Modeling a complex production process as a State-Task-Network formulation

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OSE-seminar

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Agenda

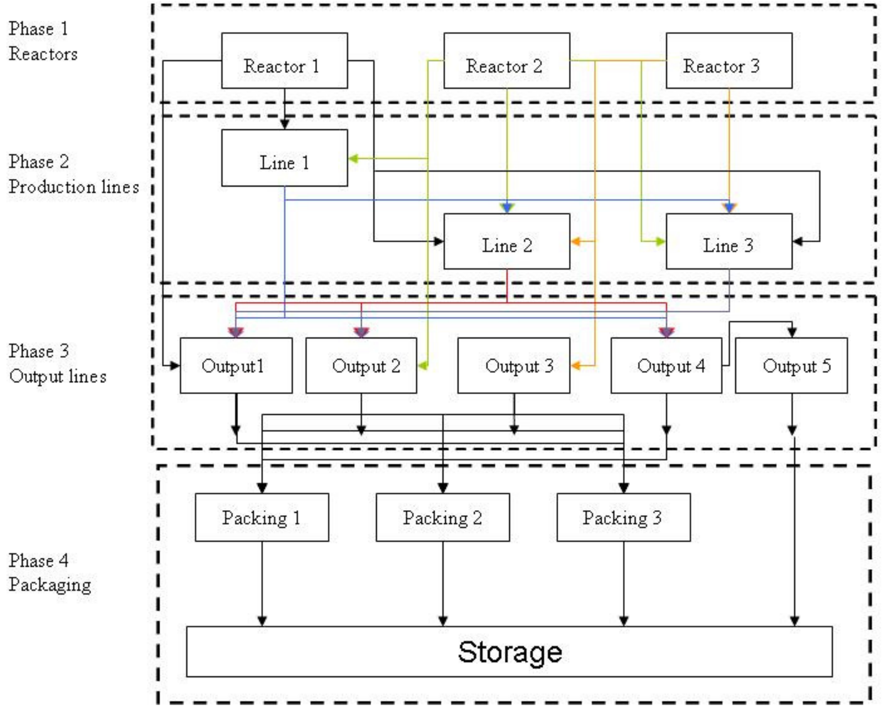
- Why is this interesting?
- The system
- Tailor made model
- STN-model
- Comparison of models
- What's next?
- The future

Why is this interesting?

- General model frameworks have substantial benefits compared to custom built models
  - Lesser modeling time
    - Large part of constraints already modeled (and tested)
  - Usable on a big variety of problems
  - Reusable on similar systems with only minor reformulations
- …But they also have drawbacks
  - Can lead to larger models
    - Slower convergence
  - Challenging to include necessary level of detail
- I want to answer the question: is it worth the extra modeling effort to create custom built models for large-scale scheduling problems?

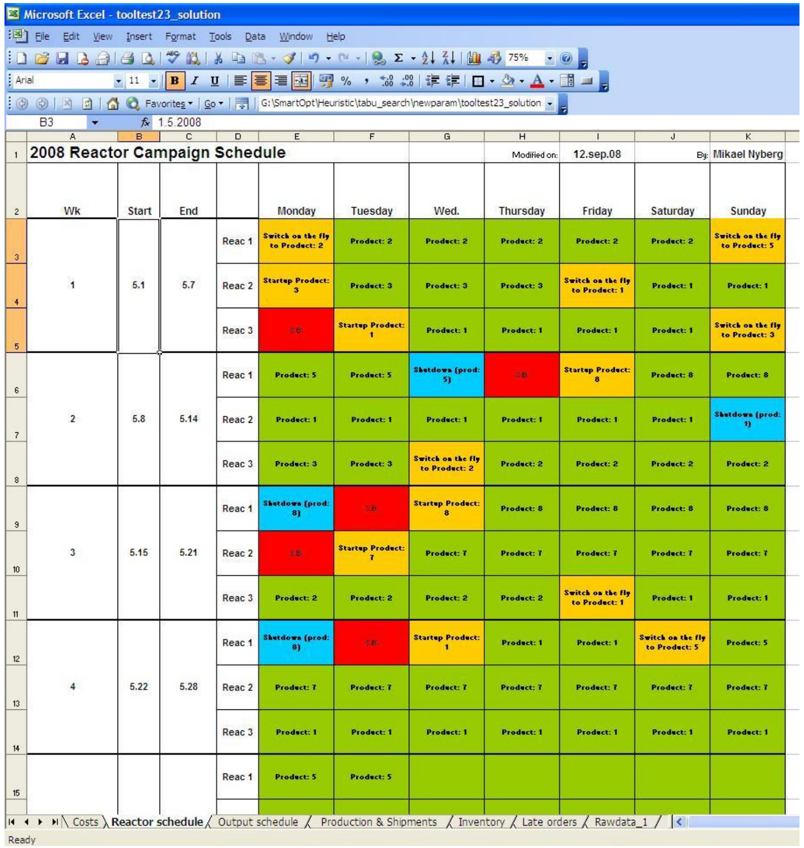
The system (1)

