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Scope for industrial applications of production scheduling models and solution methods

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Review

Scope for industrial applications of production scheduling models and solution methods

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We dedicate this paper to Prof. Dr. Peter Bongers, who inspired us all and shared his valuable experiences in the border of academia and industry and cannot be with us today to see the final result of this joint

ABSTRACT

This paper gives a review on existing scheduling methodologies developed for process industries. Above all, the aim of the paper is to focus on the industrial aspects of scheduling and discuss the main characteristics, including strengths and weaknesses of the presented approaches. It is claimed that optimization tools of today can effectively support the plant level production. However there is still clear potential for improvements, especially in transferring academic results into industry. For instance, usability, interfacing and integration are some aspects discussed in the paper. After the introduction and problem classification, the paper discusses some lessons learned from industry, provides an overview of models and methods and concludes with general guidelines and examples on the modeling and solution of industrial problems.

Acknowlegdements
International author team


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Review

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solution metho

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Motivation


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- Bridge the gap between theory and practice in the scheduling area by providing
  - for academic researchers some insights into the industrial aspects of solving real scheduling problems at hand and deploying theoretical models
  - for industrial practitioners an overview and tutorial to some of the available solution methods and their main characteristics and limitations
- Target not to exhaust the article with equations but refer to other scientific papers and classify methods highlighting their main idea (strengths, limitations)

Content


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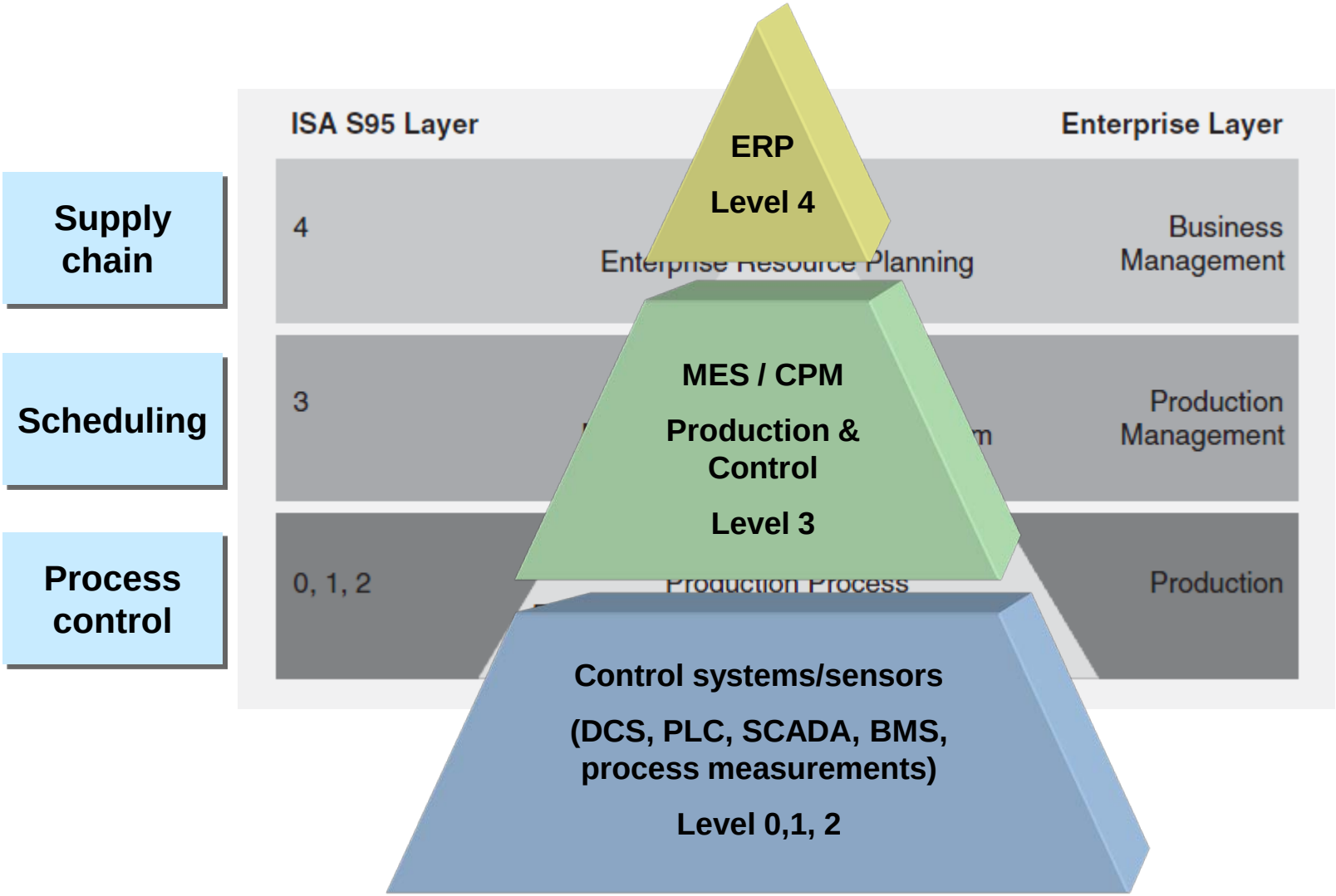
- Classification of scheduling problems
- Summary of industrial requirements for scheduling
- Review of existing scheduling optimization models and methods, including heuristics, metaheuristics and constraint programming
- Lessons learned and success stories on real industrial scheduling implementations
- General guidelines and examples on the modeling and solution of industrial problems
- Future challenges for industry in the area of planning and scheduling

Where is scheduling “located”
Traditional system hierarchy (Automation pyramid)



Production Management @ Industry
Functionalities

ERP

(mainly supporting business functions, strategy and targets)

