Optimization in SAP Supply Chain Management

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THE BEST-RUN BUSINESSES RUN SAP

Agenda

Optimization in SAP SCM

Acceptance of Optimization

Summary

Introduction: Supply Chain Management

Supply Chain Management: Set of approaches utilized

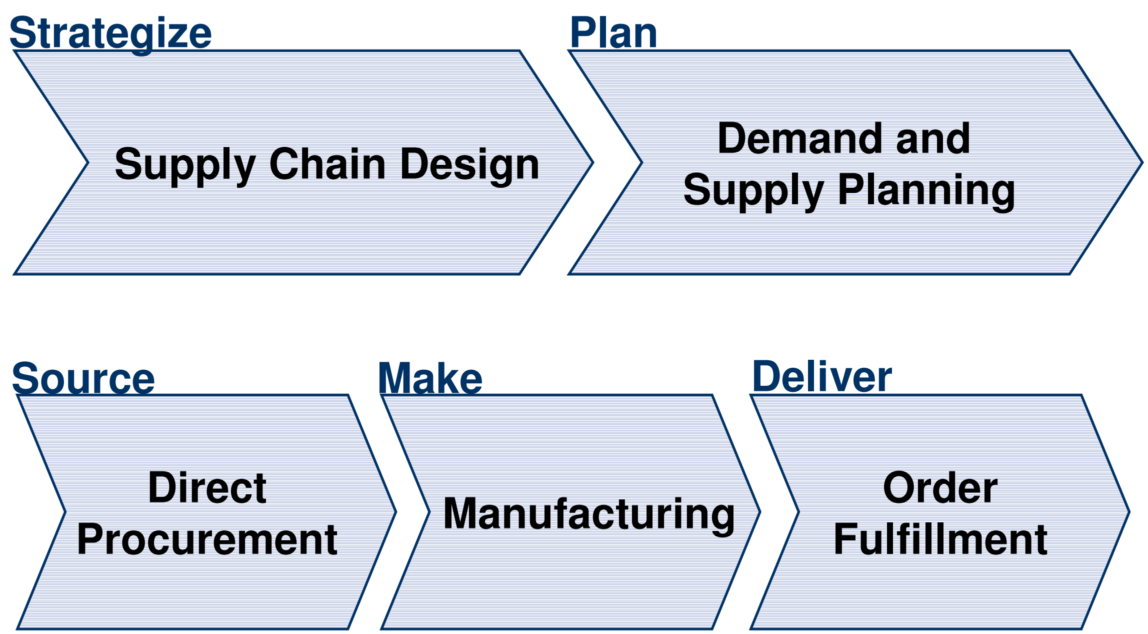
- to integrate suppliers, manufactures, warehouses and stores
- so that merchandise is produced and distributed at right
  - quantity
  - locations
  - time
- in order to **minimize cost** while satisfying service level requirements

[Simchi-Levi et al 2000]

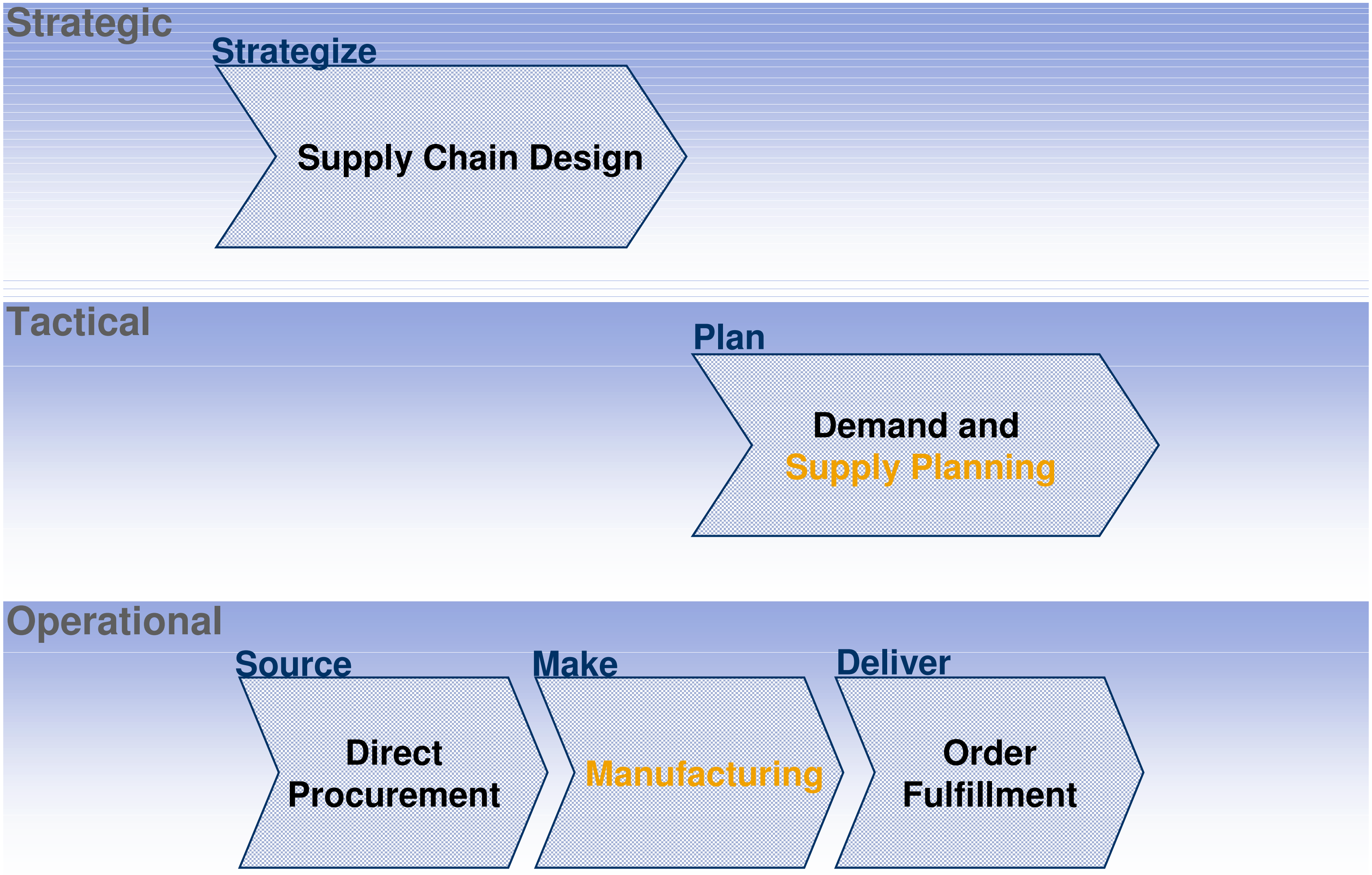
Prerequisite: Integrated Supply Chain Model

Customers DCs Plants Supplier

Supply Chain Management – mySAP SCM



mySAP SCM: Planning Levels



Challenge: Maximize the application of Optimization in SCM

Do´s

- Model Planning Problems as optimization problems
- Use the best optimization algorithms
- Respect the given run time for solution

Don´t do´s

- Restrict the modeling to optimal solvable instances
  - Size
  - Constraints
- Restrict your optimization algorithms to exact approaches neglecting
  - Iterated Local Search
  - Evolutionary Algorithms etc.

Our Goal

Leverage optimization algorithms by

- Aggregation
- Decomposition

for solving the Planning and Scheduling problems in SCM

Optimization - Expectation by our customer

☺ **Optimal Solution ?** ☹

☺ **At most 5% above Optimum ?** ☹

😐 **Best-of-Breed = Efficiency → Acceptance !**

- Depending on problem complexity (model, size)
- Given run time

Efficiency

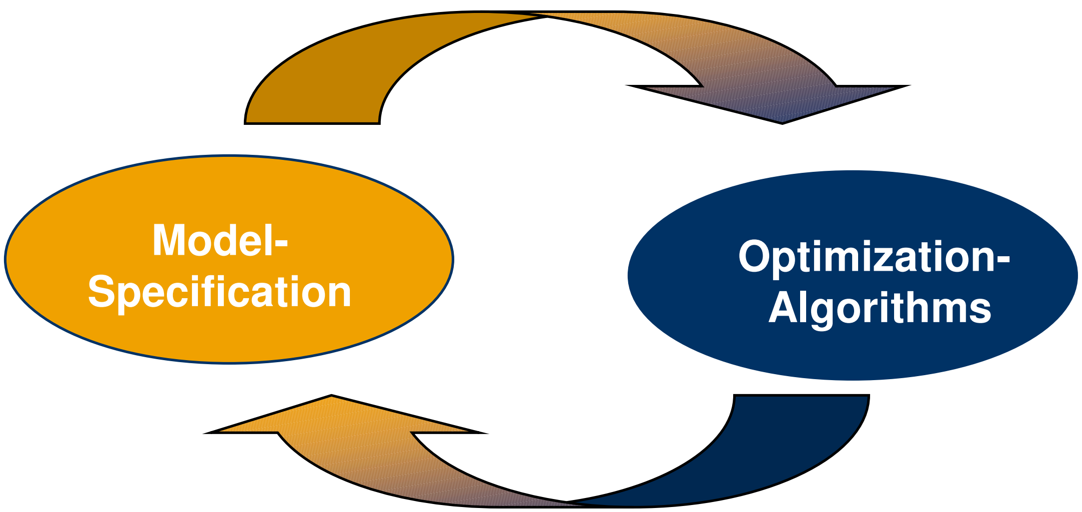
- **Scalability**
  - Decomposition = quasi linear
  - Toolbox: alternative algorithms
  - Parallelization
- **Return On Investment (ROI)**
  - Solution Quality
  - Total Cost of Ownership (Licenses, Maintenance, Administration, Handling)

Problem versus Algorithms

OR-Researcher: accepts Problems, which solves his algorithm optimally

OR-developer: accepts Problems, which solves his algorithm efficiently

OR-user: accepts algorithms, which solves his problem effectively



Optimizer - Expectation by our customer

Idealist

- Searching for the global Optimum

Realist

- Improving the first feasible solution until Time Out

Sisyphus

- Knows, that the problem has changed during run time

Pragmatic

- Solves unsolvable problems

Challenge: Mastering the planning complexity of SCM

Hierarchical planning

- **Global optimization using aggregation (Supply Network Planning)**
- **Feasible plans by local optimization (Detailed Scheduling)**
- **Integration by rolling planning schema**

→ Modeling is crucial !!

Hierarchical Planning

Supply Network Planning (SNP)

- Mid term horizon
- Time in buckets (day, week,..)

