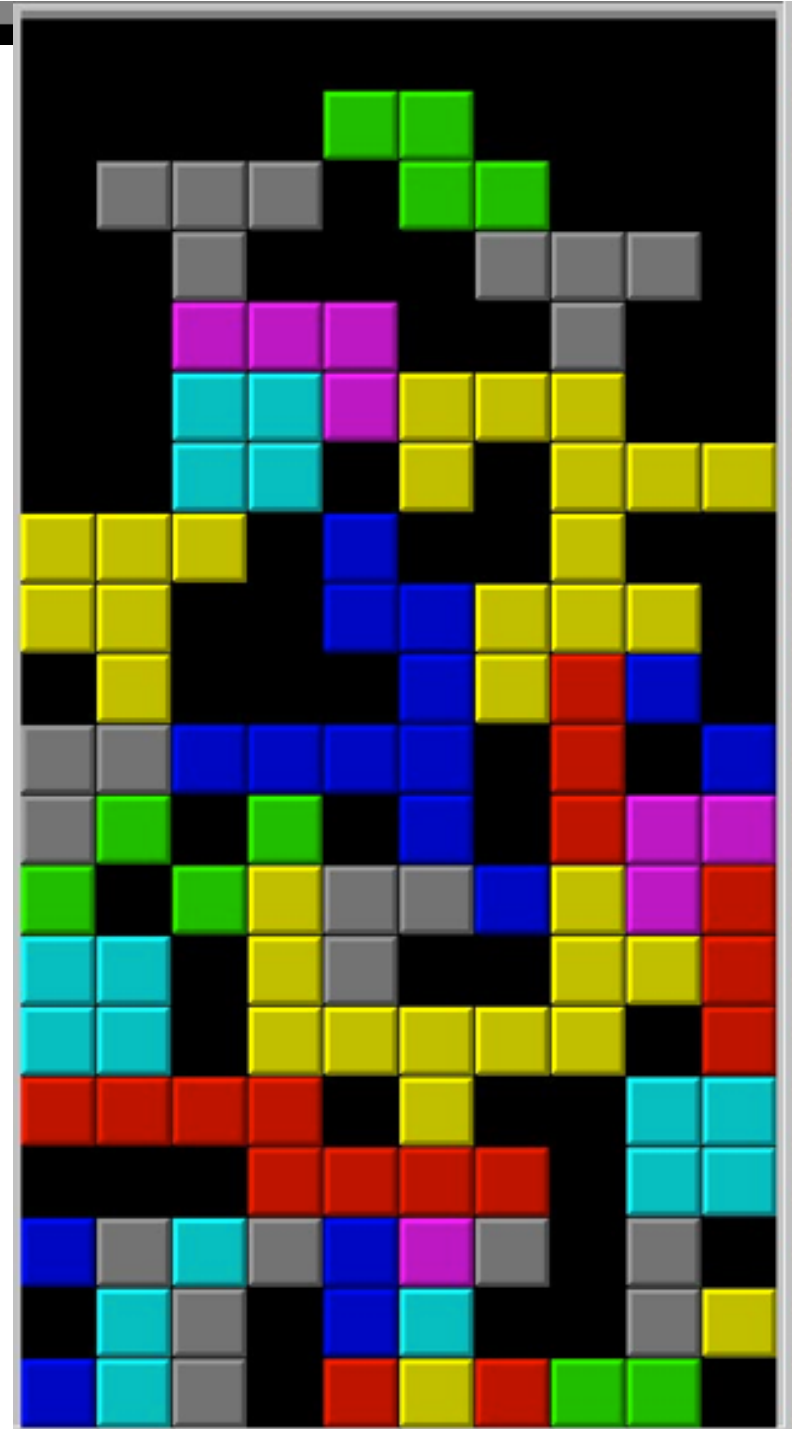
Visualizing More Complex Situations

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



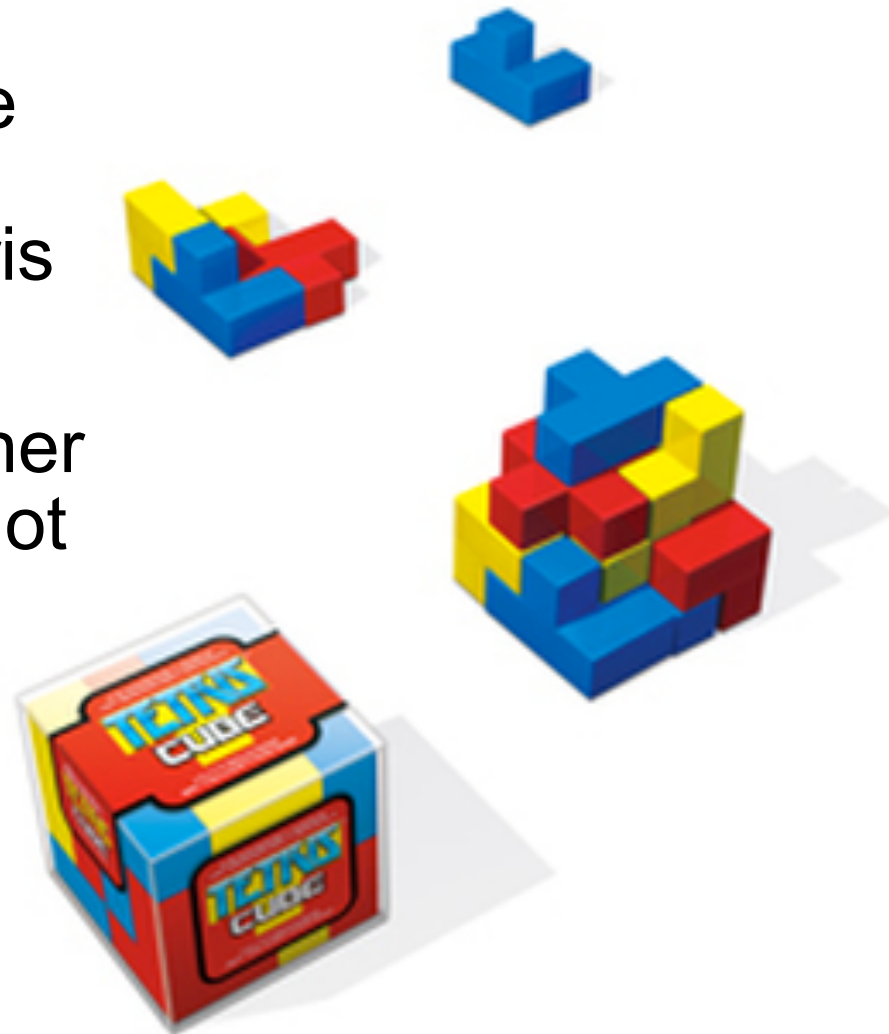
Tetris

- 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.FreeTretis.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](#)