Production cost

Equipment health & condition

Product quality

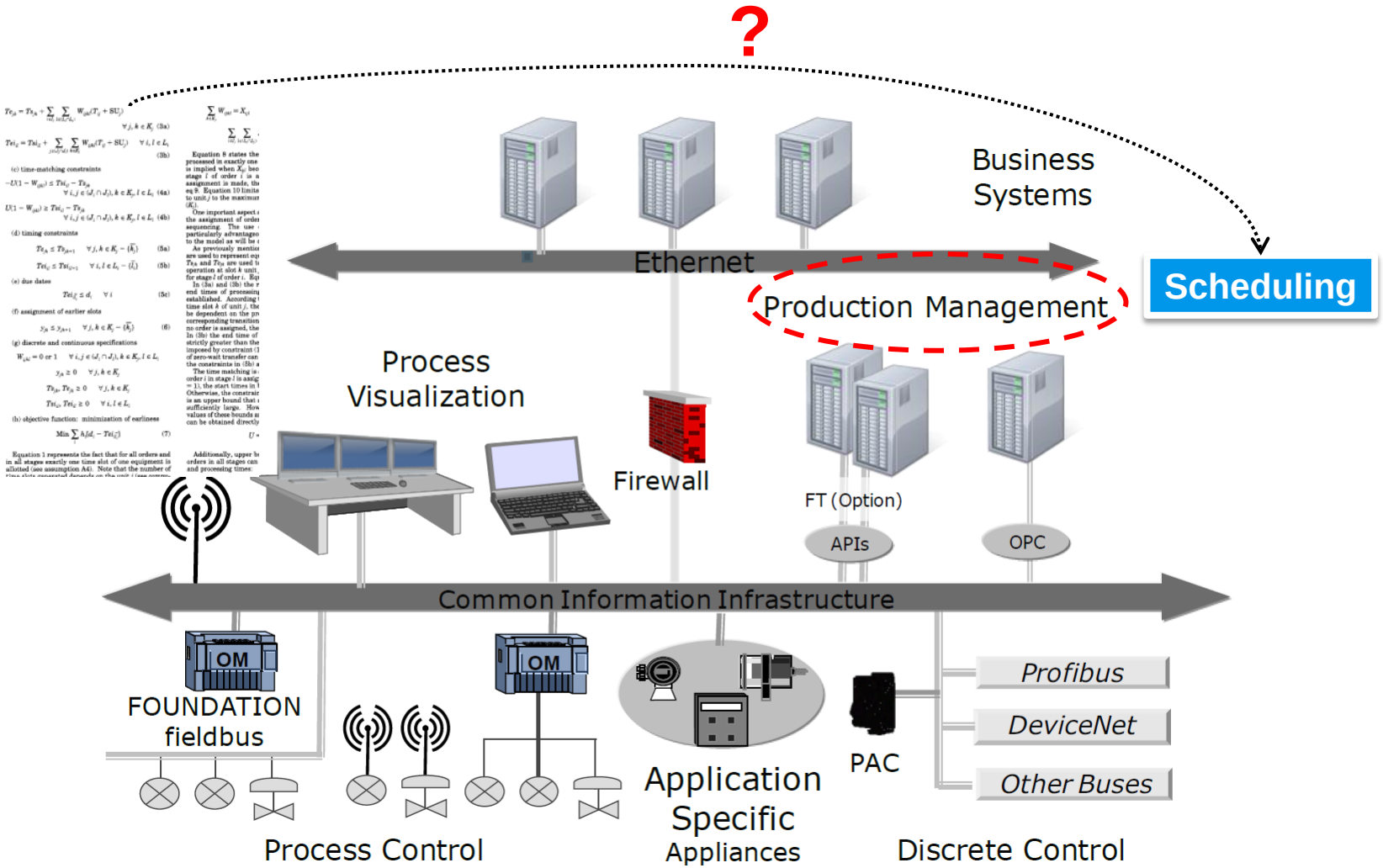
Energy efficiency

Inventory, safety, …

Control

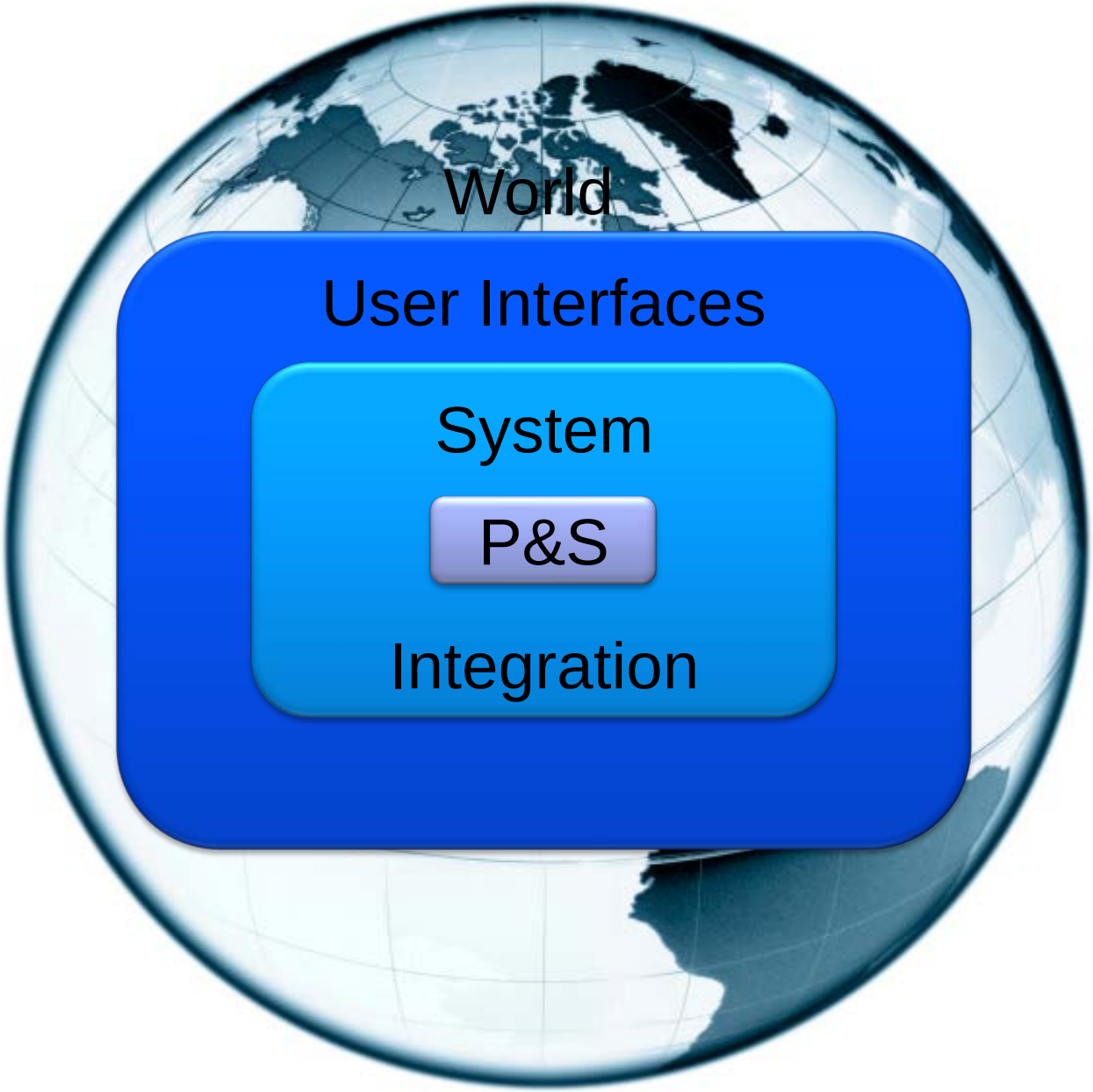
(execution layer, data collection, short-term decisions)