- Global optimization

- Maximize profit
- Decide
  - Where to produce
  - How much to produce
  - How much to deliver
  - How much capacities

- Linear optimization (MILP)

Detailed Scheduling (DS)

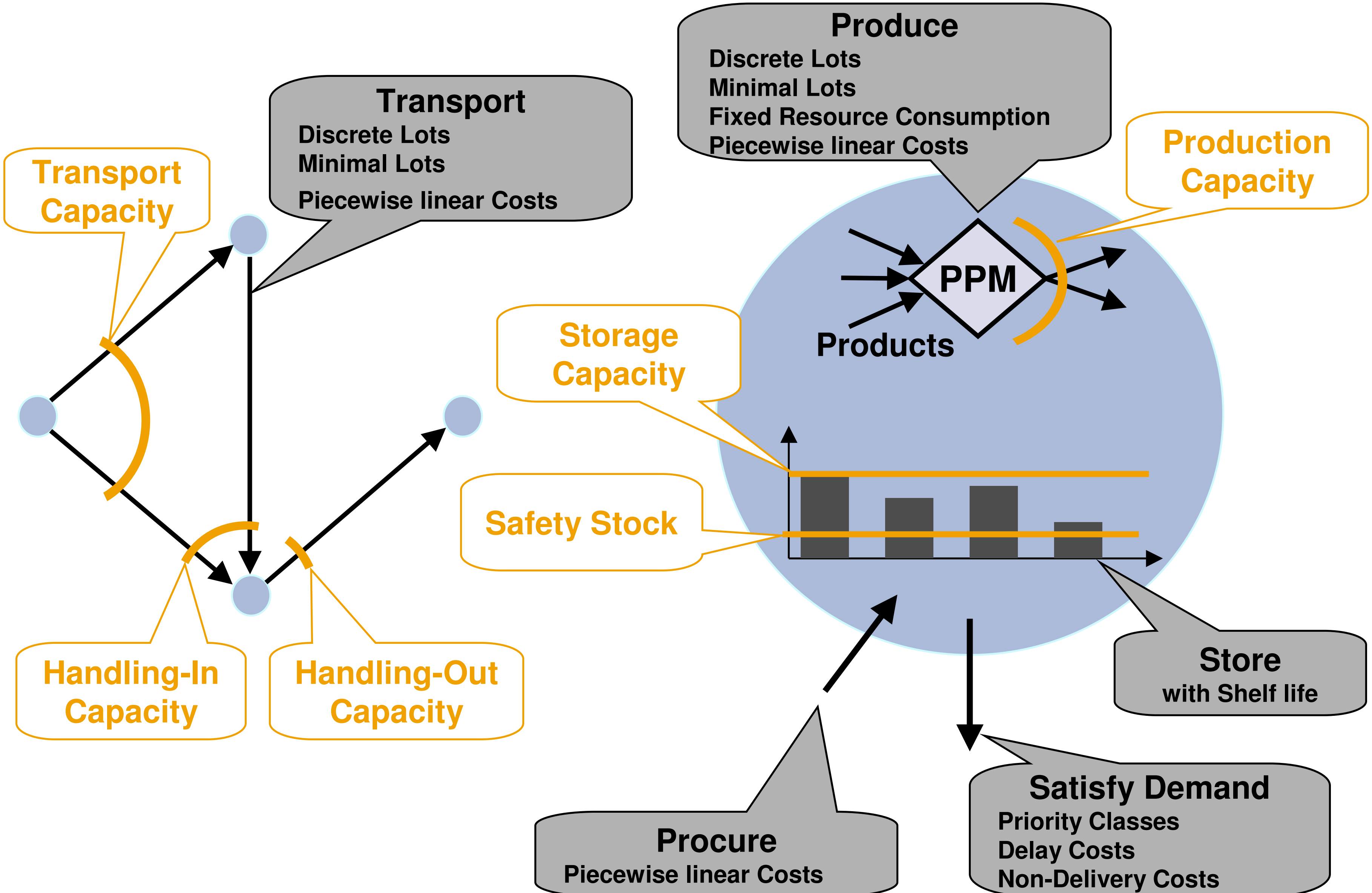
- Short term horizon
- Time in seconds

- Local optimization

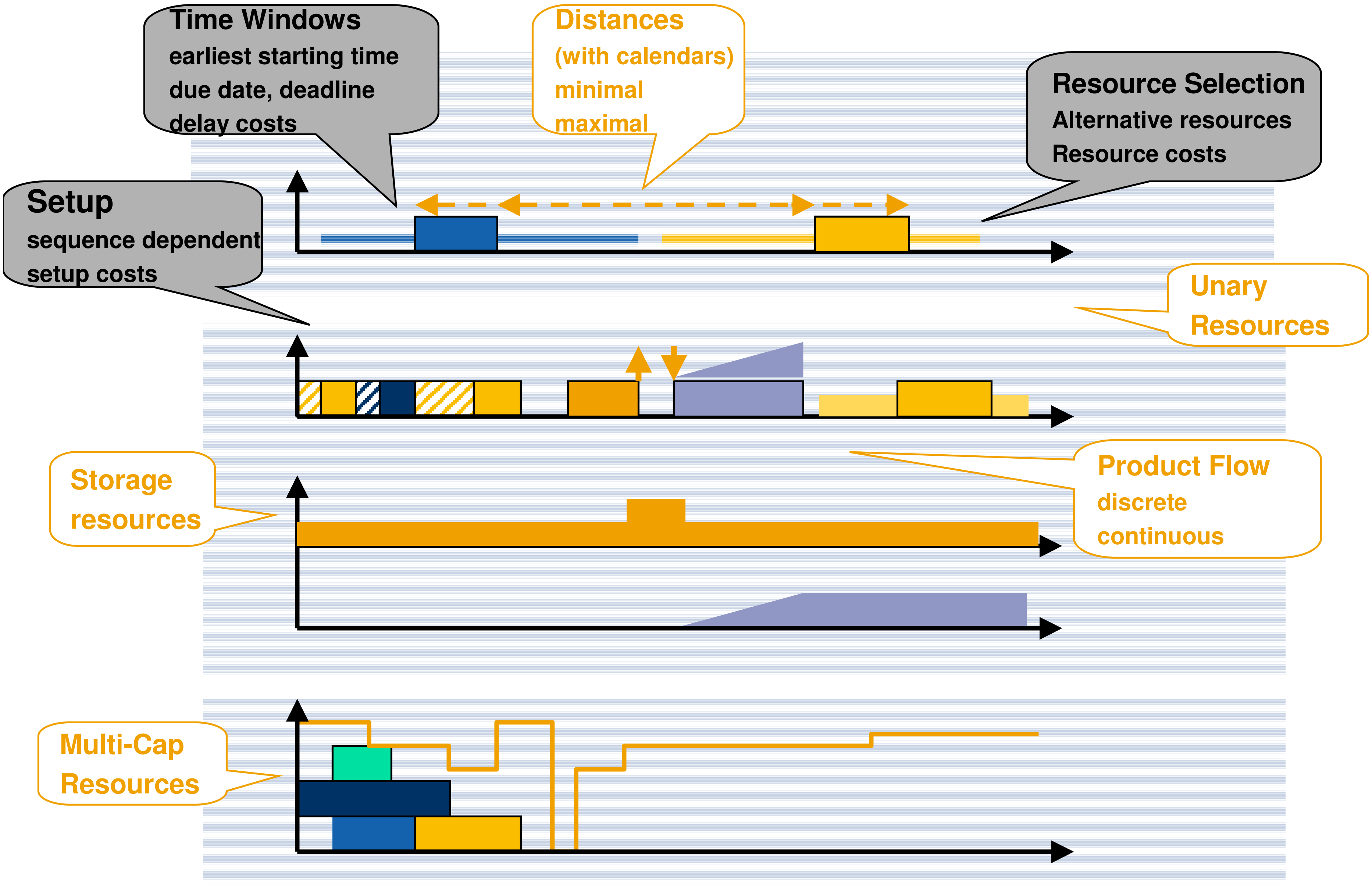
- Disaggregate global plan
  - Time: When to produce
  - Resource:
    On which alternative resource
- Optimize production sequence

- Scheduling algorithms (GA, CP)

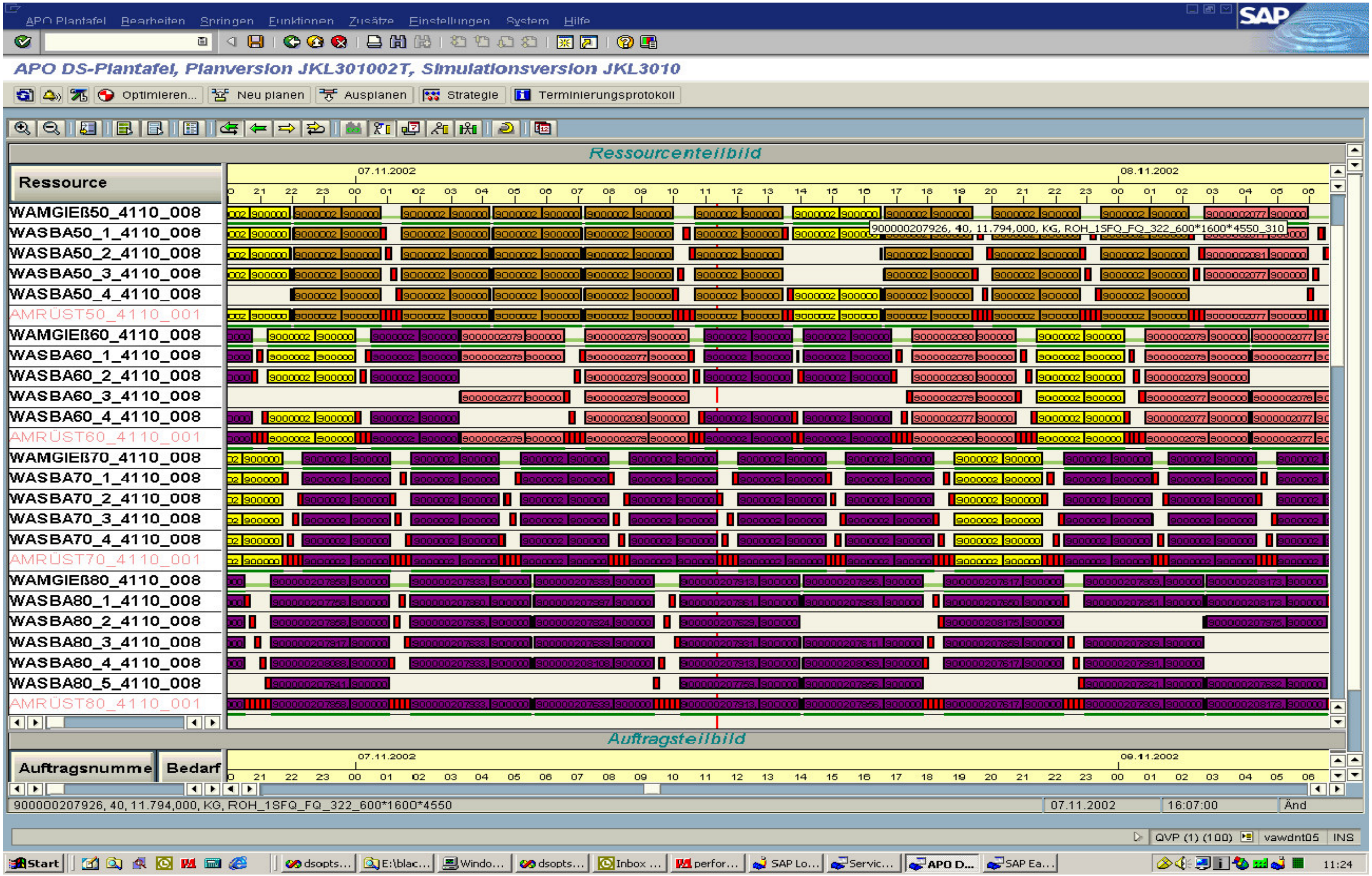
SNP Optimizer: Model Overview



PP/DS Optimizer: Model Overview



Example: Complex Modeling



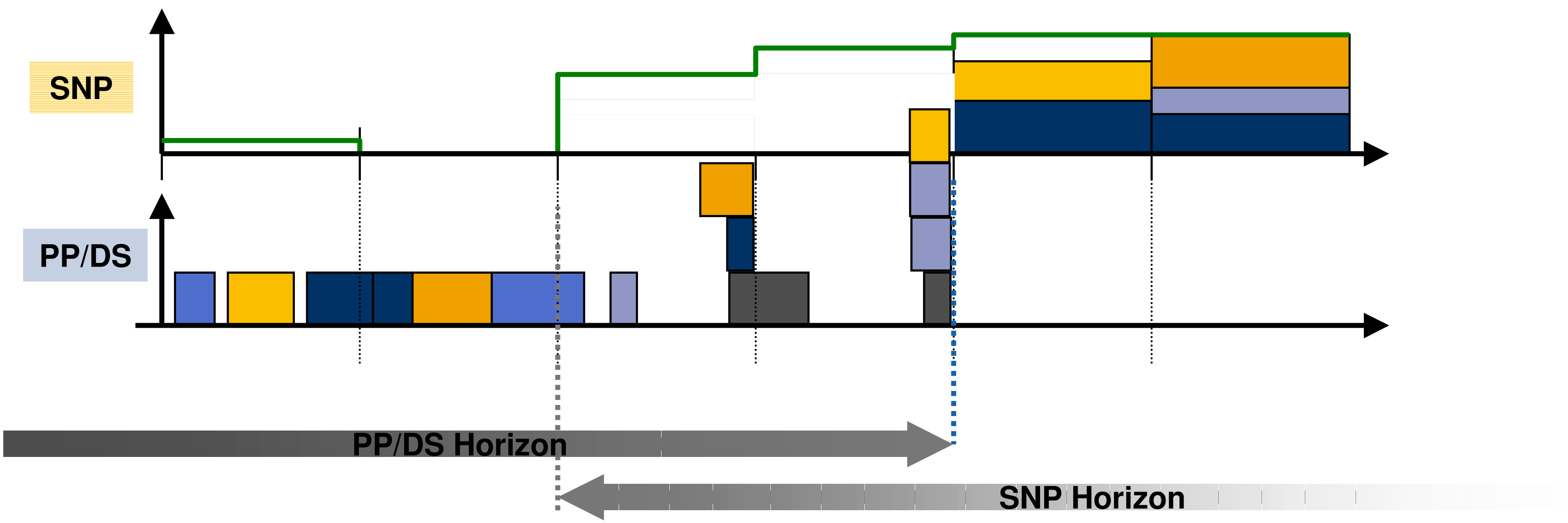
Integration between SNP and PP/DS

SNP

- Planning only in SNP horizon
- Release SNP Orders only in PP/DS horizon
- Respect PP/DS orders as fixed
  - capacity reduction
  - material flow