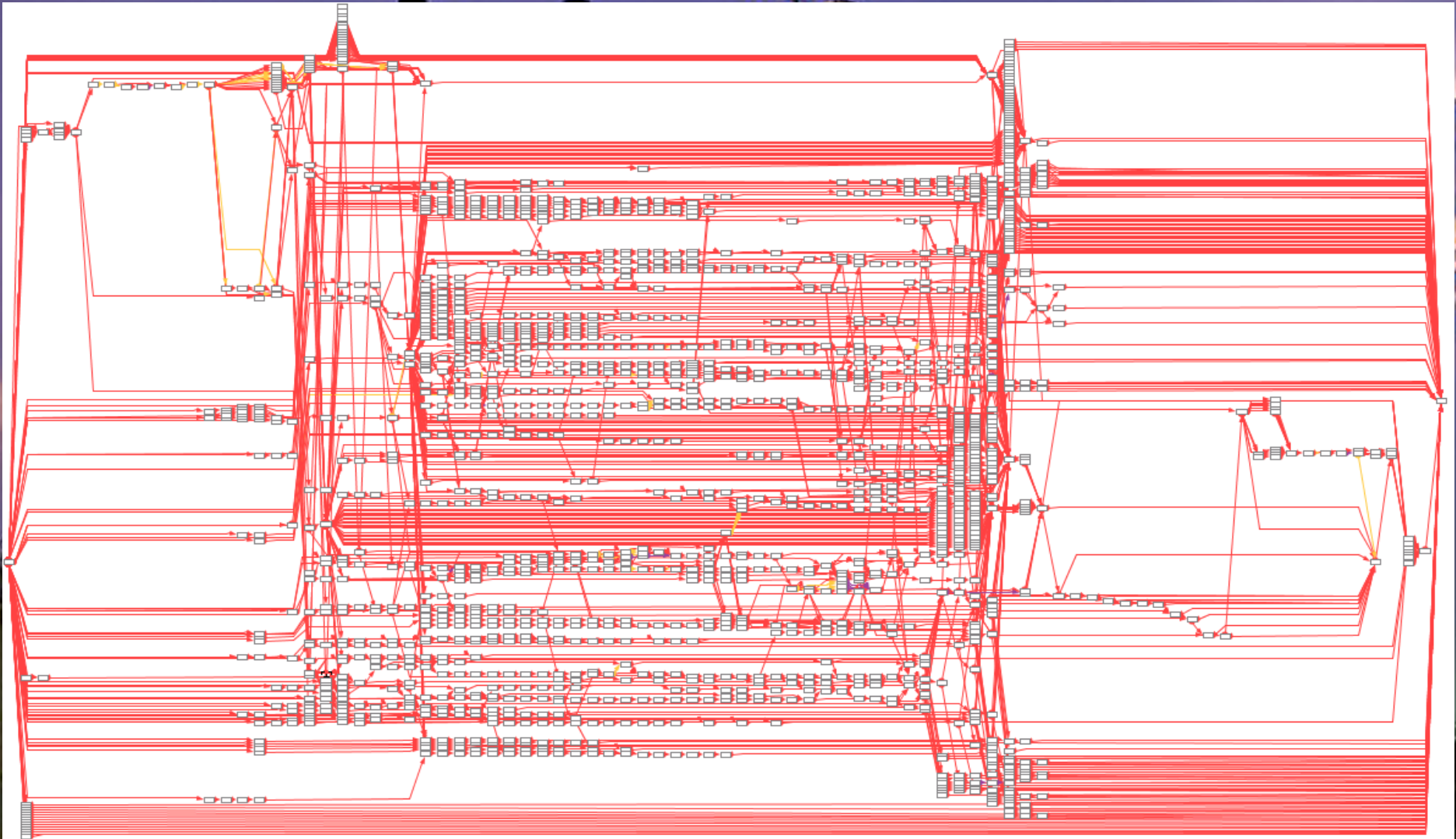


The background image shows the interior of the Aurora particle accelerator facility. It is a large, industrial space with a complex network of pipes, machinery, and structural elements. The lighting is bright, and the overall color palette is dominated by metallic greys, blues, and yellows. A prominent feature is a large, circular structure in the upper right, possibly a component of the accelerator. The text is overlaid on a semi-transparent grey box in the upper left quadrant.

Aurora: Intelligent Scheduling

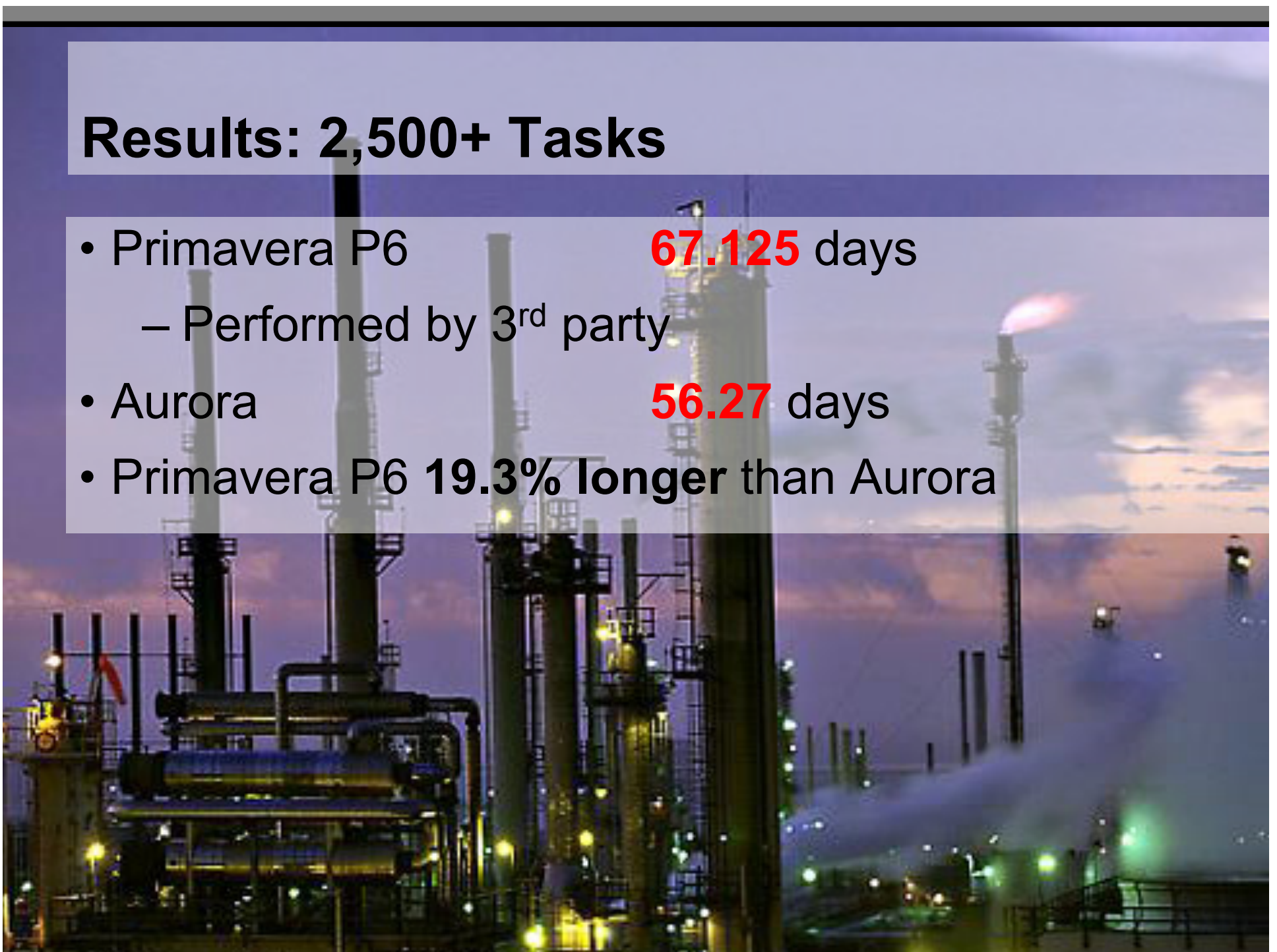
- Default & Customized Scheduling
 - Multiple-pass intelligent resource-constrained scheduling
 - Leverages the best of academic mathematical algorithms
 - Proprietary enhancements from our expertise / experience
 - Scheduler will investigate different resource allocations before it begins scheduling.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