Where is Scheduling Located?
Part of a Complex SW & HW System



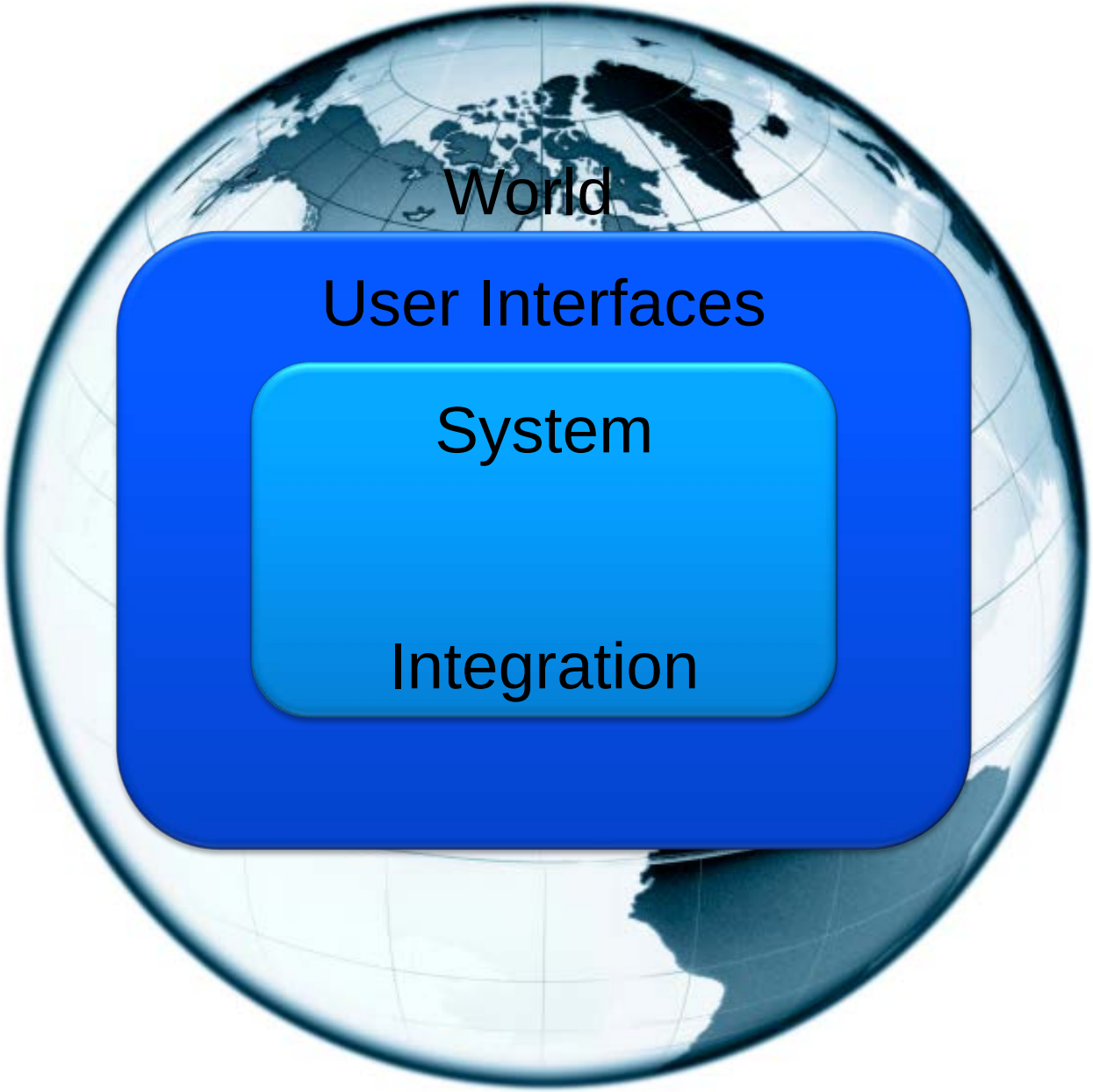
Source: ARC (2010)