PP/DS

- Respect pegged SNP Orders as due dates
  - No capacity reduction
  - But material flow
- No restrictions for scheduling PP/DS orders



Integration between SNP and PP/DS

SNP

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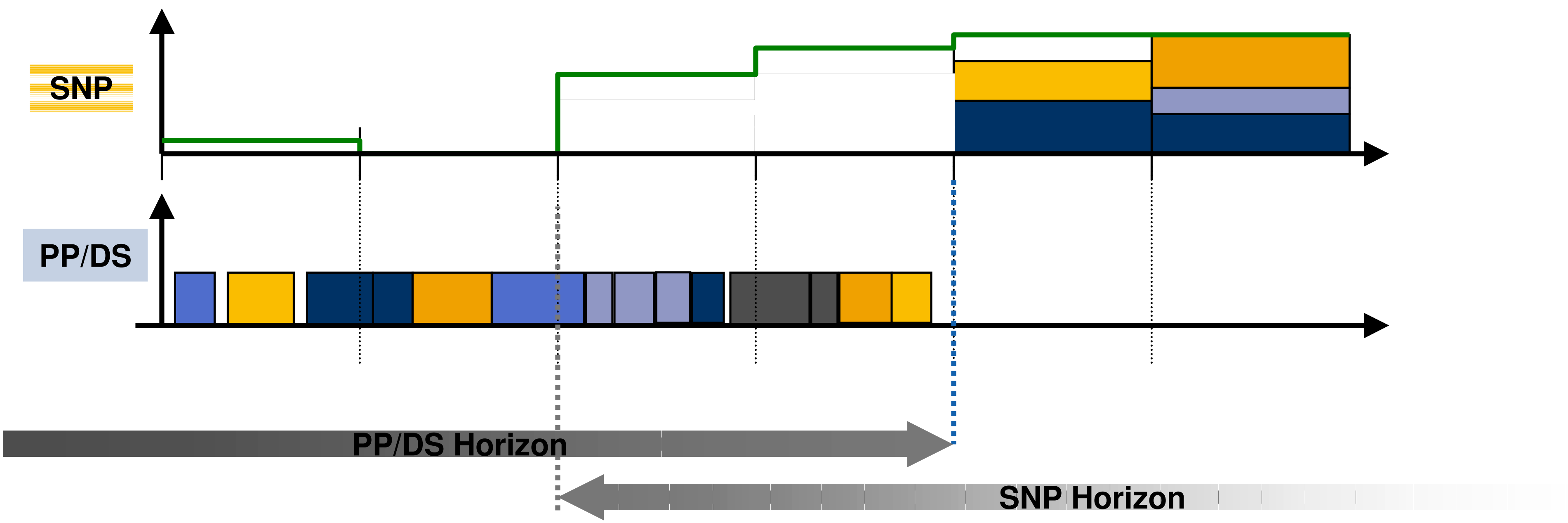


Mastering the algorithmic complexity: Aggregation

Model Accuracy versus Solution Quality -> SNP

- Time Aggregation (telescopic buckets)
- Limit the discretization
- Product Aggregation (families of finished products)
- Location Aggregation (transport zones, distribution centers)

However: Sufficient model accuracy of SNP for DS

- Modeling of setup (important for process industry)

SNP Optimization: Anticipation of Setup

Multi-Level Capacitated Lot Sizing Problem (MLCLSP)

Setup cost and/or consumption in each bucket

Good results

Setup consumption small compared to bucket capacity (small lots)

Bad results

Setup consumption big compared to bucket capacity (big lots)

SNP Optimization: Lot Sizing in SAP SCM

Proportional Lot Sizing Problem (PLSP)

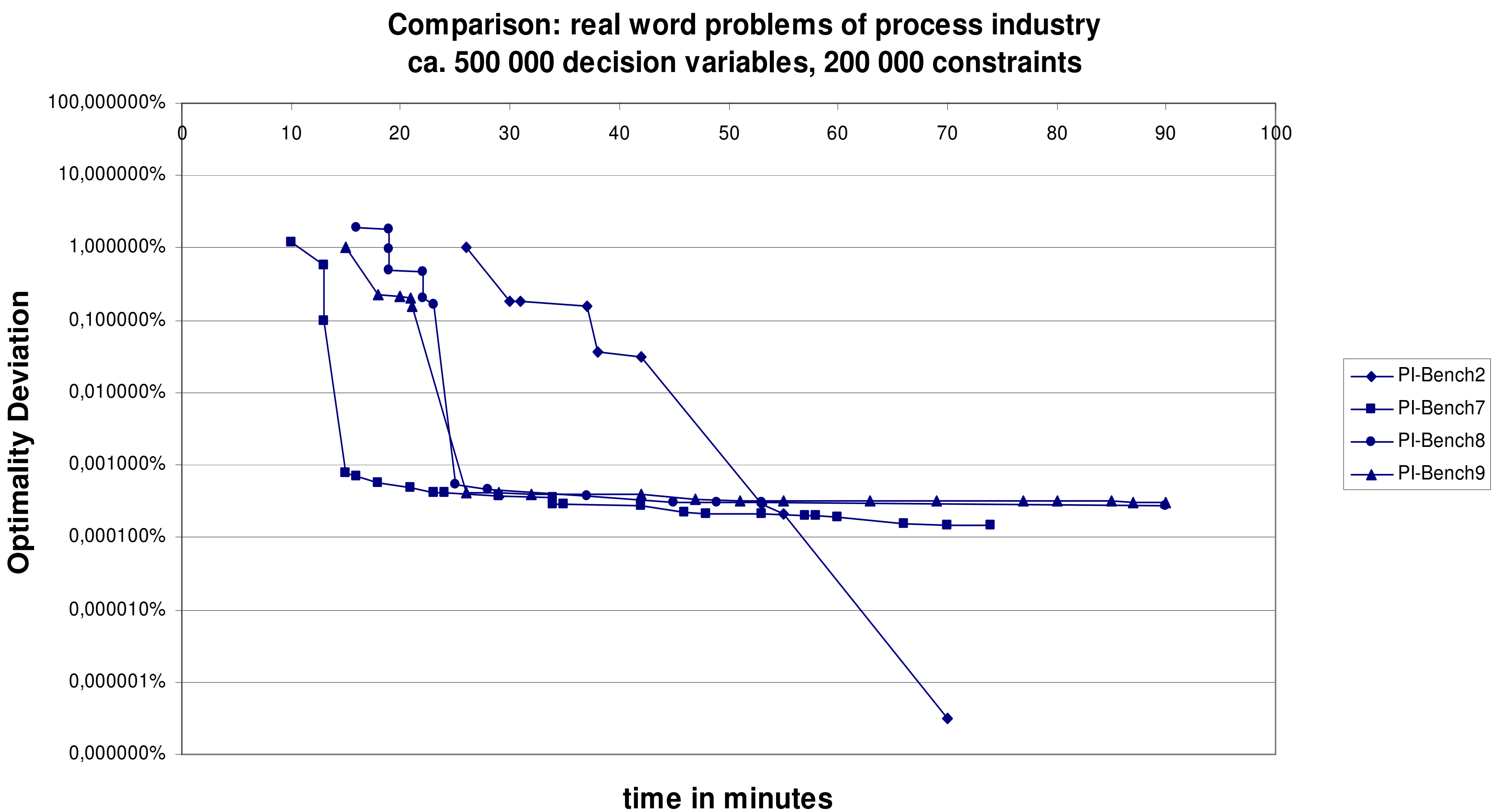
- Considering setup in preceding bucket
- At most one setup per bucket

Constraints on cross-period lots (= campaign quantity)

- Minimal campaign quantity

- Campaign quantity integer multiple of batch size

SNP Campaign Optimization: Benchmarks



Mastering the algorithmic complexity: Decomposition

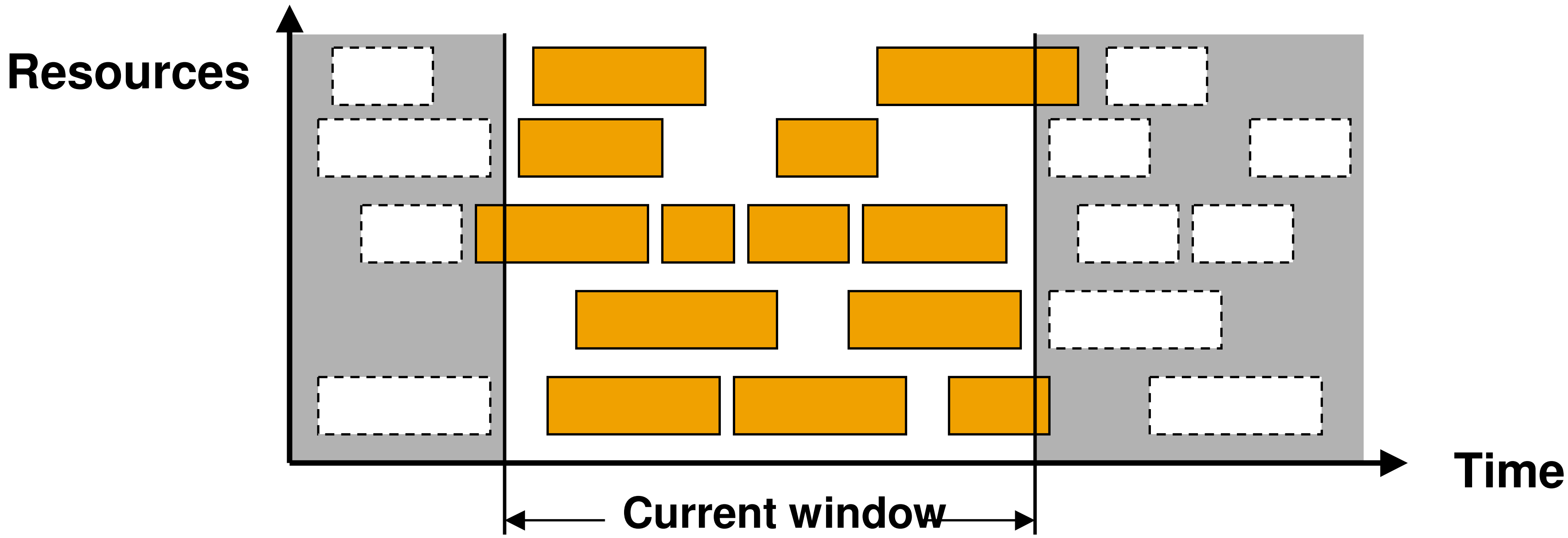
Global versus local optimality -> SNP + DS

- Local optimality depends on neighborhood
- High solution quality by local optimization
- Local Optimization = Decomposition

Decomposition strategies

- SNP: time, resource, product, procurement
- DS: time, resource
- Parallelization by “Agents”