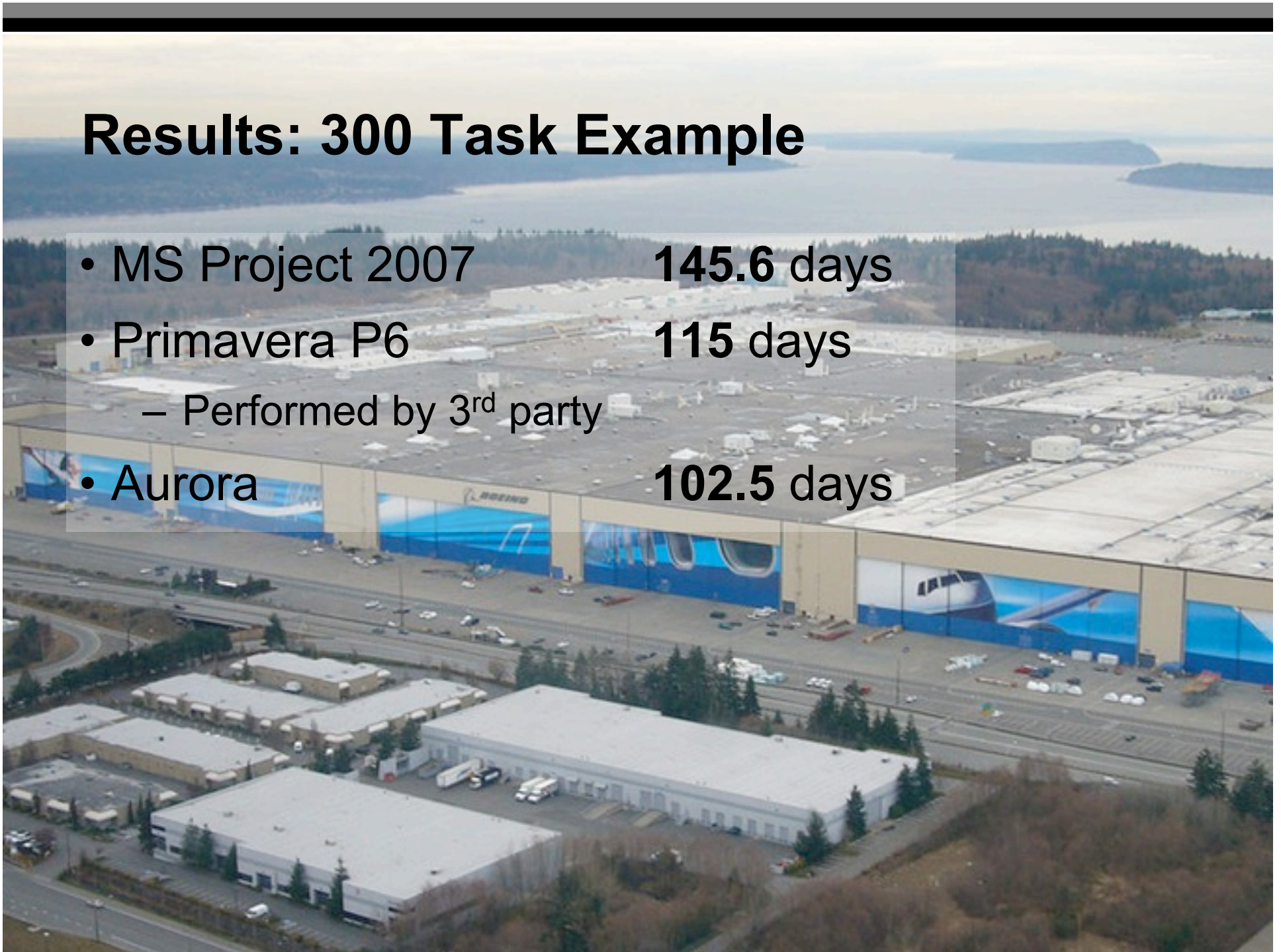


Aerospace Application: 300 Task Example

The screenshot displays a project management application interface. On the left, a task list is shown under the heading "300 cleaned3", with tasks numbered 1 through 44. Task 8 is highlighted. The main panel shows details for "IP Number: 8" and "Name: 8". The "Requirements" tab is active, displaying various sets (PLANE, RFR, RFTE, RFLE, RFD, LFR, LFTE, LFLE, LFD, MECH) with a value of 1 and a "use full set" checkbox. On the right, a complex network diagram illustrates the dependencies between tasks, with red lines connecting nodes representing task relationships.

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

The background of the slide is a photograph of the Aurora satellite in space. The satellite is a yellow, cylindrical structure with large, blue, grid-patterned solar panels extending from it. It is positioned against the blackness of space, with the blue and white horizon of the Earth visible in the lower-left and bottom portions of the frame.

- 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

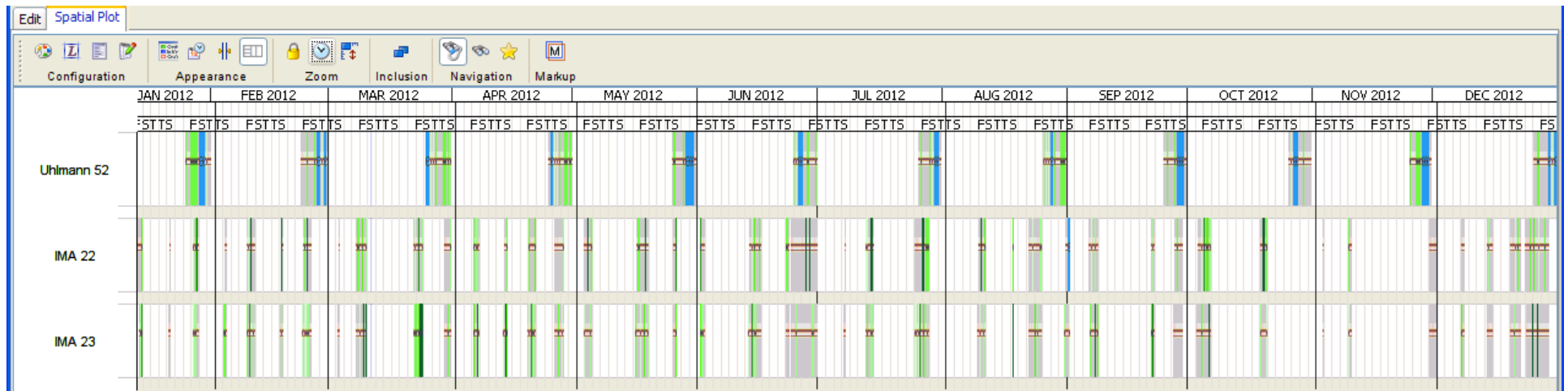
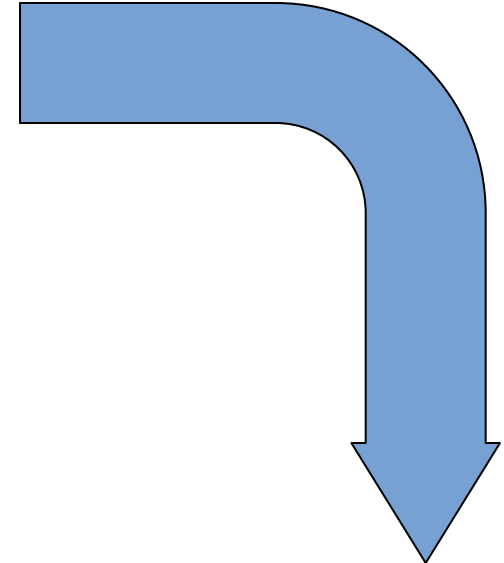