Planning and Scheduling – the Big Picture

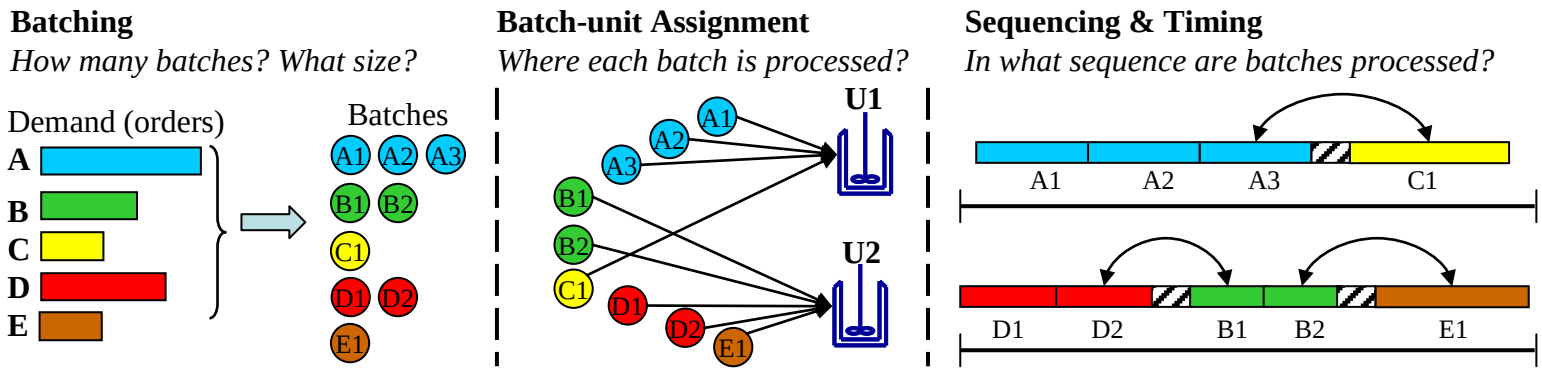


Planning and Scheduling – how academics like to think

Planning and Scheduling – industrial view



Classification of scheduling problems
Main scheduling decisions



based on

- Production facility data; e.g. processing unit and storage vessel capacities, availability of utilities, manpower
- Detailed production recipes; e.g. processing times/rates, utility and material requirements, mixing rules
- Equipment unit suitability to carry out specific tasks
- Production costs; e.g. raw materials, utilities, cleaning
- Production targets or orders with due dates

Classification of scheduling problems
Various aspects

- Market environment
  - Commodity/specialty products, make-to-order or –stock
- Planning functions
  - Procurement, distribution, push / pull driven production
- Production facility
  - Batch / continuous process

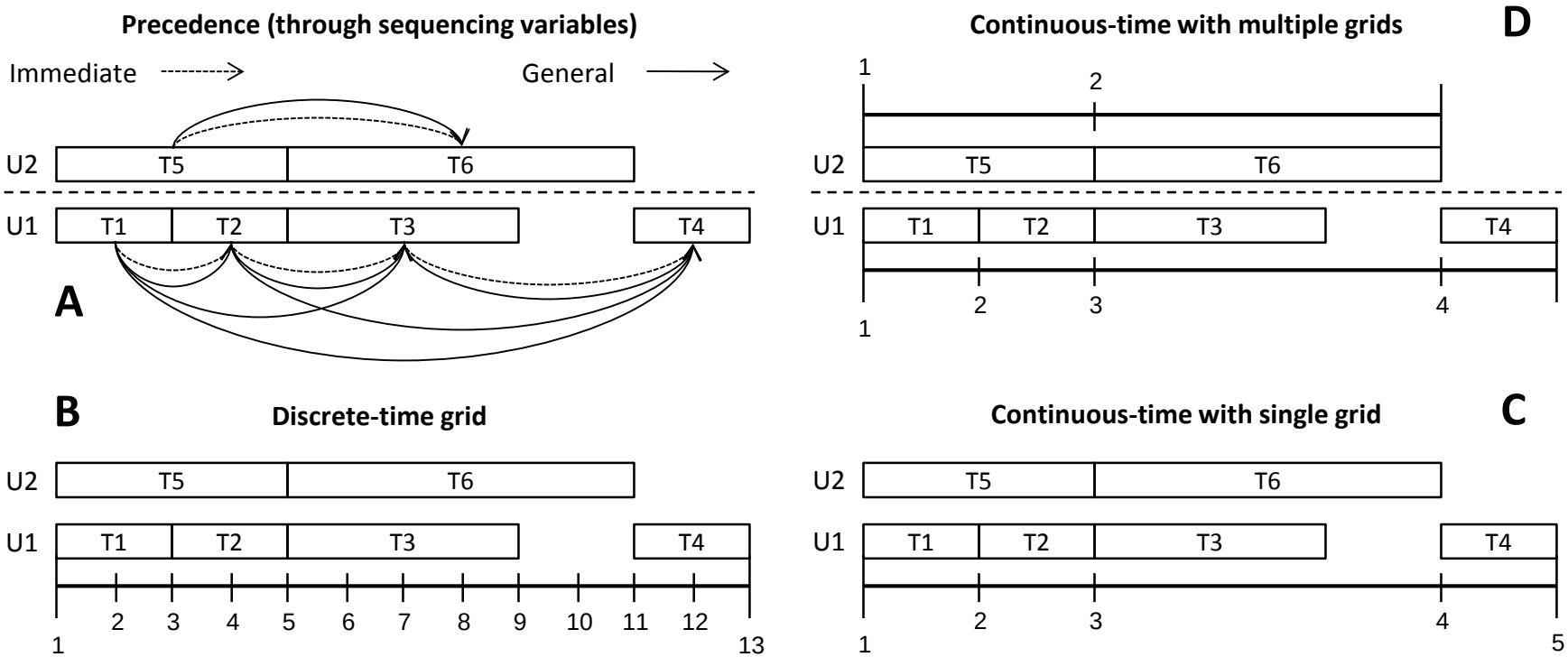
Requirements for scheduling
When integrated to an industrial SW-environment