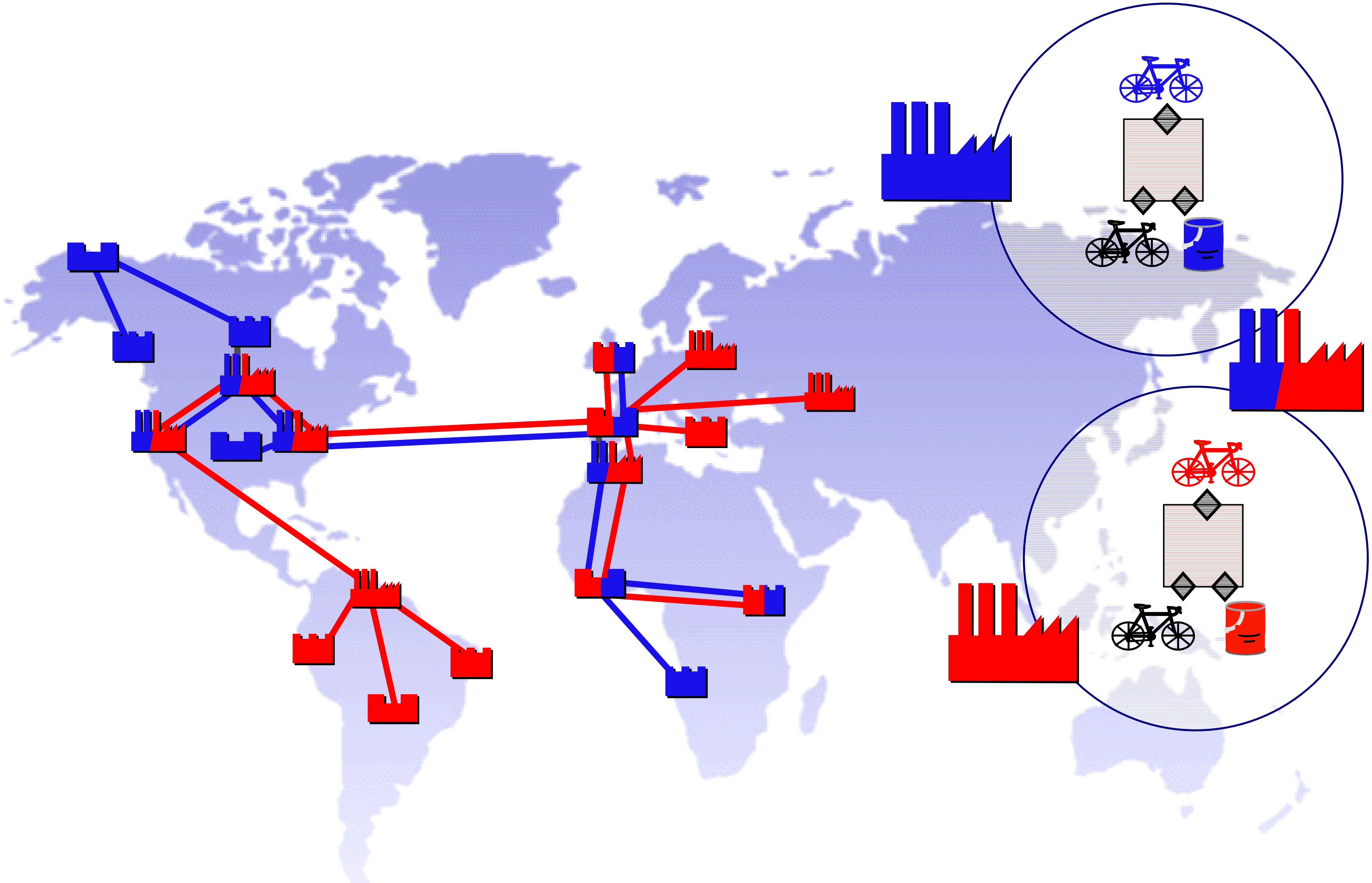
Time Decomposition - Local Improvement



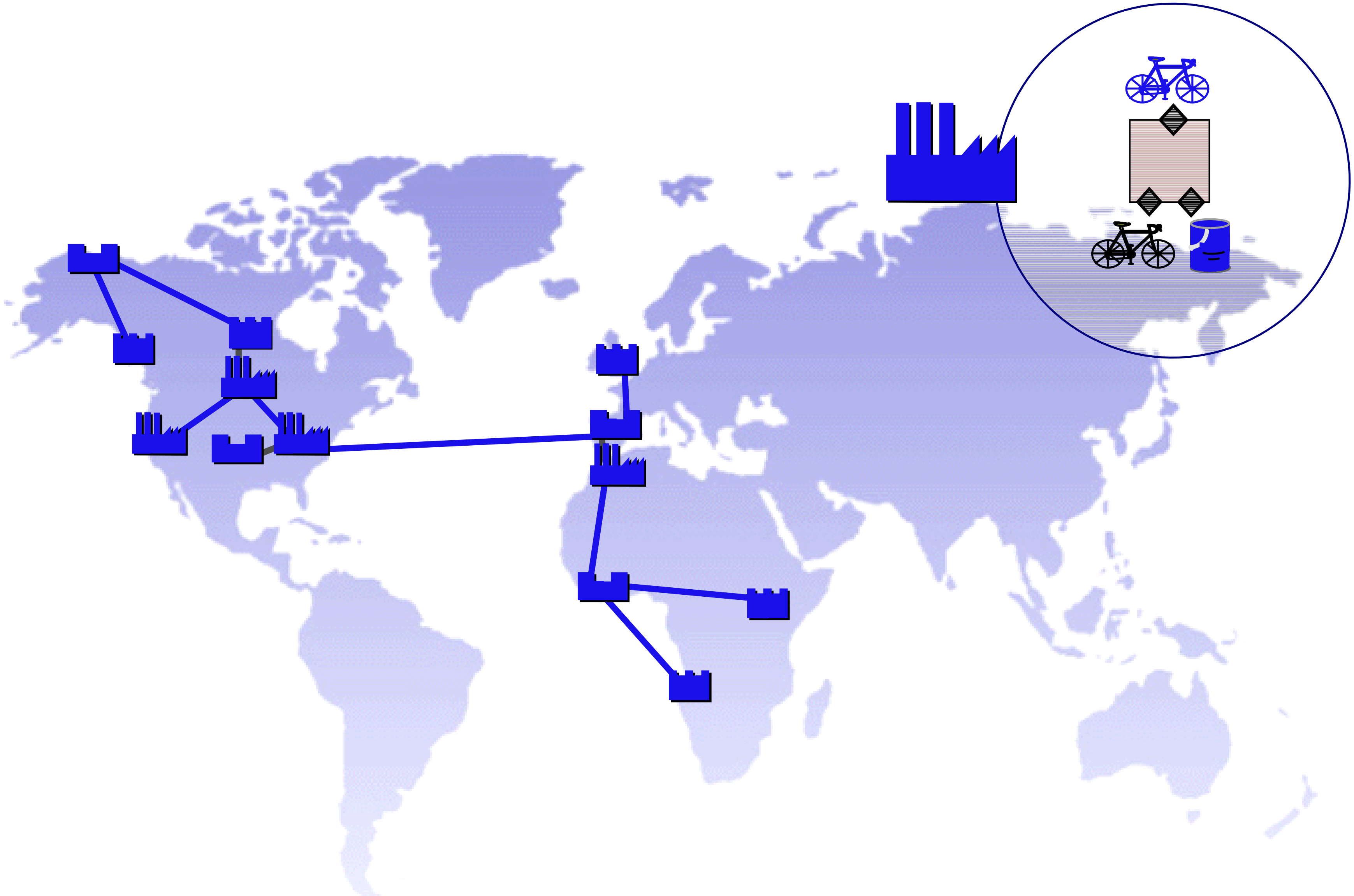
Gliding window script

1. Optimize only in current window
2. Move window by a time delta
3. Go to first step

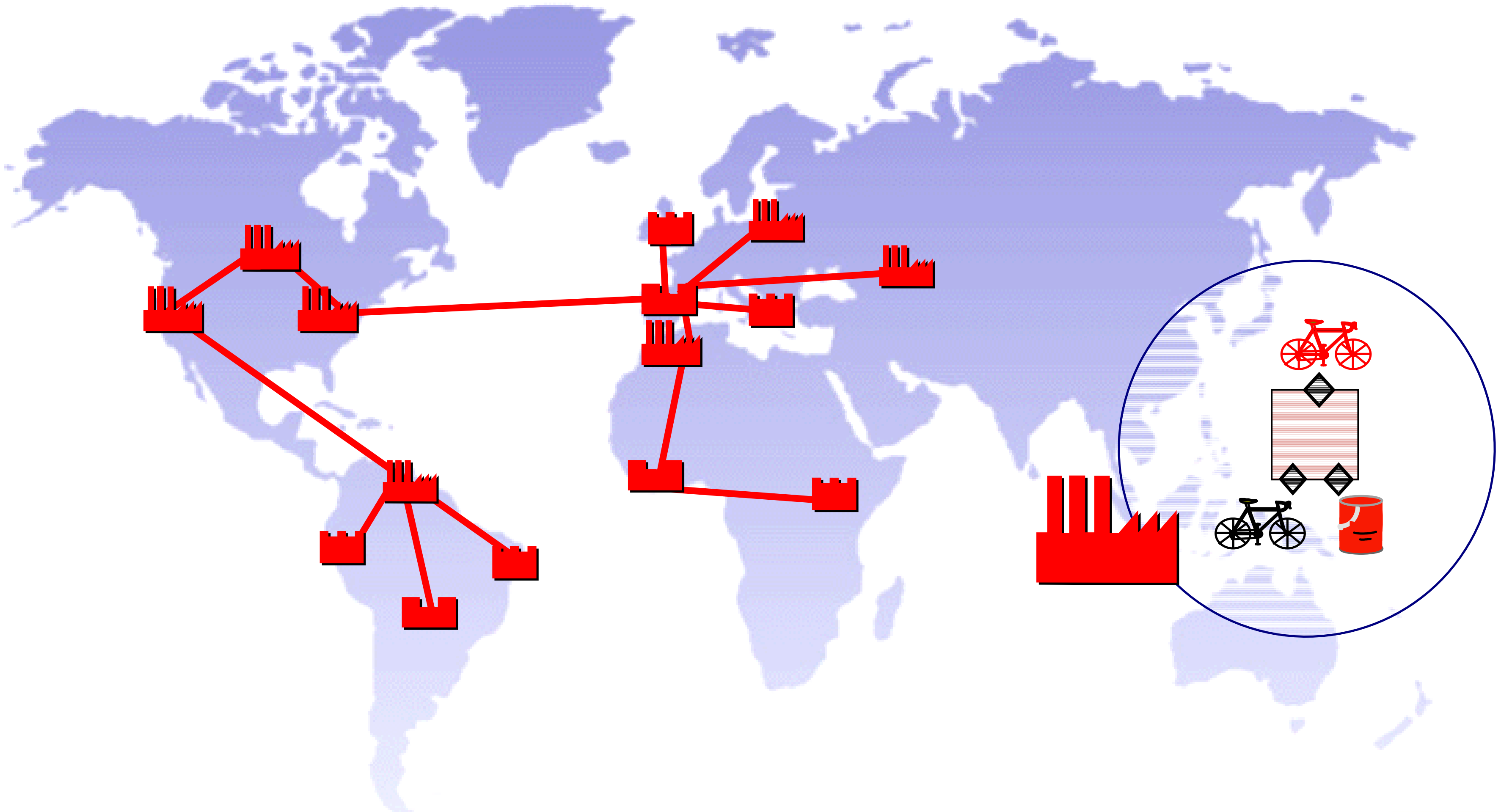
SNP Product Decomposition



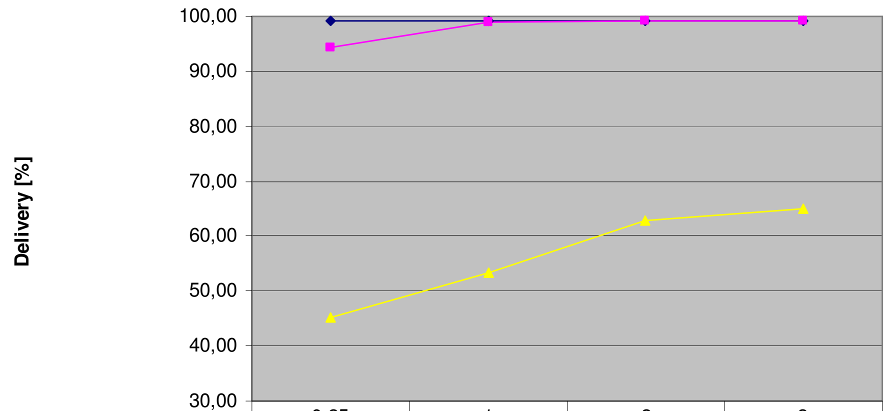
SNP Product Decomposition



SNP Product Decomposition

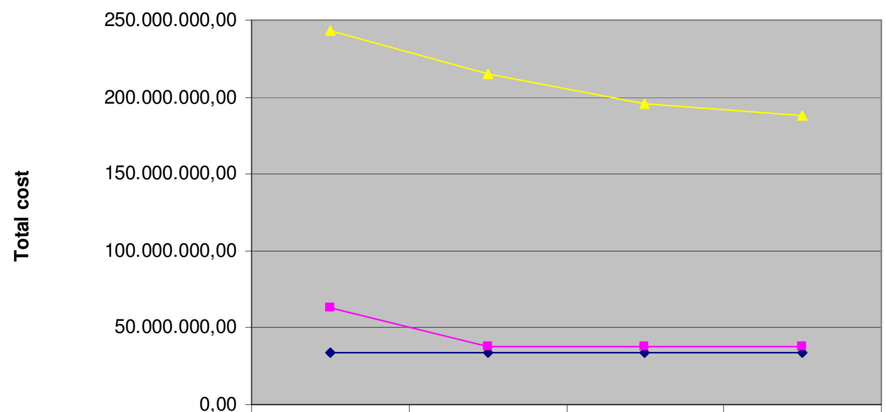


SNP Product Decomposition



	0,25	1	2	3
LP Relaxation	99,17	99,17	99,17	99,17
Decomposed MIP	94,40	98,98	99,07	99,09
Global MIP	45,1162	53,33	62,81	65,13

Solution time [hrs]



	0,25	1	2	3
LP Relaxation	34.075.500,00	34.075.500,00	34.075.500,00	34.075.500,00
Decomposed MIP	63.231.900,00	38.170.900,00	37.871.200,00	37.860.100,00
