



Enterprise  
Ireland



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**EDIH** | European  
Digital Innovation  
Hubs Network



# Advanced Concepts

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## Constraint Based Production Scheduling



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# Key Points



- We present some more advanced concepts in scheduling
- These occur in more specialized problem areas
- Typically require more work on modelling
- Solver support may be limited

# Outline



Sequence Dependent Setup-Time

Transportation Time

Summary

# Sequence Dependent Setup-Time ✓



- Our usual disjunctive resource model assumes that we can change easily from one task to the next
- There might be a cleaning/setup time required
  - This is part of the fixed duration part of a processStep description
- In some cases it is more complex
  - On some machines there is a setup-time required which depends on both the previous and the next product
  - This time varies significantly between product combinations
  - Typically, the time depends on some properties of the products
- The setup time is non-productive, and should be avoided when possible

# Computed Setup-Time Matrix



- This needs to be computed from first principles, not maintained by hand!
  - Available as input data in JSON format

# Relation to TSP

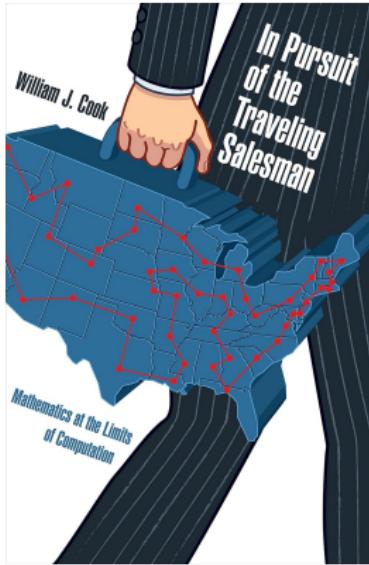


- Computing the optimal sequence of setup times is a variant of the *Travelling Salesman Problem (TSP)*
- Another of the classical hard combinatorial problems
- Due to the structure of the data, setup-time problems often are simpler to solve
  - Changing between very similar products needs no setup-time
  - Using a simple rule about product compatibility produces best results
  - Example: dark-chocolate → milk chocolate → white chocolate → milk chocolate → dark chocolate
- Problems get more difficult when release/due dates need to be respected
- This is the equivalent to the *VRPTW (Vehicle Routing Problem with Time Windows)*

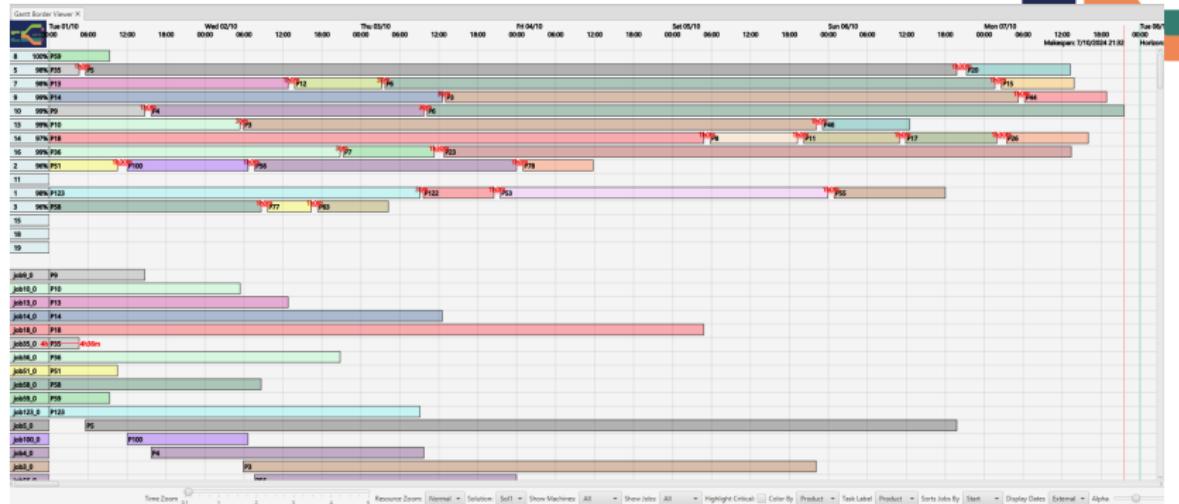
# Xmas Shopping Hint



- W. Cook. *In Pursuit of the Travelling Salesman*. Princeton University Press, 2011
- Entertaining general science presentation of the TSP and related issues



# Setup Times Constraints can be Included in Model



- Shown in Machine Gantt chart, enable display in Layout tab
- So far, only in CPO, not in CPSat model

# Related Problem: Forbidden Transitions X



- For safety reasons, it may be forbidden to change from some product to some specific other products
- Contamination risk is considered too high
- Examples
  - In food production: Is this product peanut free?
  - In food production: Directly changing from dark to white chocolate is not allowed
  - In chemical plants: Contamination may lead to explosions
- These transitions are called *forbidden*, and must be avoided
- Careful, it is easy to paint yourself into a corner!