- Complex fine chemical plant
  - 3 product families
    - 10 final products
  - 4-phase production
    - Multiple machines in each stage
    - Dynamic machine configuration (parallel/serial)
  - Both continuous and batch processes



Production process

The system (2)



30-day production plan

- Detailed 30-day production plans
  - Daily reactor schedule
  - Includes
    - Frequency-dependant cleanup
    - Product switch cleanup
- Minimize total costs
  - Production
  - Storage
  - Lateness

Tailor made model

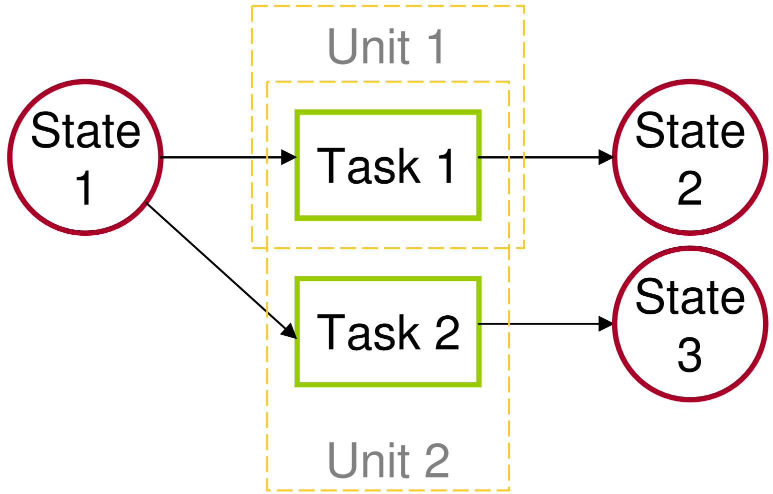
- The first mathematical model was tailor made
  - System is very complex
    - Hard to find suitable general formulation
    - Concerns about solution times
  - Overall picture of the system was vague
    - Uncertain what level of detail was needed to produce feasible reactor schedules

Tailor made model

- Large-scale, discrete time model
  - 4184 variables
    - Of which 2637 are binary variables
  - 20 types of constraints
    - ~7000 constraints
- Solution times (CPlex 10.0, 2.4GHz Core 2 Duo)
  - 15-120 hours