- Solution must be robust, scalable and stable. In case optimization fails, a feasible schedule must be reported
- Every schedule is a re-schedule. In case of sudden disturbances, generate new adjusted solution efficiently
- Solution must be maintainable, both updating models and keeping up with major software updates in the plant
- Easy integration and connection to other applications, e.g. ERP-software or tools that calculate and predict total costs
- Cost to implement solution should ensure a good ROI – affected by related software license and development costs

Review of existing scheduling optimization models
Modeling of time

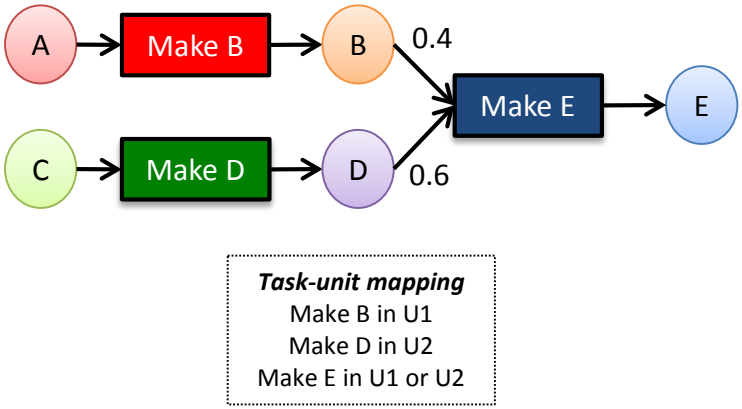
- One of the most important decisions in scheduling is how to represent the time



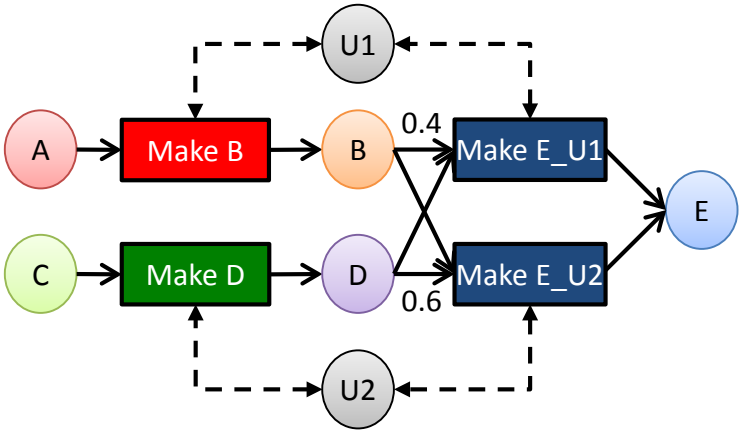
Review of existing scheduling optimization models

- Sequential processes contains successive production stages and requires modeling of stages, units and routing
- Network representation relies on the modeling of materials, tasks, units and utilities
  - Most typical ones STN and RTN

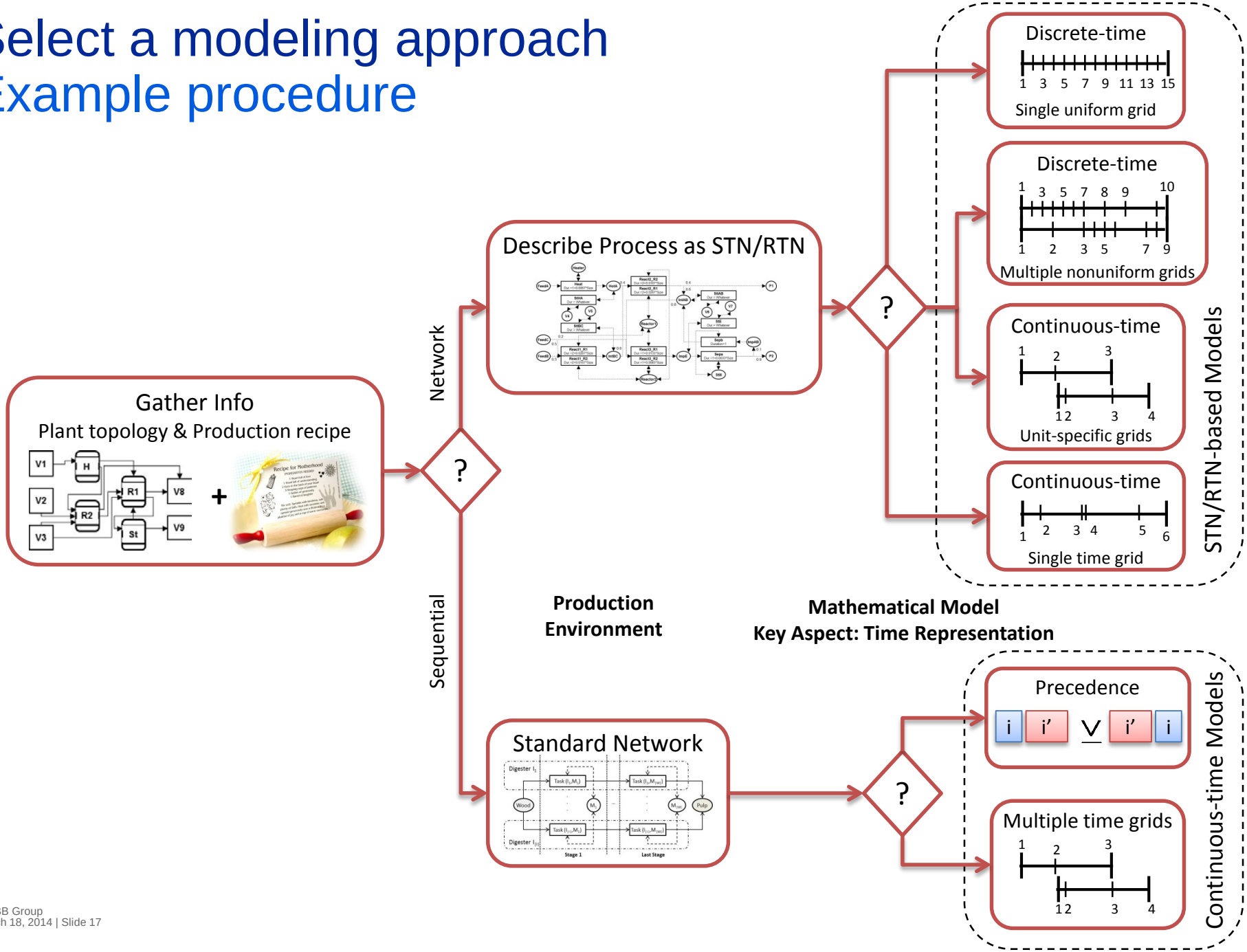
State-Task Network (STN)