Global MIP	2,44E+08	215.404.000,00	195.649.000,00	187.900.000,00

Solution time [hrs]

Customer model

„Production Grouping“

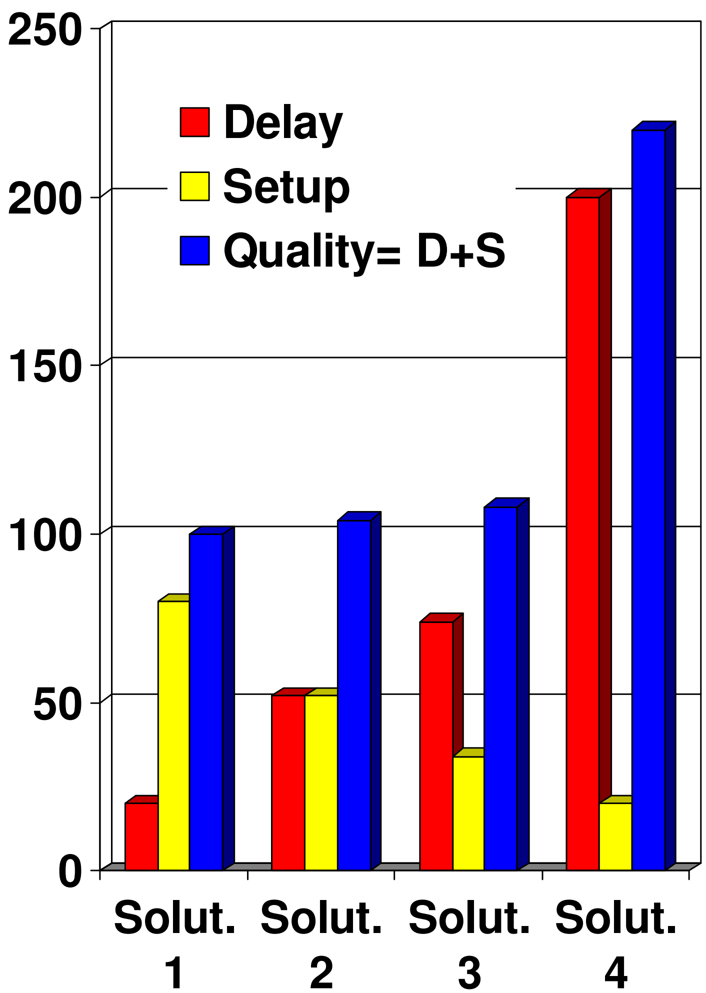
~15 comparable selections

179‘086 Variables
66‘612 Constraints
10‘218 Binary variables

OPAL Executable
CPLEX 8.0

Pentium IV 1,5 GHz
1 GB Main memory

Multi Agent Optimization



Objective

- Multi Criteria Optimization
- user selects out of solutions with
  - similar overall quality
  - different components
- Use power of Pallelization

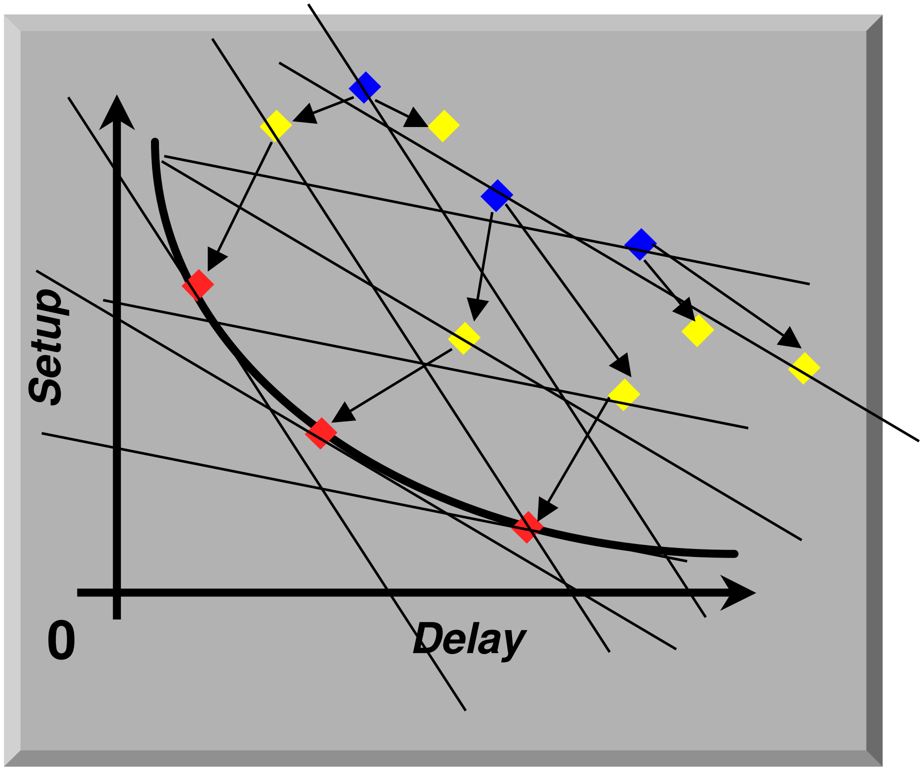
Multi Agent Strategy

- Different AGENTS focusing on Setup or Delay or Makespan
- Agents may use any optimizer (CP, GA, ..)
- New solutions by local improvement
- Integrated in Optimizer Architecture