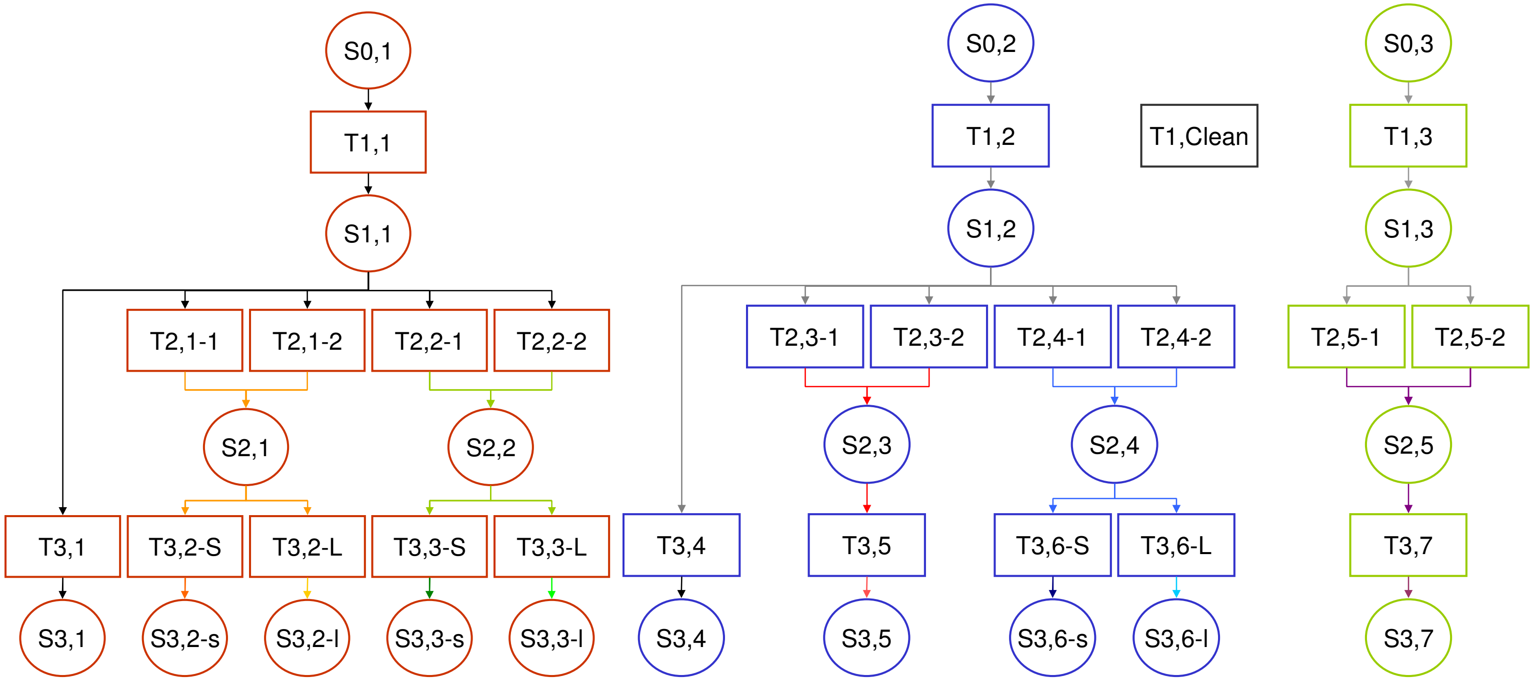
State Task Network (STN)

- General framework for production scheduling
  - By E.Kondili, C.C.Pantelides and R.W.H.Sargent
- Raw materials, intermediates and final products are represented as *states*
- Operations are represented as *tasks*
  - *Tasks* are carried out by *units*
  - *Tasks* transform one material from one *state* to another



"A STN presents the recipe for production, NOT the underlying system"

STN



- 22 States
- 25 Tasks
- 11 Units

→

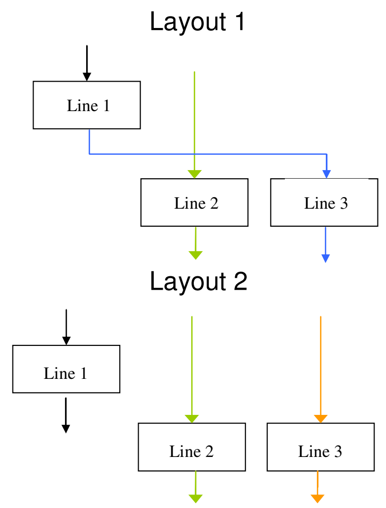
- 4800 Variables
  - Of which 1530 binary
- 6480 Constraints

Modeling the system as a STN

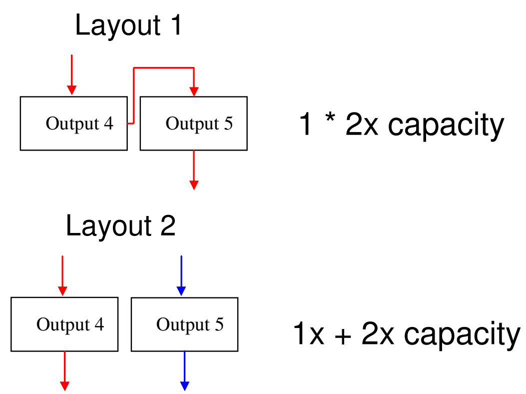
- STN-formulation works well
  - Represents the production more realistically
  - Smaller number of binary variables than original formulation
  - Lesser modeling effort
    - No need to invent the wheel yet again
    - But, some system restrictions posed challenges