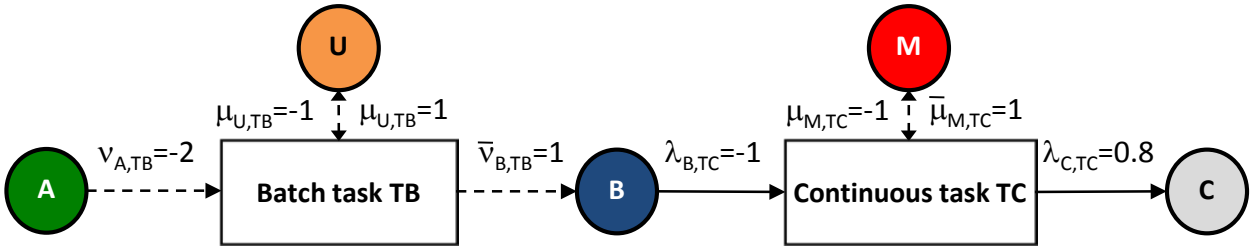
Resource-Task Network (RTN)



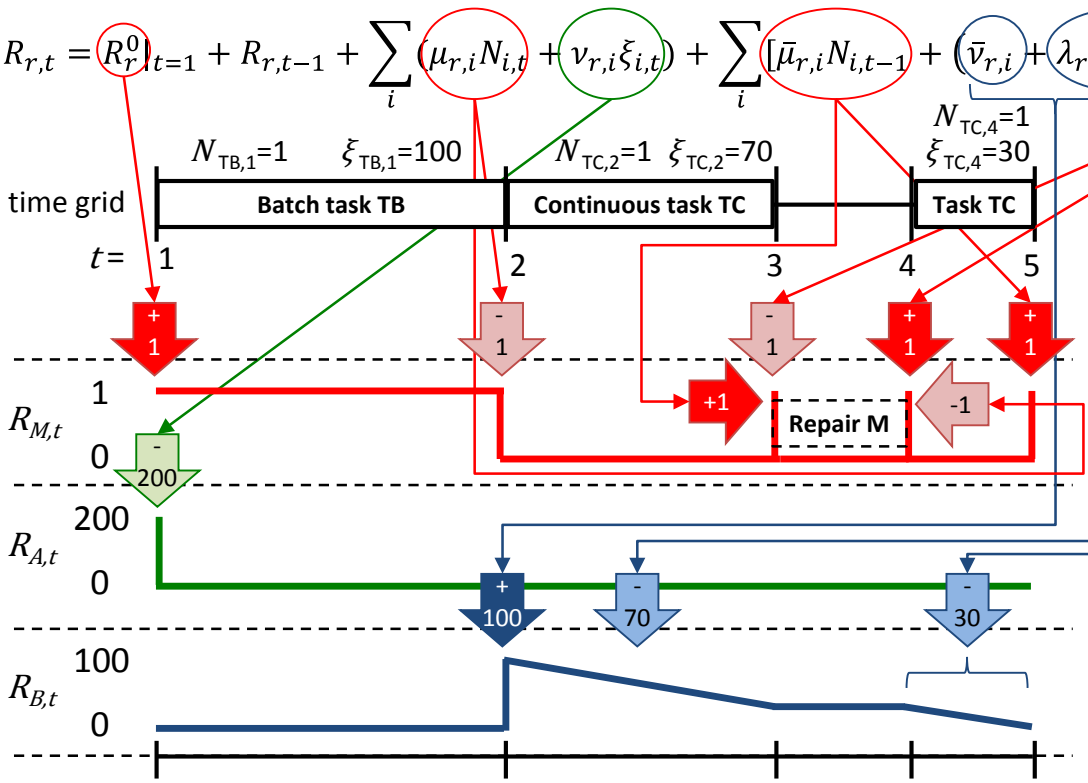
Select a modeling approach
Example procedure



Basic RTN-model explained graphically



$$R_{r,t} = R_r^0|_{t=1} + R_{r,t-1} + \sum_i (\mu_{r,i} N_{i,t} + \nu_{r,i}\xi_{i,t}) + \sum_i [\bar{\mu}_{r,i} N_{i,t-1} + (\bar{\nu}_{r,i} + \lambda_{r,i})\xi_{i,t-1}] + \pi_{r,t} \quad \forall r, t$$



Assumption for illustrative purposes: Instance of a task lasts a single slot

Indices

r - resources
i - tasks
t - time points

Variables

$R_{r,t}$ - excess resource
$N_{i,t}$ - assignment (binary)
$\xi_{i,t}$ - extent

Variables or parameters

R_r^0 - initial availability

Structural parameters

	related to		interaction		event location		
	$N_{i,t}$	$\xi_{i,t}$	discrete	continuous	start	end	through
$\mu_{r,t}$	x		x		x		
$\bar{\mu}_{r,t}$	x		x			x	
$\nu_{r,t}$		x	x		x		
$\bar{\nu}_{r,t}$		x	x			x	
$\lambda_{r,t}$		x		x			x