Summary

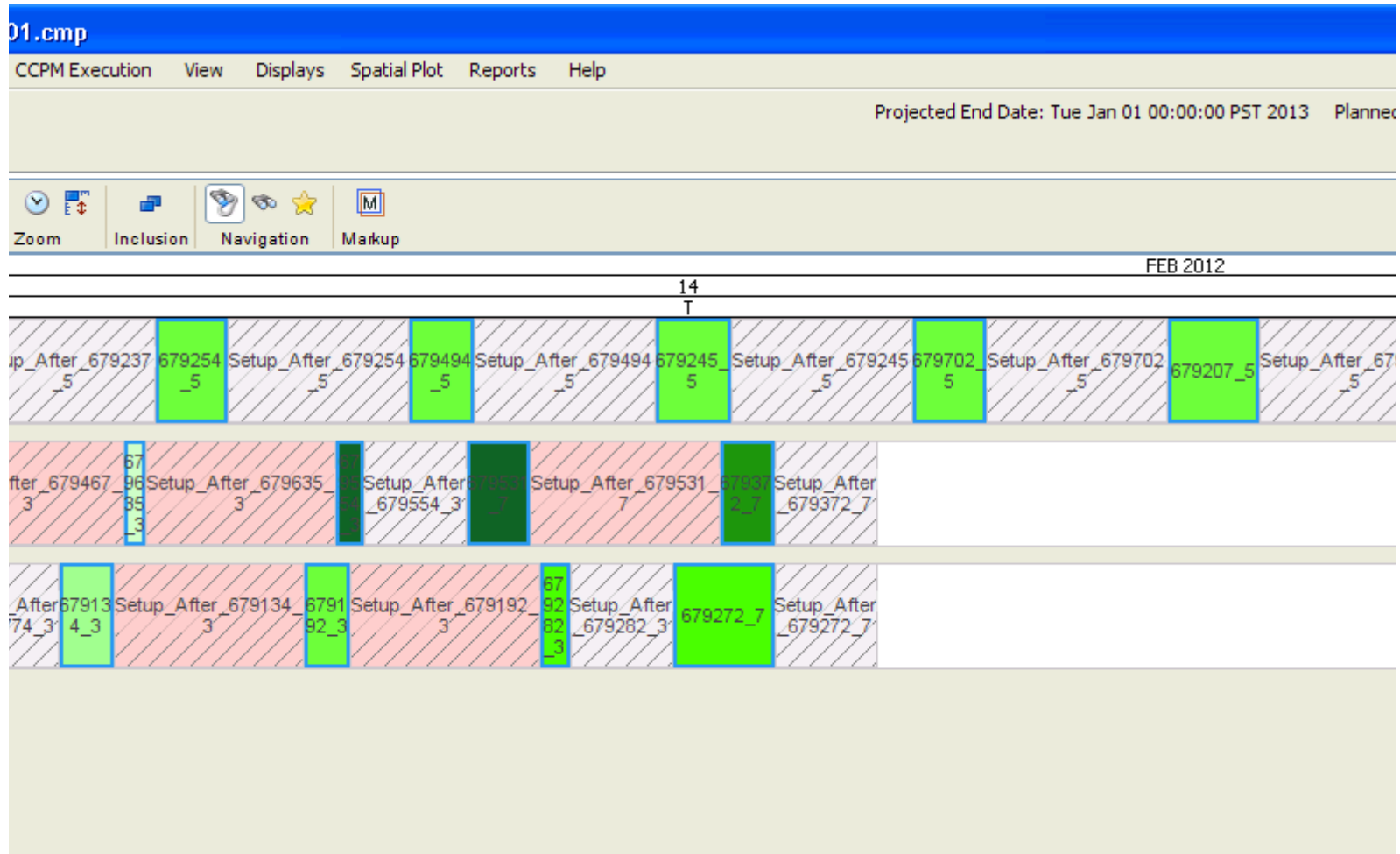
Production Data

→ Stottler Henke's Aurora

→ Production Schedule

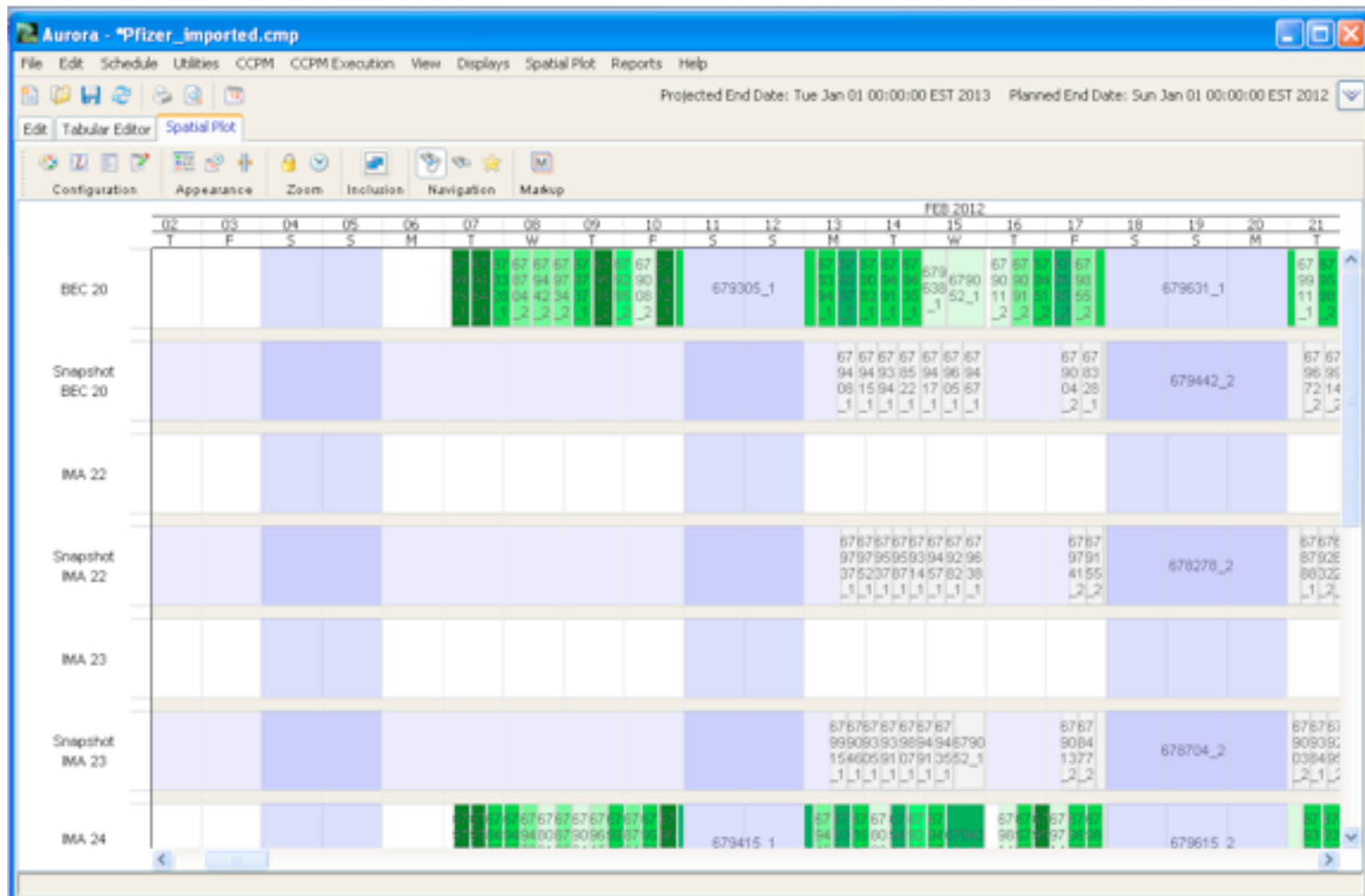


Graphical Differences: Setup vs Production

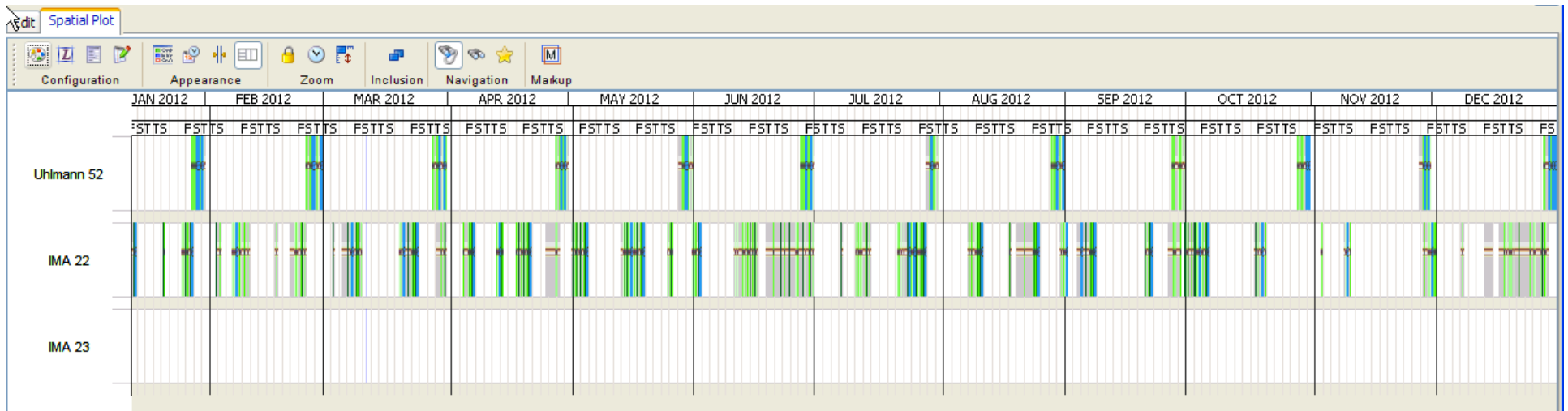
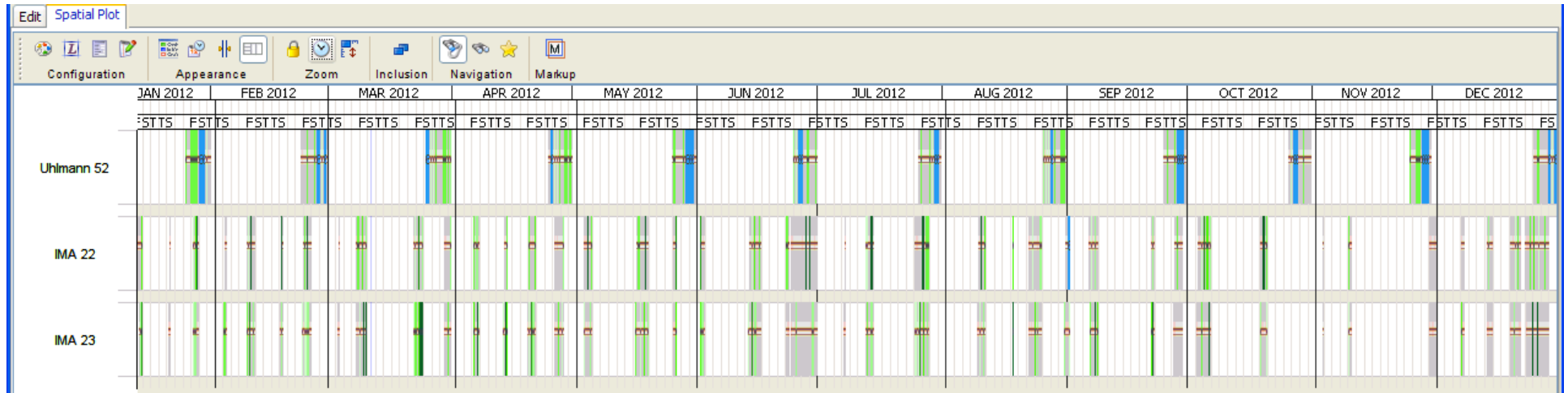


What-If Capabilities

- The user can manually add/remove machines or change calendars to see the effect on the schedule.