Modeling challenges (1)

- How to include dynamic machine layouts in STN?
  - For some products machines are ran in series
  - For other products they can be ran i parallel
  - Affects production capacity and speed
- Possible to implement introducing only one new (continuous) variables
  - Smart usage of *utilities*
    - Originally intended for modeling the requirements of e.g. steam, cooling water or manpower
    - Now used in combination with capacity limitations to guide *unit* usage



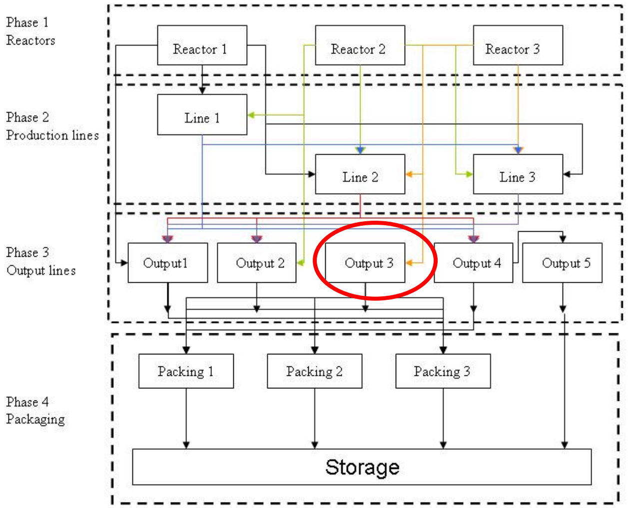
Production phase 2

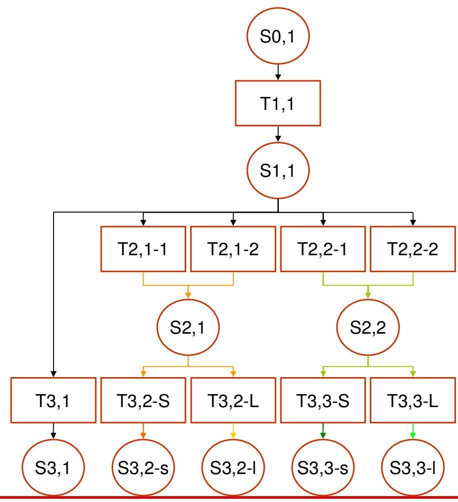


Production phase 3

Modeling challenges (2)

- Restriction: If product *S1-1* is produced on Reactor 3, then Task *T3,1* must be executed on OP3
- Challenge: In STN units are not explicitly modeled
  - Task *T3,1* can normally be ran on 4 units but for this special case it can only run on a specific unit
- Solution: Use another *utility*-formulation to link batches coming from Reactor 3 to OP3
  - Again, only one new continuous variable needed





STN-model

- Large-scale, discrete time model
  - 4800 variables
    - Of which 1530 are binary variables
  - 8 types of constraints
    - 6480 constraints
- Solution times
  - Unknown

Comparison of models (1)

	Tailor made model	STN-model
Variables	4184	4800
Binary Variables	2637	1530
Constraints	7000	6480
Solution times	15-120 hours	Unknown

Comparison of models (2)

	Tailor made model	STN-model
Pros	▪ Designed for this system ▪ Lends itself well for hybridization ▪ Reactor schedules directly from solution variables ▪ Good quality solutions	▪ General formulation = better reusability ▪ Lesser modeling effort ▪ Solves some difficult modeling issues elegantly
Cons	▪ Slow convergence ▪ Large modeling effort ▪ Need to extend optimization beyond optimization period ▪ Sensitive to parameter changes	▪ Reactor schedules have to be constructed with post processing
Question marks		▪ Solution speed/quality ▪ Possibilities for hybridization ▪ Parameter sensitivity