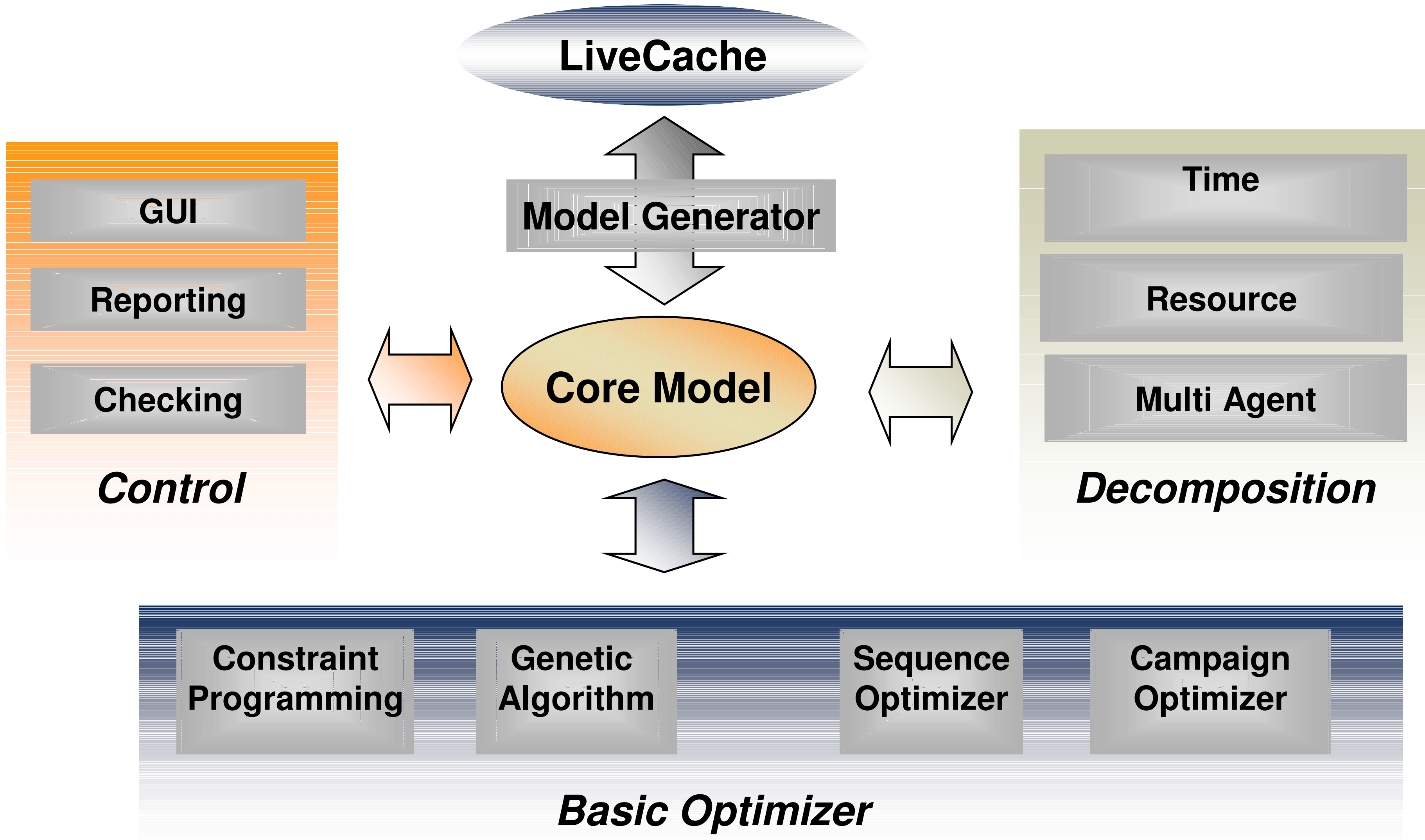
Performance

- Speedup ≈ available processors

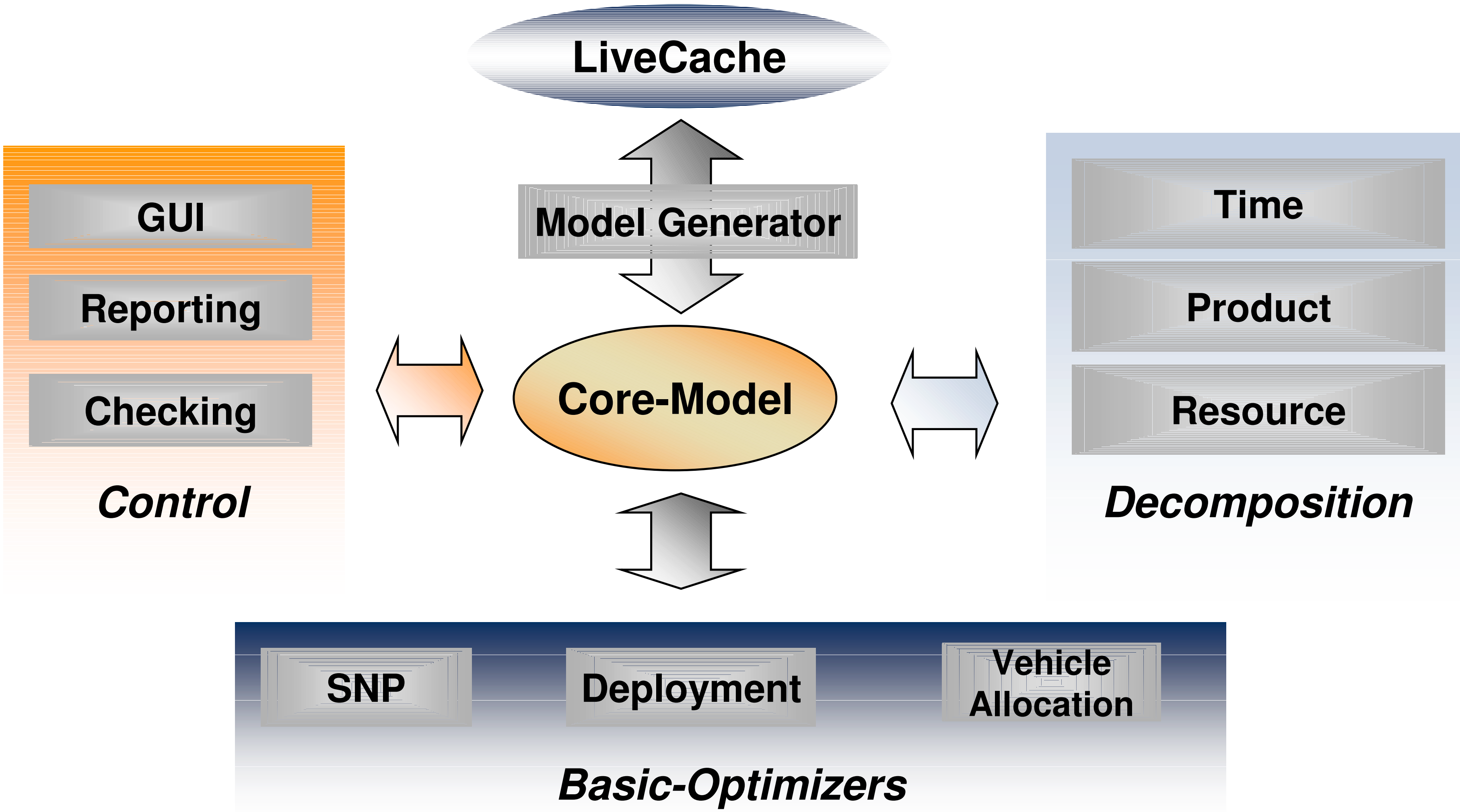
Several Solutions



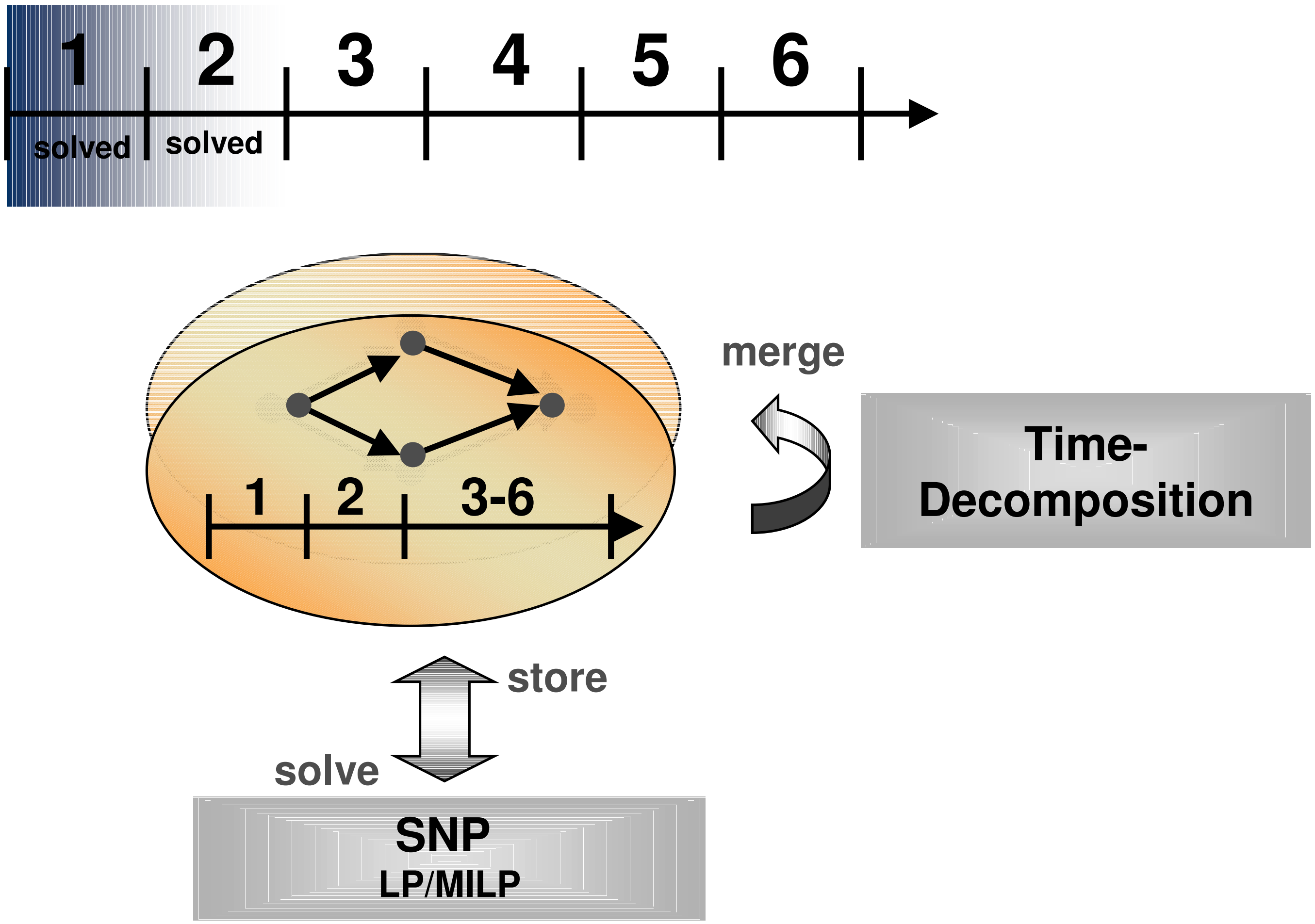
Scheduling Optimizer Architecture



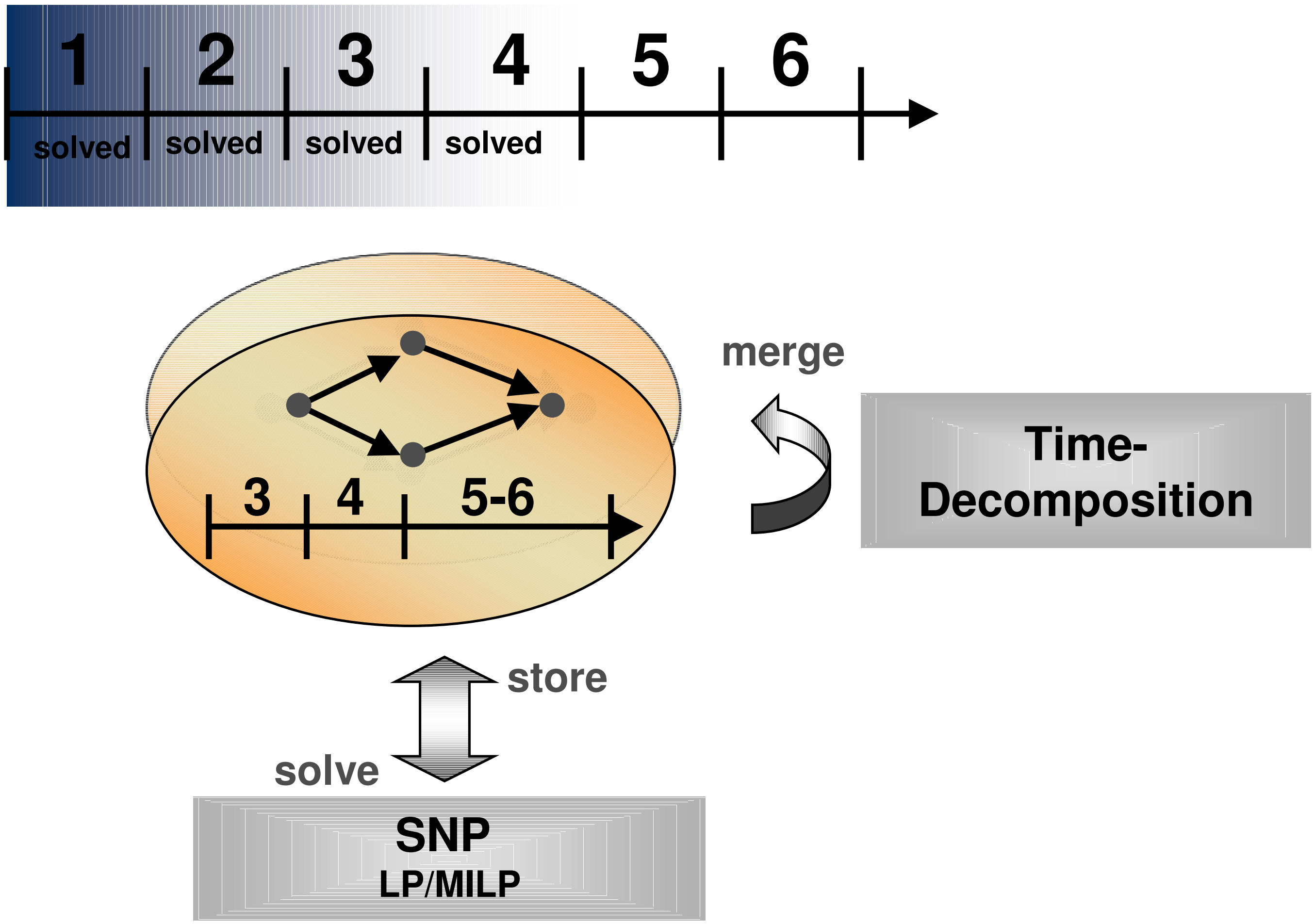
Optimizing with Time Decomposition



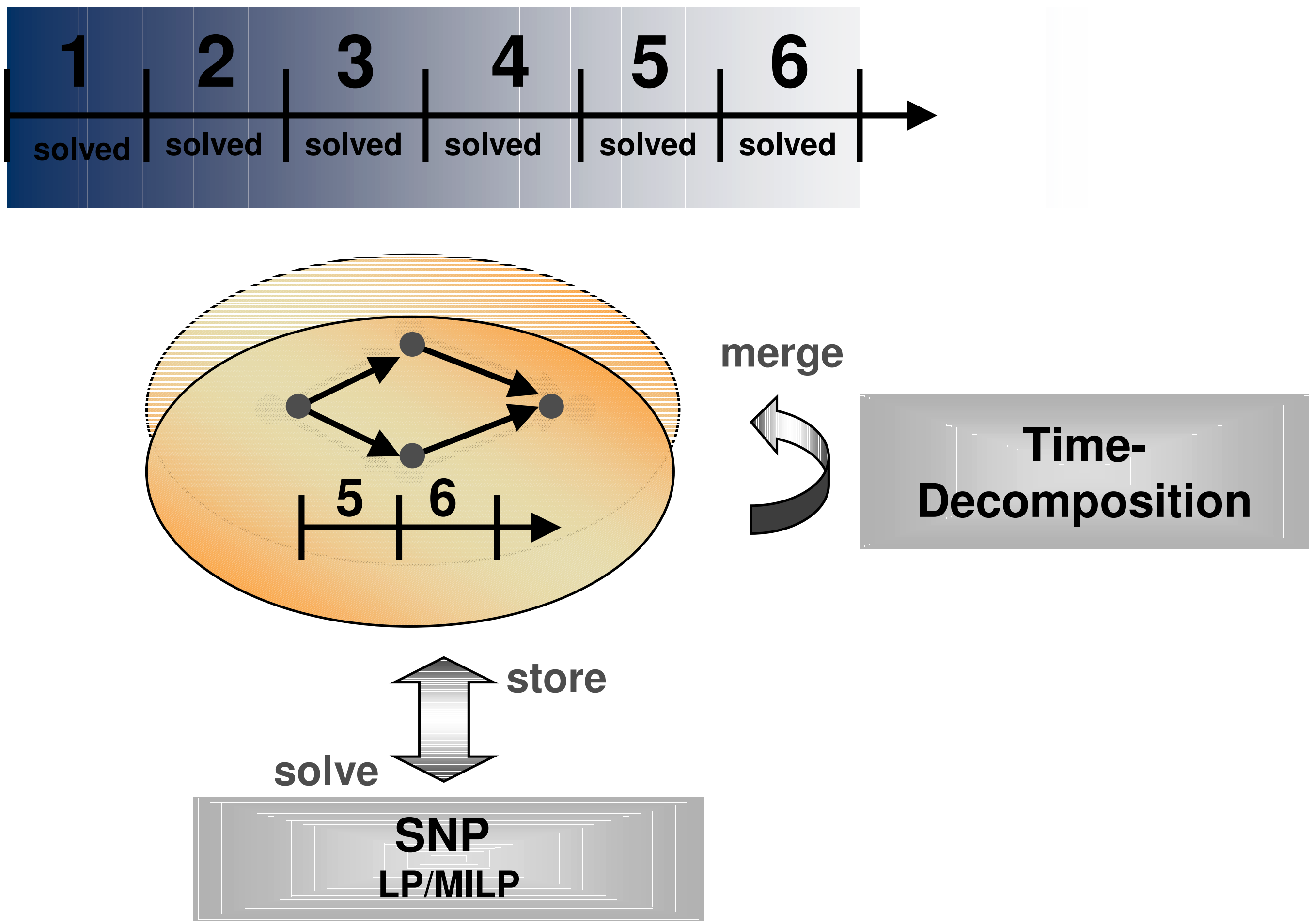
Optimizing with Time Decomposition



Optimizing with Time Decomposition



Optimizing with Time Decomposition



Optimization Performance

Supply Network Planning

- Pure LP
  - Without discrete constraints
  - Up to several million decision variables and about a million constraints
  - Global optimum guaranteed
- For discrete constraints
  - No global optimum guaranteed
  - Quality depends on run time and approximation by pure LP

Detailed Scheduling

- Up to 200 000 activities

  (no hard limitation)
- First solution

  as fast as greedy heuristics
- More run time

  improves solution quality

Summary - Mastering the Algorithmic complexity

- Aggregation
  - SNP: time, product, location
  - Automated Generation: SNP model deduced from DS model !!
- Decomposition
  - SNP: time, resource, product, procurement
  - DS: time, resource
  - Parallelization by “Agents”
- Hierarchy of Goals (customized by scripts)
  - SNP ←→ DS
  - SNP: Service Level ←→ Production Costs
  - DS: Service Level ←→ Storage Costs
- Open to partner solutions: Optimizer extension workbench

Our Mission

Optimization as an integrated standard software solution

Focus of Development

In the past

- larger optimization problems
- better solution quality
- more functionality

Current customer view

- Very confident with performance, solution quality, functionality
- Problem: Mastering the solution complexity (e.g. data consistency)

Current focus of development

- More sophisticated diagnostic tools
- Parallelization by GRID Computing

Agenda

Optimization in SAP SCM

Acceptance of Optimization

Summary

Acceptance Criteria

Heuristic (relaxing capacity) versus Optimization

Or

Why do not all SNP-Customers use optimization?

Model Accuracy

SNP Heuristic

- Interactive Planning: Planner responsible for feasibility
  → limited model accuracy sufficient

SNP Optimizer

- Automated Planning: Optimizer responsible for feasibility
  → high model accuracy necessary
- Application in complex scenarios

Acceptance criteria: Solution quality

	SNP Heuristik	SNP Optimierer
Scaling of Model size	✔	LP: ✔ MILP: using decomposition
Scaling of Model accuracy	Limited model accuracy	Very detailed → MILP: using decomposition
Acceptance by end user	simple model + Transparency of algorithms → acceptable solution	■ Not sufficient: (Global) integer gap as Indicator ■ Not acceptable: apparent improvement potential ◆ Producing too early ◆ Neglecting Priorities ◆ ... ■ Goal: Local Optimality → Decomposition

Acceptance criteria: Solution transparency

	SNP Heuristic	SNP Optimizer
Solution stability	■ Sequential processing of orders and few constraints → robust for small data modifications	■ Global Optimization → small data modifications may cause large solution changes MILP: change of search
Interaction Data/Model versus Solution	■ No "Black-Box" ■ algorithms transparent	■ Unforeseeable effects: by considering both ◆ globally and simultaneously ◆ costs and constraints ■ Soft versus Hard Constraints ◆ violation depending on solution quality! ◆ Question: violation avoidable by more run time?

Acceptance by different roles

- **OR Specialists**
  - solution quality
  - run time behavior