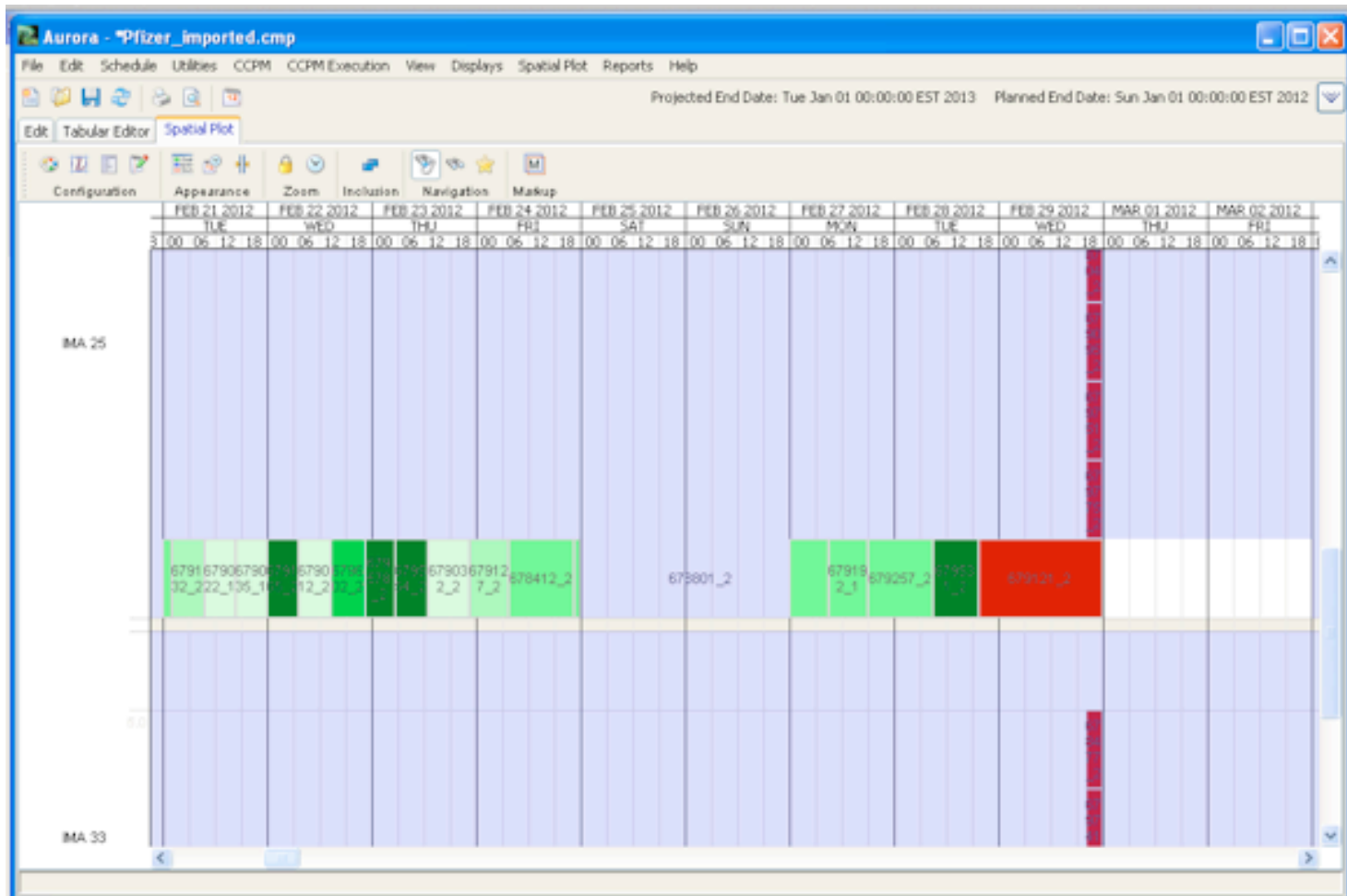


What-If: Same Demand 3 vs 2 Lines

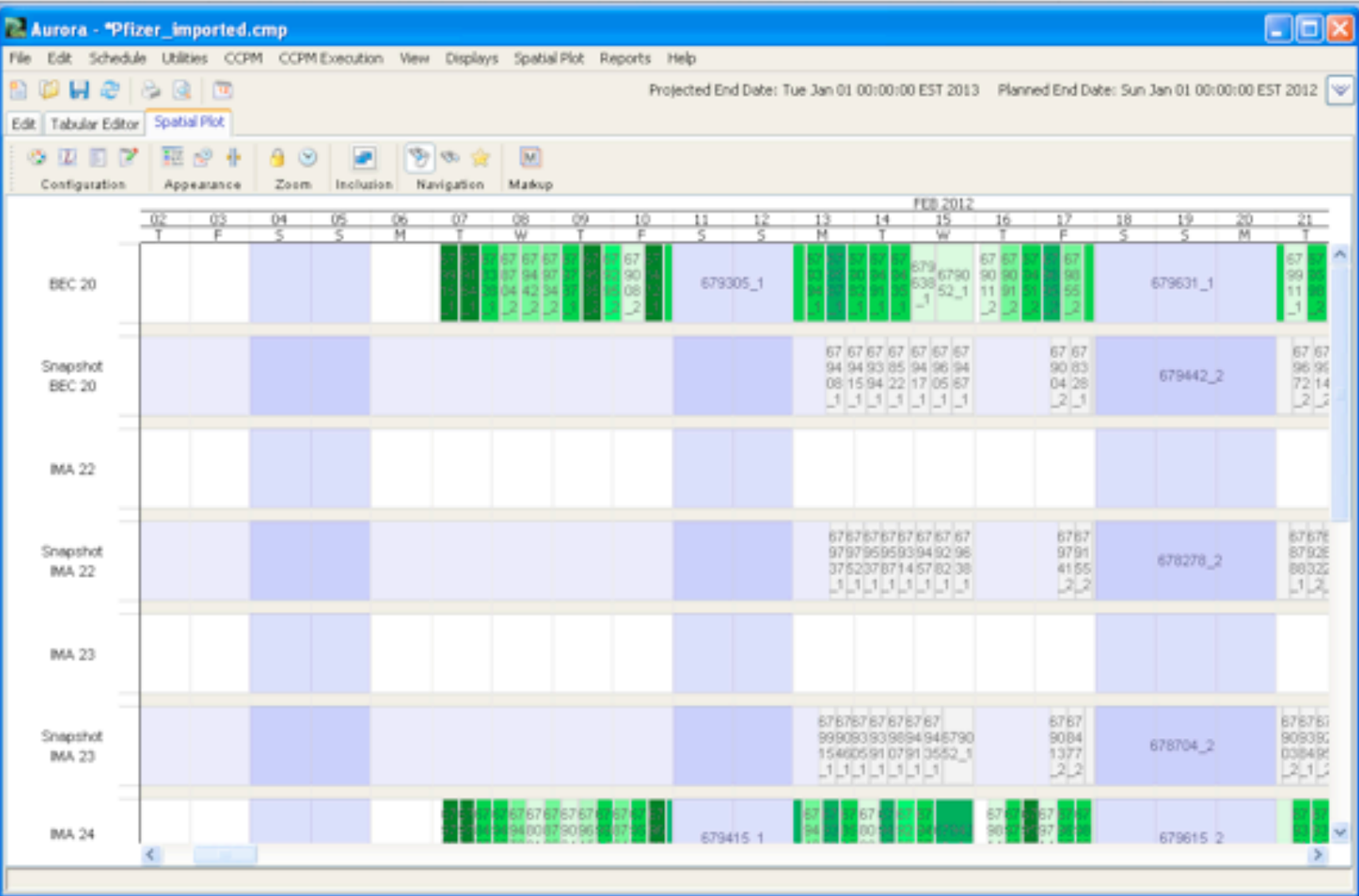


Conflicts

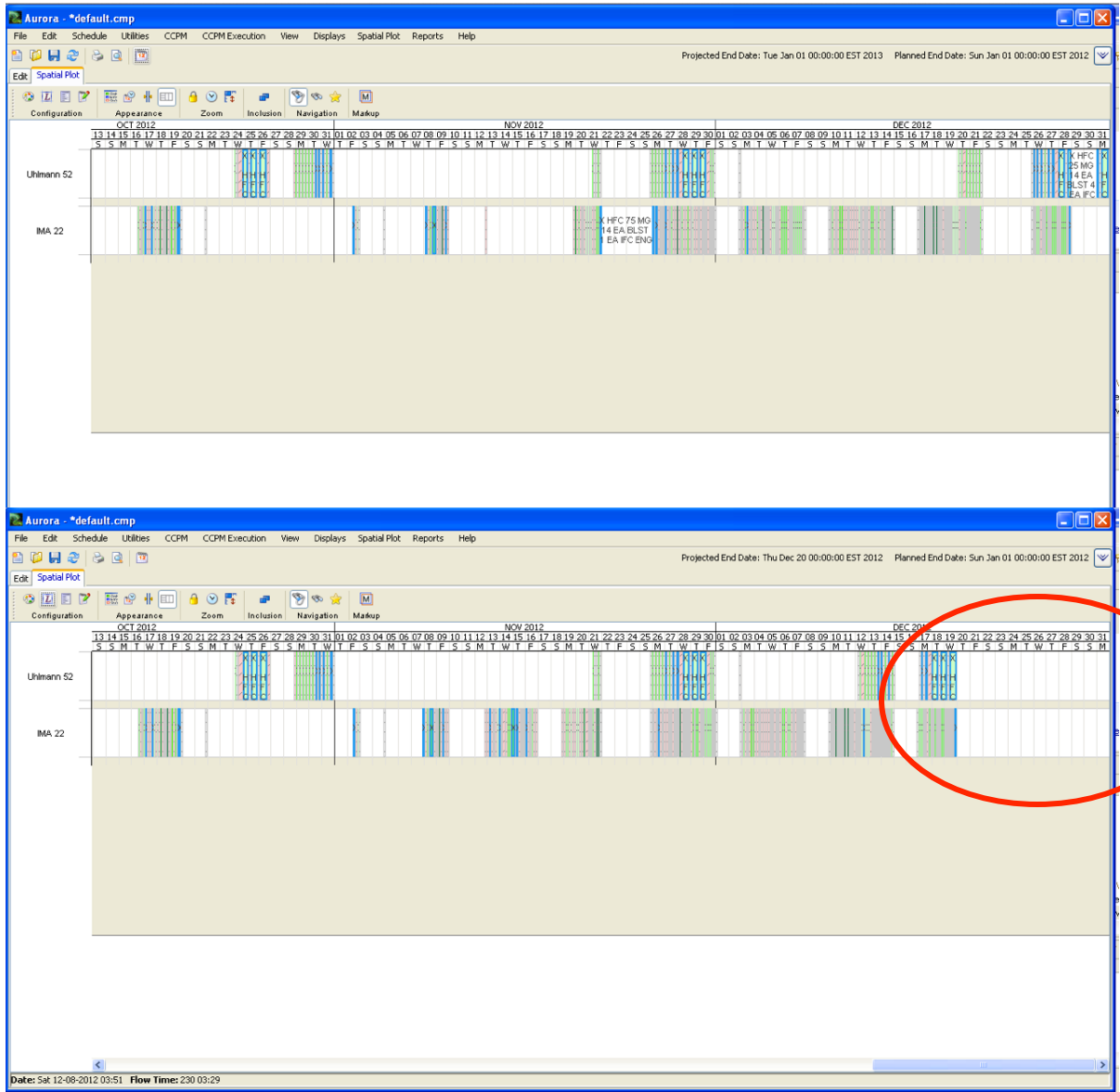
- Conflicts will occur if there are not enough lines / machines
 - Conflicts shown in red