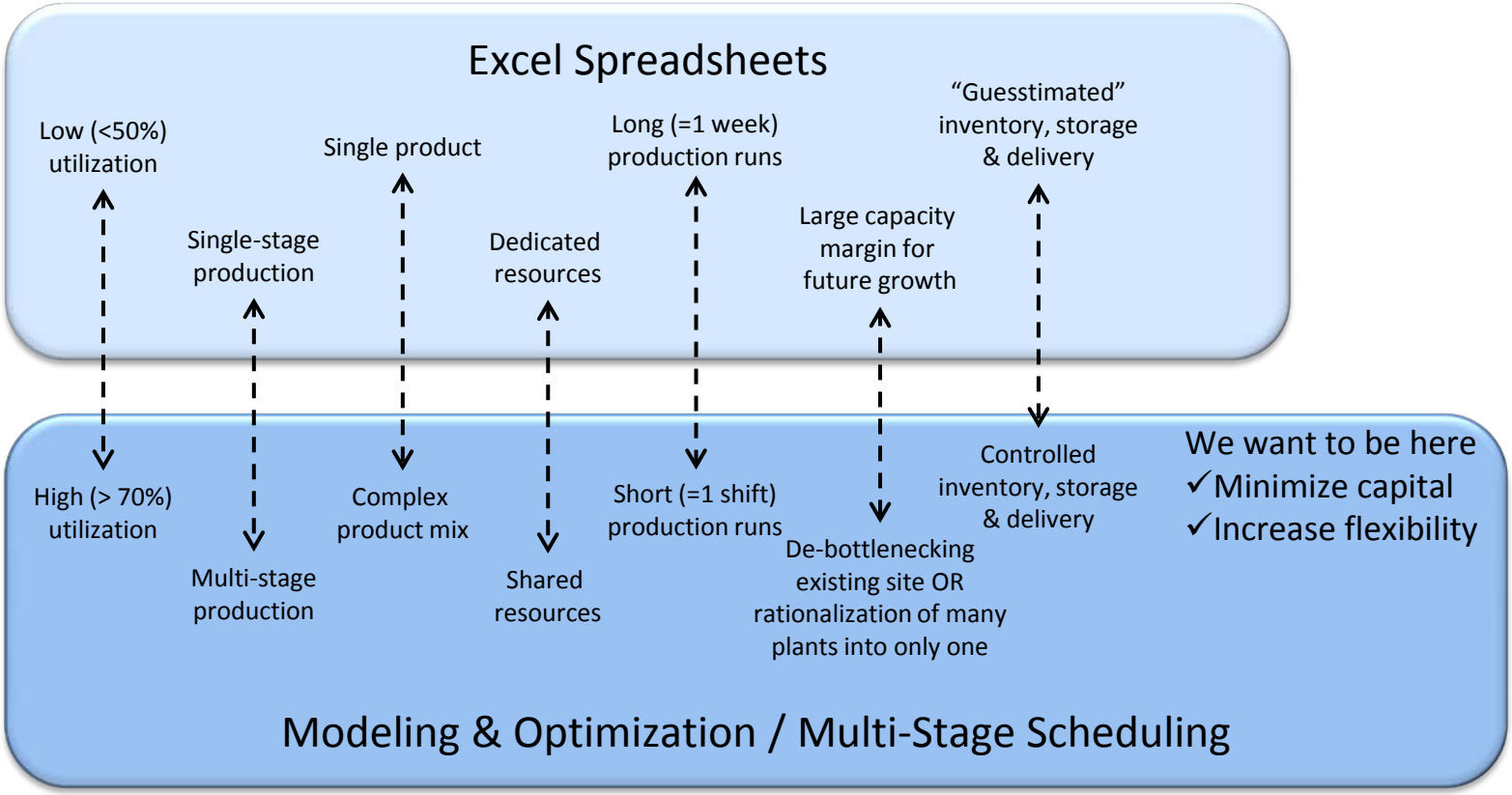
Other parameters

$\pi_{r,t}$ - external interaction

Review of existing scheduling optimization models

- Discrete-time models
  - Most typically STN or RTN
- Continuous-time models
  - Precedence-based
  - Time-grids (single or multiple)
  - RTN / STN
- Constraint programming models
- Nonlinear scheduling models

Scheduling methods
Do you need optimization in first place?



Scheduling methods

Environment	**Sequential**			**Network**
	$k = 1, \lvert J_k \rvert = 1$	$k = 1, \lvert J_k \rvert > 1$		
	$k > 1, \lvert J_k \rvert = 1$	$k > 1, \lvert J_k \rvert > 1$		
Decisions	S/T	A, S/T	B, A, S/T	B, A, T
Methods				
Heuristics	√			
Meta-heuristics	√	√		
TA	√	√		
CP	√	√		
Math Programming	√	√	√	√
Hybrid		√		√

Types of mathematical programming models for different classes of problems

				Processing characteristics and constraints										
				Changeover times	Changeover costs	Storage restrictions	Shared utilities	Intermediate due dates	Variable batch sizes	Variable processing times	Holding & utitlity costs	Time-varying utitlity costs	…	…
Sequential	Precedence-based	Immediate		√	√	√		√	√	√				
		Global		√		√		√	√	√				
	Time-grid-based	Discrete	Common			√	√	√	√		√	√		
		Continuous	Unit-specific	√	√			√	√	√				
Network	Time-grid-based	Discrete	Common	√	√	√	√	√	√		√	√		
			Specific	√		√		√	√		√	√		
		Continuous	Common	√	√	√	√	√	√	√				
			Unit-specific	√	√	√		√	√	√				