- IT department (TCO = Total Cost of Owner Ship, ROI = Return on Investment)
  - Maintenance
  - Administration
  - Integration
  - Upgrades / Enhancements
- Consultants
  - Training / Documentation / Best practices
  - Complete and validated scenarios
  - Sizing tools
- End user (Planner)
  - Modeling capabilities
  - Solution quality
    → *acceptable* solution in given run time, error tolerance
  - Solution transparency
    → Diagnostics, Warnings, Tool tips in case of errors

Optimization as standard software?!

Tradeoff

- Solution quality
- Solution costs (development, maintenance, ..)

Problems for special solutions

- Modeling as „moving target“
  - Changing master data
    - additional constraints
    - additional resources (machines)
  - Changing transactional data
    - Number of orders
    - Distribution of orders to product groups
  - Changing objectives (depending on the economy)

- Effort for optimization algorithms only <10% of overall costs
  - Integration
  - Interactive Planning
  - Graphical user interface

Optimization algorithms

Which algorithms for which planning levels?

Supply Network Planning

- LP / MILP Solver (CPLEX)

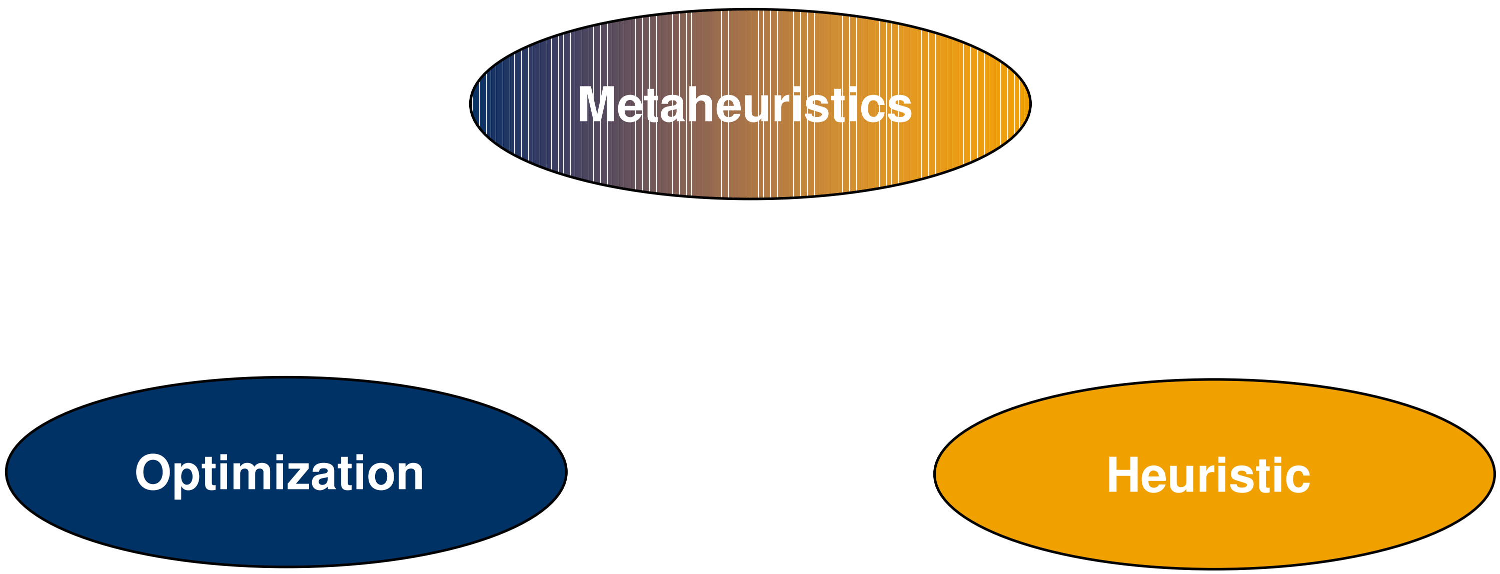
Classical Operations Research

Detailed Scheduling

- Constraint Programming
- Evolutionary Algorithms

Metaheuristics

Dialectic of naming debate



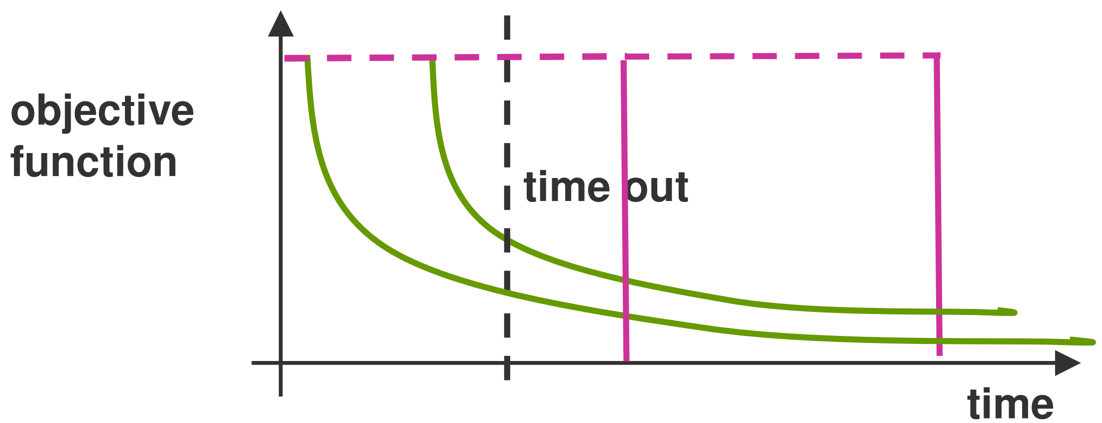
Academic: Optimization as an algorithm

- find an optimal solution

or

Practical: Optimization as a dynamic process

- „the path is the goal“



Optimization – in practice

Global optimal

- Often missed
- Tradeoff: Model accuracy <-> solution quality

Metaheuristics

- Very robust
- Quality scales with given run time

Local optimal

- A must have
- The planer may not find simple improvements

Acceptance by different roles

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- **IT department (TCO = Total Cost of Owner Ship, ROI = Return on Investment)**
  - **Maintenance**
  - **Administration**
  - **Integration**
  - **Upgrades / Enhancements**

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Optimizer architecture

„Acceptance“-Criteria: ROI

- Total Cost of Ownership
  - Licenses (development effort)
  - Maintenance
  - Enhancements
- Integration (to system landscape at customer)
- Planning quality

Architecture

- Toolbox
- Exchangeable Components
- Idea: Divide and Conquer for improving the components

→ SAP Netweaver

Toolbox: alternative Optimizer

Evolution / Competition of Optimizer

- cf. Linear Optimization (ILOG CPLEX)
  - Primal Simplex
  - Dual Simplex
  - Interior Point Methods

- Alternative Optimizer for Scheduling
  - Constraint Programming (ILOG)
  - Evolutionary Algorithms (SAP)
  - Relax and Resolve (University of Karlsruhe)

- Alternative Optimizer for Vehicle Routing and Scheduling
  - Constraint Programming, Tabu Search (ILOG)
  - Evolutionary Algorithms (SAP)

Acceptance by different roles

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- IT department (TCO = Total Cost of Owner Ship, ROI = Return on Investment)
  - Maintenance
  - Administration
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- End user (Planner)
  - Modelling capabilities
  - Solution quality
    → *acceptable* solution in given run time, error tolerance
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Acceptance in Consulting

Problem: Know How

- Consultants sell methods to the customer which they can
  - master
  - modify (additional heuristics)
- Consequence for Optimization?!