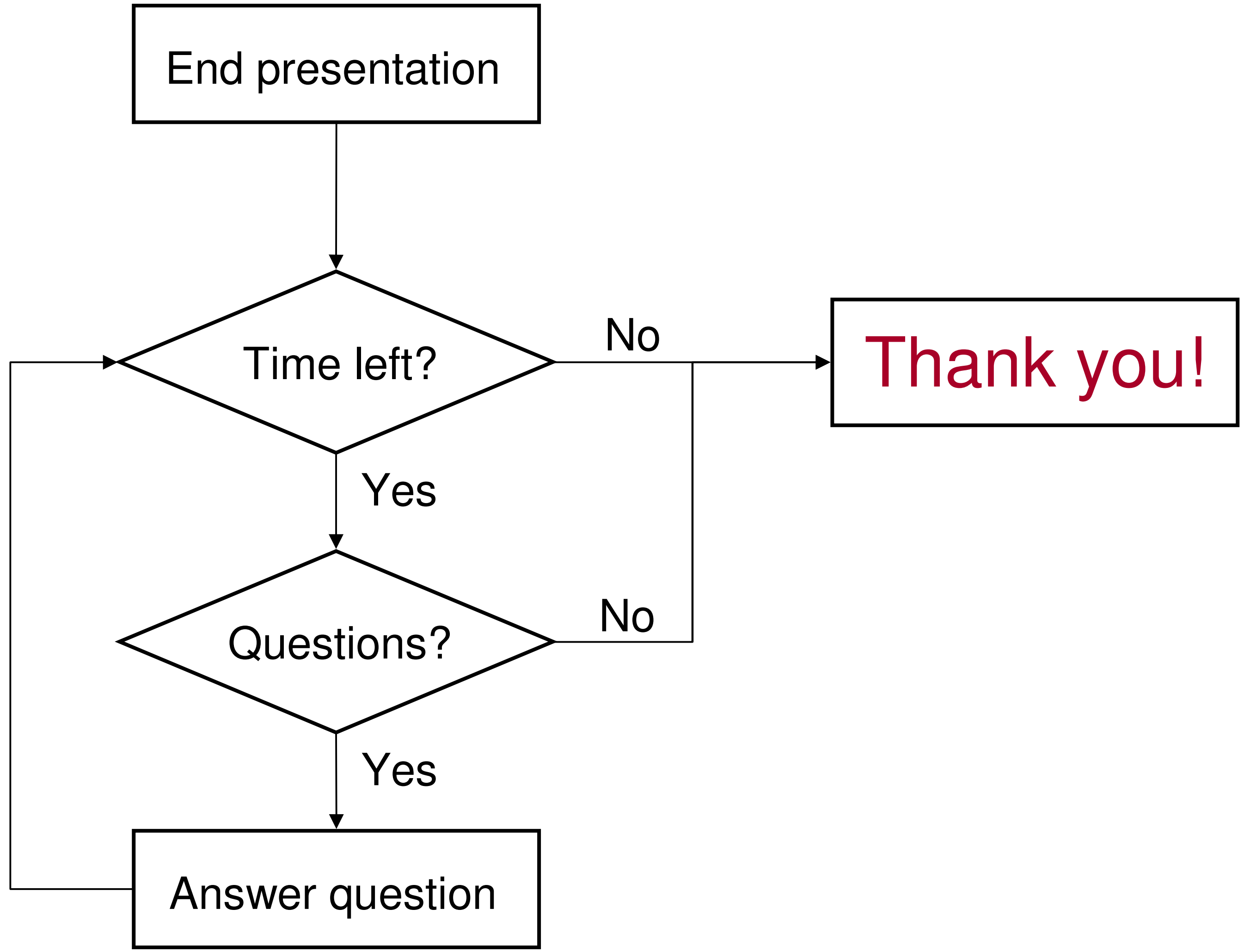
Åbo Akademi

What’s next?

- Implement STN-model in existing optimization framework
  - Test for correctness
- Synchronize model parameters
  - Test behavior
- Run large number of test cases to determine
  - Solution speed
  - Solution quality
  - Solution likeness
- Answer the question; is it worthwhile to create tailor made solutions for large-scale production planning problems?
  - Study the literature to see if other similar studies have been done and compare their results with mine

The future

- Investigate how RTN-formulations (Resource Task Network) work for this case
  - Compared to custom made model and STN-model
- Test other (?) general formulations
- Do similar studies on other large-scale cases


End presentation
Time left?
No
Thank you!
Yes
Questions?
No
Yes
Answer question