Success stories on real industrial scheduling implementations

A number of successful examples

- Example from the dairy industry (Unilever) 30%
- Scheduling optimization in the petrochemical industry

ult to prove the impact of scheduling optimization

Defining KPIs for estimating benefits not trivial

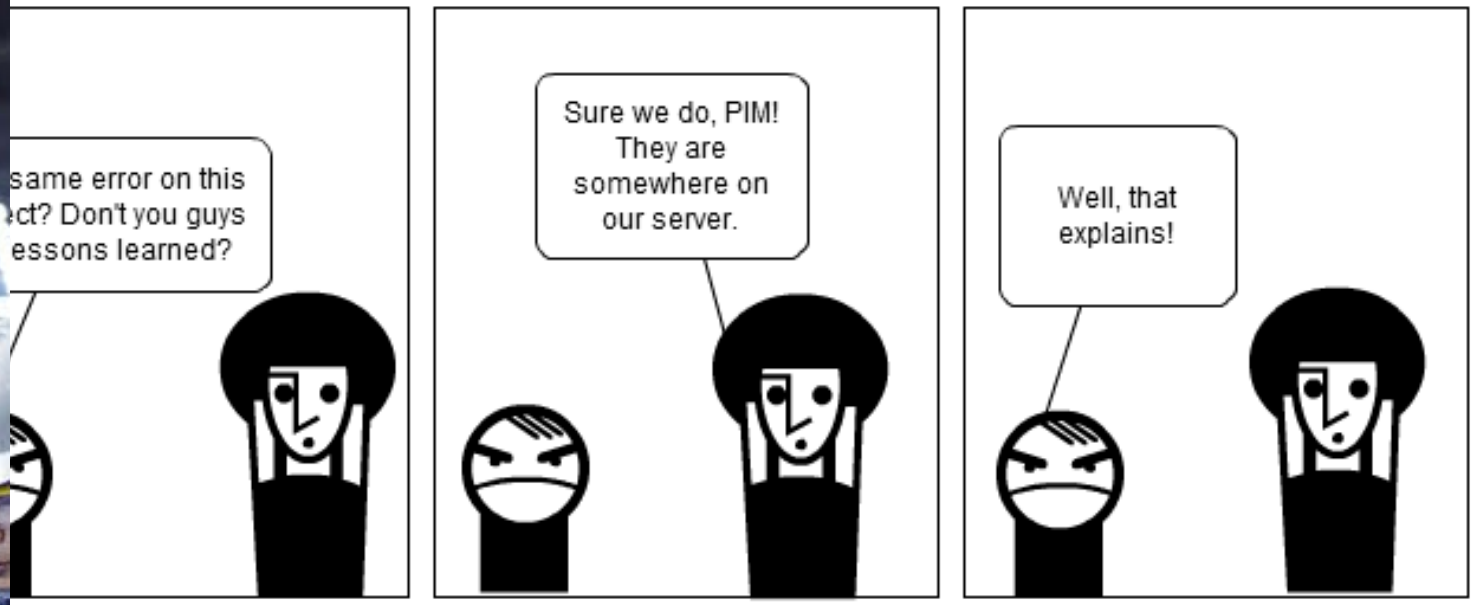
Many companies unwilling to reveal benefits

- Scheduling in an integrated chemical complex (The Dow Chemical Company) $
- Medium-term scheduling of large-scale chemical plants (ATOFINA Chemicals, BASF) ?

Lessons learned
Some general comments

- An optimal schedule and production plan can only bring true benefits when the production is aligned to it
- Often only partially following an optimized schedule is not sufficient and may even lead to worse solutions than before
- It is crucial that the planning system is able to capture the major decisions in a correct way and the user expectations and needs are fully aligned with the system and its user interfaces

Lessons learned
Elements of successful implementation



- Assume the scheduler will adjust the schedule. Do not try to model all scheduling contingencies!
- Focus on the needs of the scheduler, who must feel that his job is enhanced and simplified with the advanced scheduling technology. The scheduling model or algorithm is only a part of the solution

Lessons learned
Elements of successful implementation

- Quick proof-of-concept study: Expected value, ability to solve the problem, availability of data, how to integrate the advanced solution
- Stakeholder alignment critical: Production scheduler, his management, and the aligned groups need to all agree on the need and value of the solution
- A generic modeling approach is preferred: Easy to instantiate new model elements, add scheduling heuristics in the model, separate data from underlying equations or algorithm (fully parameterized model)
- Assume the scheduler will adjust the schedule. Do not try to model all scheduling contingencies!
- Focus on the needs of the scheduler, who must feel that his job is enhanced and simplified with the advanced scheduling technology. The scheduling model or algorithm is only a part of the solution

General guidelines on the modeling and solution of industrial problems

- A true production management system comprises scheduling as a natural part of a well-orchestrated environment, which raises many challenges on how to interface and compromise between various – potentially competing – optimization functions.
- Industry provides enough real-life problems to the research community and helps evaluating the results in order to guideline the research to look for the right KPIs
- Academia values the importance of practical applicability of methods as to ensure fast solution of large and complicated problems, not necessarily to optimality
- Various research fields and communities join in projects to merge methodologies where certain strengths can lend themselves to collaborative solutions
- How to efficiently bring the various disciplines together to raise the state-of-the-art to the next level is a key question

Emerging and future challenges for industry

- How to deal with energy (energy efficient, flexible, agile and adaptable)
- Electricity pricing / immediate impact on scheduling and potential new opportunities
- Raw-material pricing and availability
- Regulations on emissions (e.g. CO_2, NO_X, SO_2) novel component
- Globalization – increased the transportation costs and multi-site planning
- How to efficiently use ever increasing data and knowledge
- Rapid market changes calls for more flexible processes and the design of which may need to be adapted on-the-fly
- How to measure “goodness” of a solution and represent costs and benefits in a generic way (KPIs)

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