# Outline



Sequence Dependent Setup-Time

Transportation Time

Transportation of Materials

Transportation of Resources/Personnel

Summary

# Dealing with Transportation Times

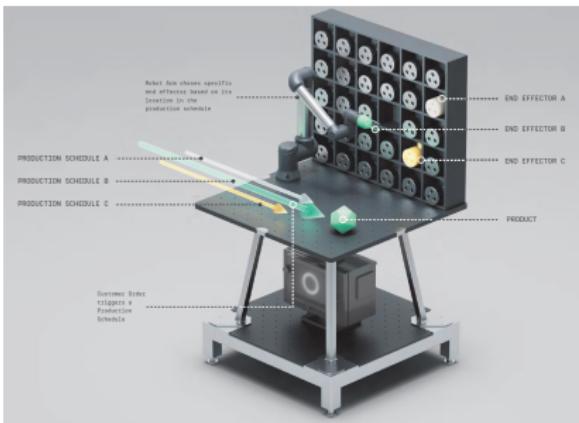


- Really two different problems
  - In one, the resources are in fixed locations, and we transport the jobs between the locations
  - In the other, the tasks are in fixed locations, and we transport the resources between them

# Transportation of Jobs

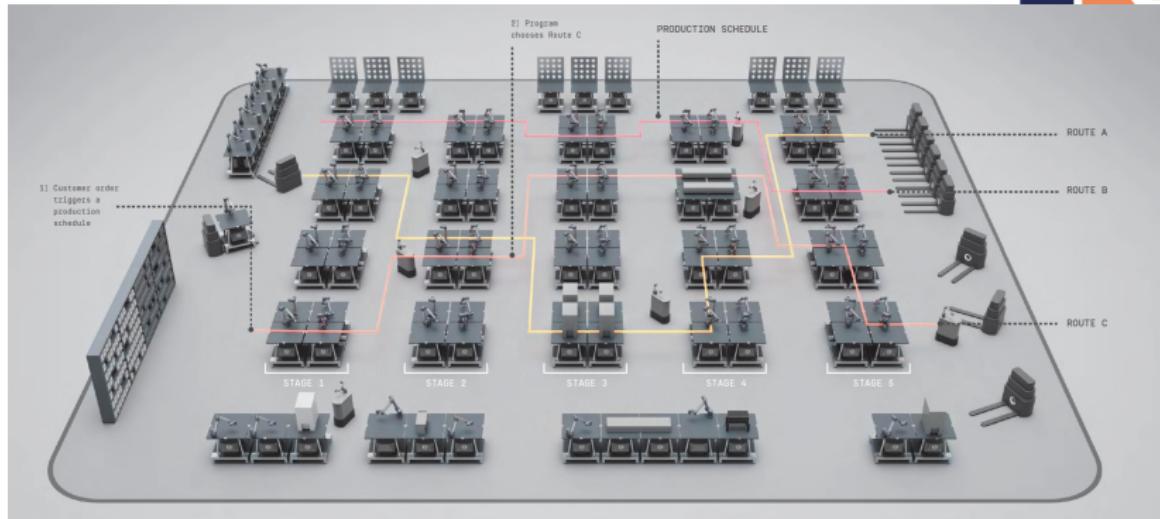


- Example from a project with J&J in Limerick
- Considering a *factory of the future* based on agile machines
- Robots that can be configured to perform many different tasks
- These robots may be inside one or more factories
- How to arrange them to minimize impact of transport on production



from J&J

# Layout of Factor in Matrix Form



- Materials are transported between stations by moving robots
- Layout of factory determines delay caused by transport

## Inclusion in Model (✓)

- Add location attribute to each resource
  - Include transport time as element in temporal constraints