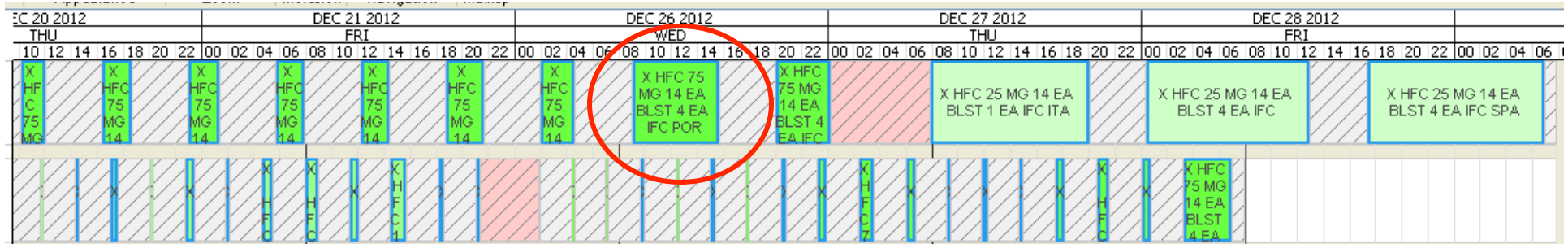
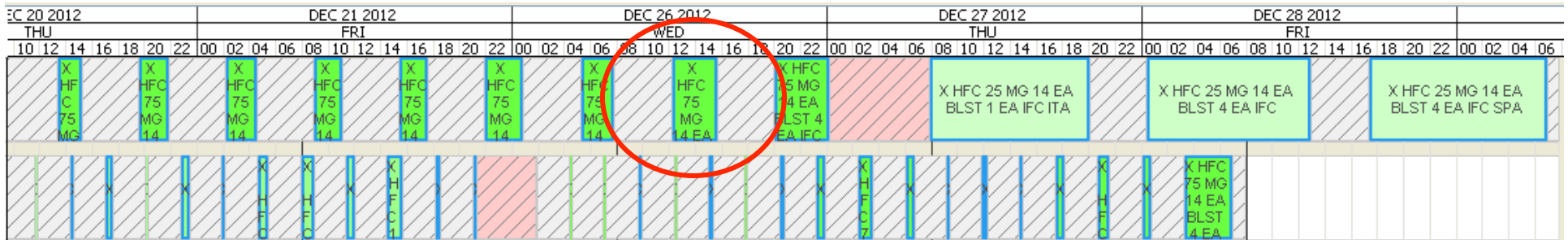
Removing Capacity Without Causing Conflicts



