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
• 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
# Construction Examples

(Kastor & Sirakoulis, 2009)

<table>
<thead>
<tr>
<th>Product</th>
<th>1st Example</th>
<th>2nd Example</th>
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<tbody>
<tr>
<td></td>
<td>Duration</td>
<td>Deviation from CPM (%)</td>
</tr>
<tr>
<td>Primavera P6</td>
<td>709</td>
<td>52.8</td>
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<tr>
<td>MS Project</td>
<td>744</td>
<td>60.34</td>
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<td>Open Workbench</td>
<td>863</td>
<td>85.99</td>
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</table>
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

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Predecessors</th>
<th>Resource Names</th>
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<tbody>
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<td>Sat 11/1/08 12:00 AM</td>
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<tr>
<td>T5</td>
<td>8 hrs</td>
<td>Thu 11/6/08 8:00 AM</td>
<td>Thu 11/6/08 5:00 PM</td>
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<td>Thu 11/13/08 5:00 PM</td>
<td>6</td>
<td>A</td>
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<tr>
<td>T7</td>
<td>24 hrs</td>
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<tr>
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<td>Thu 11/13/08 5:00 PM</td>
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</table>
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?
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
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

<table>
<thead>
<tr>
<th>Legend</th>
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<tbody>
<tr>
<td><strong>Production Task</strong></td>
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<tr>
<td><strong>Changeover Type A</strong></td>
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<tr>
<td><strong>Changeover Type BD</strong></td>
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</table>

### Criteria Information

**Appearances:**

- Production Task
- Changeover Type A
- Changeover Type BD

### Table

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Appearance</th>
<th>Zoom</th>
<th>Inclusion</th>
<th>Navigation</th>
<th>Maskup</th>
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</table>

### Notes

- Please refer to the attached schedule for detailed task and changeover information.
- The table above outlines the production tasks and changeovers for the specified dates.
- The legend provides a key for understanding the symbols and colors used in the schedule.
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