## More Complex Variant X



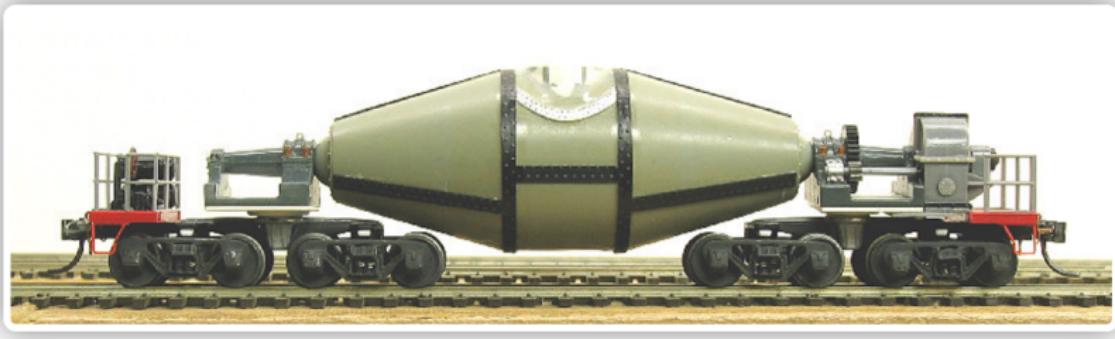
- Schedule the moving robots as well
- Assume that an empty robot travels much faster than a loaded one
- We can treat the robots as a machine choice resource for the transportation tasks

## Even More Complex Variant X



- Schedule the moving robots as well
- They move at the same speed empty and loaded
- We can bring them from the end of one transport task to the start of the next one
- This is a vehicle routing problem
- In some industries, this is the harder problem than scheduling the plant itself
  - Torpedo scheduling in steel plant: rail cars holding molten steel, quantities limited

# Torpedo Scheduling (CP 2016 Challenge)



(from ACP Website <http://cp2016.a4cp.org/program/acp-challenge/>)

# Scheduling Service Visits X



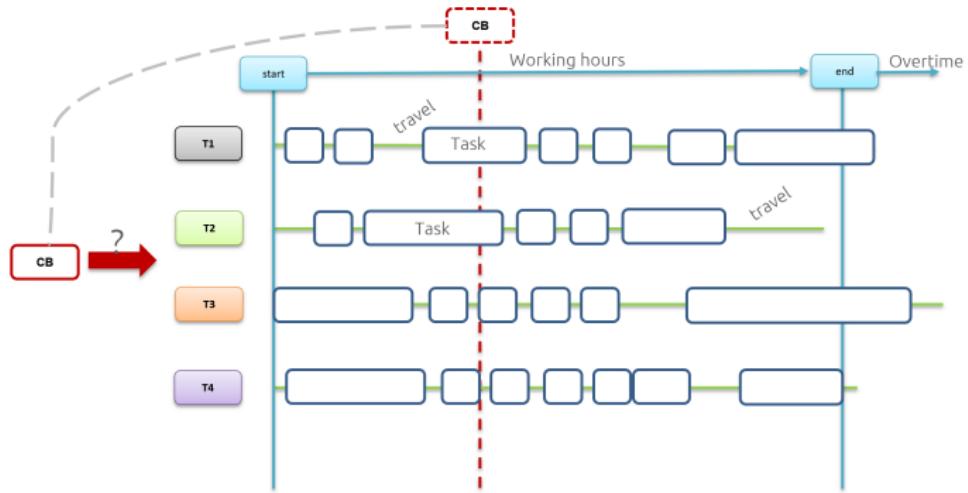
- Based on a project with UTRC-I, UTRC, OTIS
- Schedule visits to maintain equipment installed in customer premises
- Resources are the service engineers
- They have to travel between locations and perform work there
- The tasks are the maintenance operations required to keep equipment working
- Also called *Traveling Repair-person Problem*

# Planning Maintenance Visits for Service Personnel



- Include single day trips, multi-day tours
- Most of the time spent at customer locations

# Re-scheduling Problem



- How to react when a customer is trapped in an elevator
- All your engineers are on service calls
- *Who you gonna call?*

# Advertisement



- This will be described in more detail in a new course
- AI Fundamentals: Skill Development Program on Transportation Optimization
- Arriving in 2025 at this location

# Outline



Sequence Dependent Setup-Time

Transportation Time

Summary

# Summary



- We presented some more advanced topics
  - Sequence dependent setup
  - Transportation time
- Not available in every solver
- Useful concepts when dealing with specific scheduling problems
- Leading to another *Skills Development Program*