What-if: End of Year Shutdown



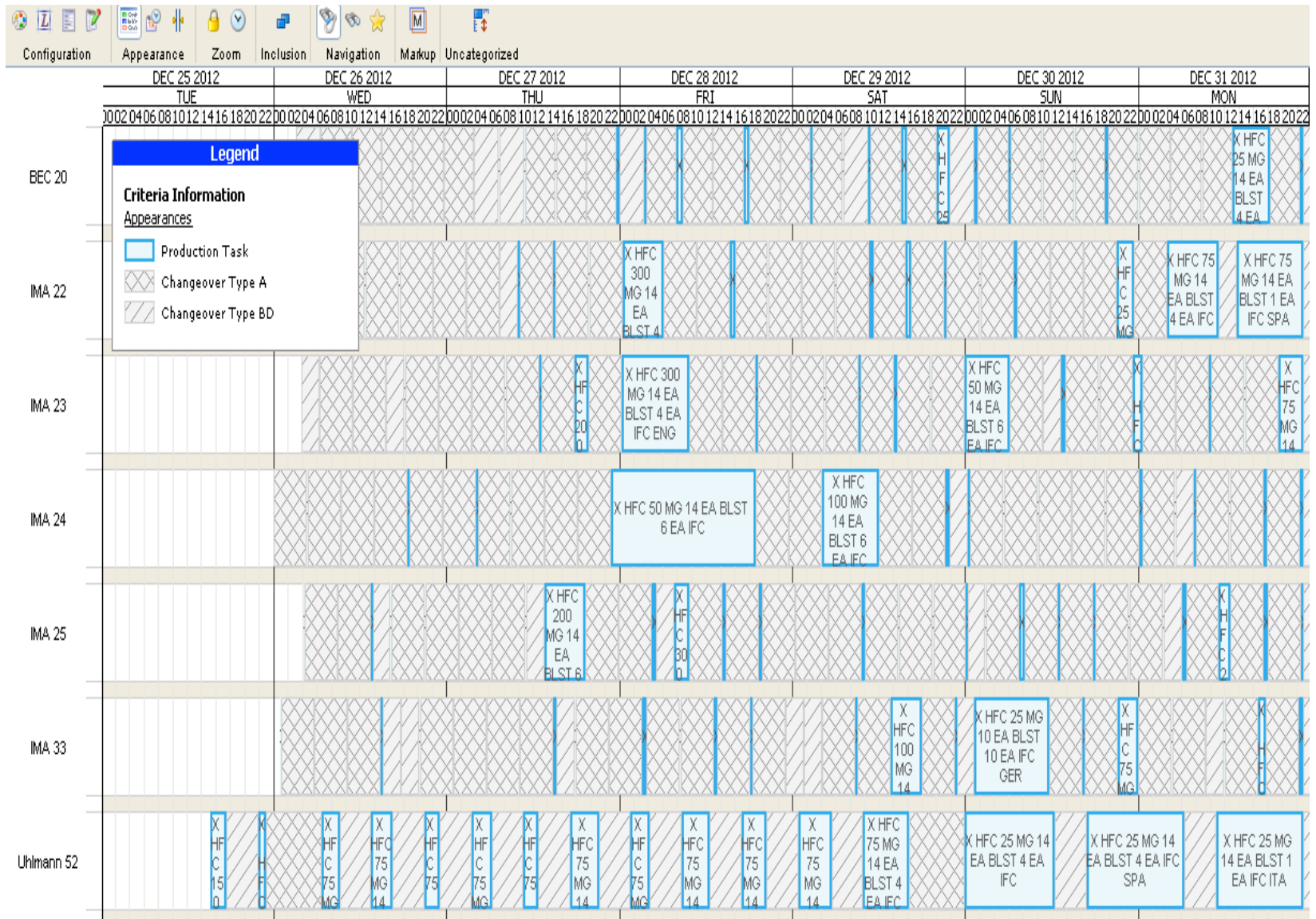
What-if: Demand Increase



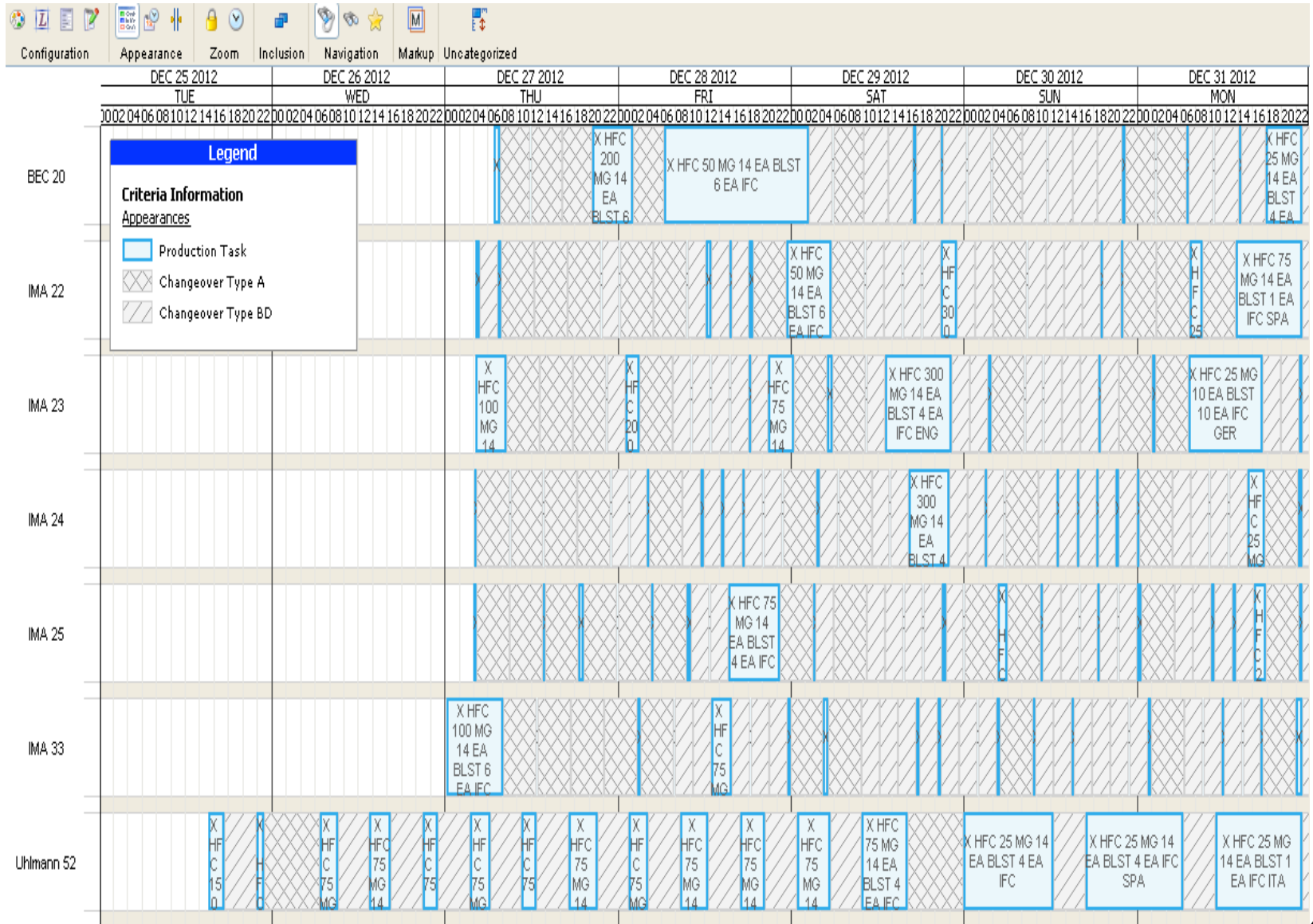
Optimizations

- Minimize the Changeover times,
- While ordering tasks in such a way as to minimize carrying costs, and other metrics.

WithOUT Optimization

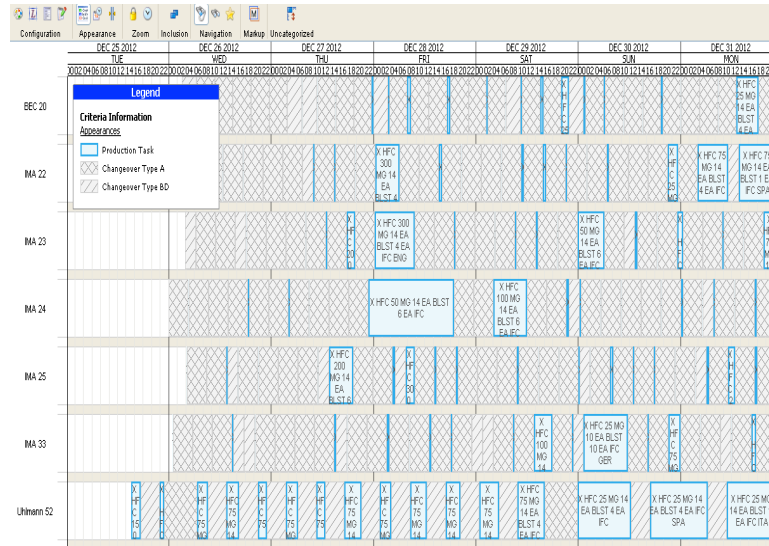


With Optimization

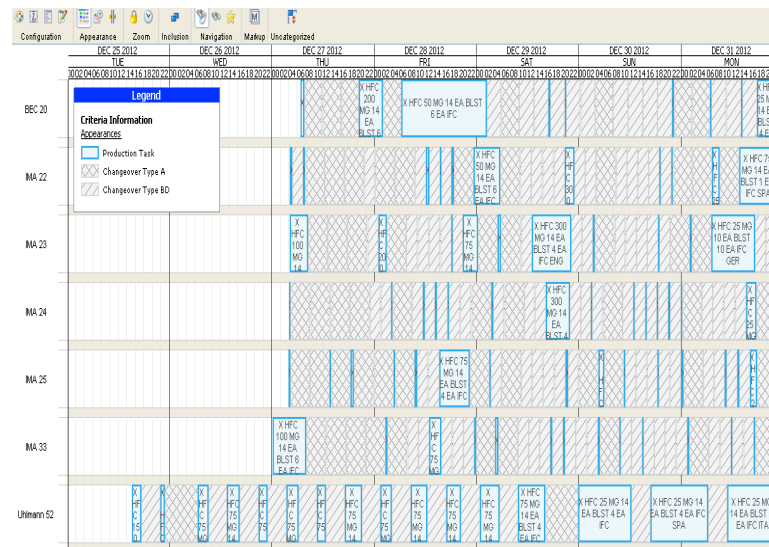


Production Optimization (changeover)

Without optimization



With optimization



The screenshot shows the Aurora software interface. The main window is titled "Aurora - *default.cmp". The menu bar includes "File", "Edit", "Schedule", "Utilities", "CCPM", "CCPM Execution", "View", "Displays", "PERT Chart", "Reports", and "Help". The interface is divided into several sections:

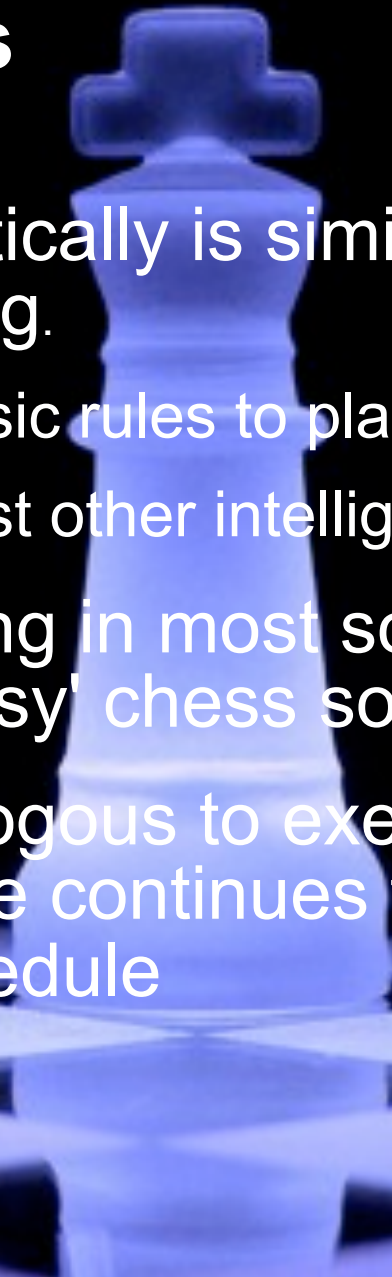
- Left Panel:** Contains a "Projects" section with a "day baseline: 00.00" and a "Filter" section. Below this is a list of activities, with "Calendar 1" selected.
- Center Panel:** A form for "Calendar 1" with fields for "Name" and "Description". Below the form is a table with columns: "Shift N...", "Start Time", "End Time", "Duration", and "Work Ti...".
- Right Panel:** A calendar view for "January 2012" and "February 2012". The January calendar shows days 1 through 31, with some days having colored bars (red, green, blue) indicating activities. The February calendar shows days 1 through 4.

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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