Expert-Consulting Service for Optimization

- Remote Consultant located in development
- In particular, expert help for consulting partner

Quick Questionnaire

- “Early watch” for planning complexity
- Simple modeling tool
  - What can I do to reduce model complexity?
  - Fallback Model: Which simplified model is uncritical?
  - Which model details are critical?

Sizing for Supply Network Planning

SNP Optimizer Questionnaire

Continuous model		*Estimate*	*Resulting variables*	*Resulting constraints*
Number of planning periods	82			
Number of (planning relevant) location product combinations	14.500		1.189.000	1.189.000
Number of transportation lane product combinations	176.000		14.432.000	
Number of location product combinations with customer demands	11.705		1.919.620	959.810
Number of location product combinations with corrected demand forecasts		0	0	0
Number of location product combinations with forecasted demands	11.705		1.919.620	959.810
Average lateness (in periods) allowed for demand items	1			
Number of location product combinations with safety stock requirements	11.705		959.810	959.810
Number of location product combinations with product-specific storage bound			0	
Number of location product combinations with an active shelf life		0	0	0
Number of production process models (PPMs)	1.641		134.562	
Number of resources (production, transportation, handling in/out, storage)	50		4.100	4.100

Number of variables: 20.558.712

Number of constraints: 4.072.530

Discrete model		*Discretized periods*	*Additional discrete variables*	*Additional constraints*
Number of PPMs with minimum lot size requirements	1.641		134.562	
Number of PPMs with discrete lot size requirements	1.641		134.562	
Number of PPMs with fixed resource consumption	1.641		134.562	
Number of production resources with discrete expansion			0	
Number of transportable products with minimum lot size requirements			0	
Number of transportable products with discrete lot size requirements			0	
Number of piecewise-linear cost functions (procurement, production, transport)			0	

Additional number of discrete variables: 403.686

Additional number of constraints: 0

Sizing for Supply Network Planning

SNP Optimizer Questionnaire

Continuous model

		Estimate	Resulting variables	Resulting constraints
Number of planning periods	13			
Number of (planning relevant) location product combinations	14.500		188.500	188.500
Number of transportation lane product combinations	176.000		2.288.000	
Number of location product combinations with customer demands	11.705		304.330	152.165
Number of location product combinations with corrected demand forecasts		0	0	0
Number of location product combinations with forecasted demands	11.705		304.330	152.165
Average lateness (in periods) allowed for demand items	1			
Number of location product combinations with safety stock requirements	11.705		152.165	152.165
Number of location product combinations with product-specific storage bound			0	
Number of location product combinations with an active shelf life		0	0	0
Number of production process models (PPMs)	1.641		21.333	
Number of resources (production, transportation, handling in/out, storage)	50		650	650

Number of variables: 3.259.308

Number of constraints: 645.645

Discrete model

		Discretized periods	Additional discrete variables	Additional constraints
Number of PPMs with minimum lot size requirements	1.641		21.333	
Number of PPMs with discrete lot size requirements	1.641		21.333	
Number of PPMs with fixed resource consumption	1.641		21.333	
Number of production resources with discrete expansion			0	
Number of transportable products with minimum lot size requirements			0	
Number of transportable products with discrete lot size requirements			0	
Number of piecewise-linear cost functions (procurement, production, transport)			0	

Additional number of discrete variables: 63.999

Additional number of constraints: 0

Sizing for Detailed Scheduling

PP/DS Optimization Questionnaire

Version 4.0.1 for SAP APO 3.0, 3.1 and 4.0

Memory consumption

		number of objects	memory per object[kb]	memory consumption[Mb]
Orders inside the optimization horizon	5.000	5.000	4,50	22
Average number of activities in an order	10,0	50.000	5,00	244
Average number of modes of an activity	3,0	150.000	1,00	146
Number of resources	10	10	530,00	5
Number of setup matrices	2	2	55,00	0
Maximum number of setup attributes in a setup matrix	500	250.000	0,10	49

Environment [Mb]:	8
Safety factor:	130%
Memory consumption [Mb]:	617

Complexity of the model

		degree of difficulty
Size		A
Backward Scheduling	yes	C
Block planning on resources	no	A
Bottleneck optimization	no	C
Campaigns	no	B
continous requirement/receipt	no	B
Deadlines modeled as hard constraints	no	B
Validity periods of orders	no	B
Cross-order relationships	no	B
Mode linkage	no	C
Sequence dependent setups activities	yes	C
Shelf life or max. pegging arcs	no	A
Container resource	no	A
Synchronization on resources	no	C
Time buffer	no	C

no of features per degree of difficulty

A: 1
B: 0
C: 2

Degree of complexity:
high

If the degree of complexity is not "moderate" SAP recommends the optimization consulting service

Sizing for Detailed Scheduling

PP/DS Optimization Questionnaire

Version 4.0.1 for SAP APO 3.0, 3.1 and 4.0

Memory consumption

		number of objects	memory per object[kb]	memory consumption[Mb]
Orders inside the optimization horizon	25.000	25.000	4,50	110
Average number of activities in an order	10,0	250.000	5,00	1.220
Average number of modes of an activity	3,0	750.000	1,00	732
Number of resources	10	10	530,00	5
Number of setup matrices	2	2	55,00	0
Maximum number of setup attributes in a setup matrix	500	250.000	0,10	49

Environment [Mb]:	8
Safety factor:	130%
Memory consumption [Mb]:	2.762

Complexity of the model

		degree of difficulty
Size		A
Backward Scheduling	yes	C
Block planning on resources	no	A
Bottleneck optimization	no	C
Campaigns	no	B
continous requirement/receipt	no	B
Deadlines modeled as hard constraints	no	B
Validity periods of orders	no	B
Cross-order relationships	no	B
Mode linkage	no	C
Sequence dependent setups activities	yes	C
Shelf life or max. pegging arcs	no	A
Container resource	no	A
Synchronization on resources	no	C
Time buffer	no	C

no of features per degree of difficulty

A: 1
B: 0
C: 2

Degree of complexity: **challenging**

If the degree of complexity is not "moderate" SAP recommends the optimization consulting service

Acceptance by different roles

- OR Specialists
  - solution quality
  - run time behavior
- IT department (TCO = Total Cost of Owner Ship, ROI = Return on Investment)
  - Maintenance
  - Administration
  - Integration
  - Upgrades / Enhancements
- Consultants
  - Training / Documentation / Best practices
  - Complete and validated scenarios
  - Sizing tools
- **End user (Planner)**
  - **Modeling capabilities**
  - **Solution quality**
    → ***acceptable*** **solution in given run time, error tolerance**
  - **Solution transparency**
    → **Diagnostics, Warnings, Tool tips in case of errors**

Model Analysis

Product properties

- Cardinality of sourcing alternatives for a location-product
- Maximum throughput per sourcing alternative for a location product
- Lead-time per location product
- Cycle analysis

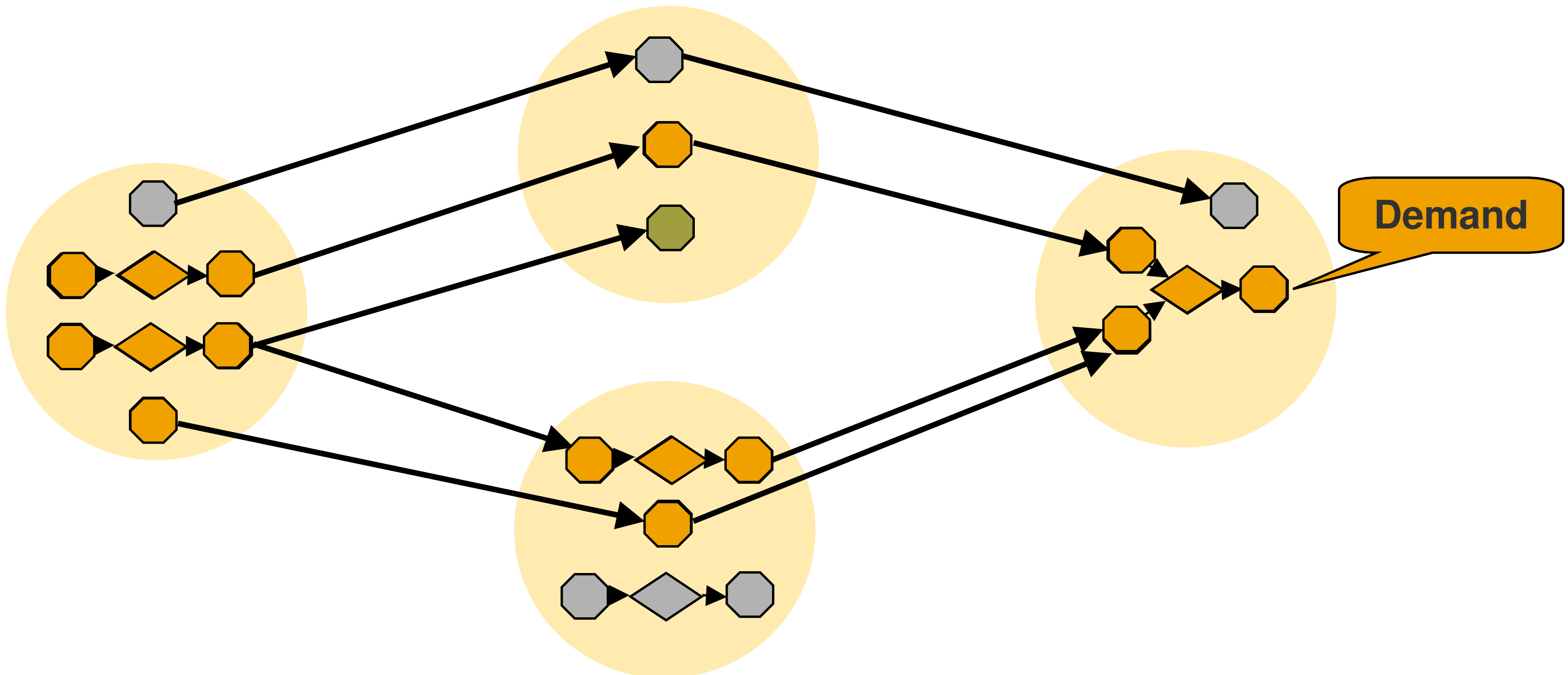
Resource properties

- Key resources
  number of (final) products requiring a resource

Cost model properties

- Non-delivery penalty configuration
  non-delivery penalty > production costs+ Delay costs ?!
- Transport-Storage
  transport_costs > storage_costs ?!
- Push analysis
  storage_costs_L1 + transport_costs < storage costs_L2 ?!

Pull/Push Redundancy: Example Pull Closure



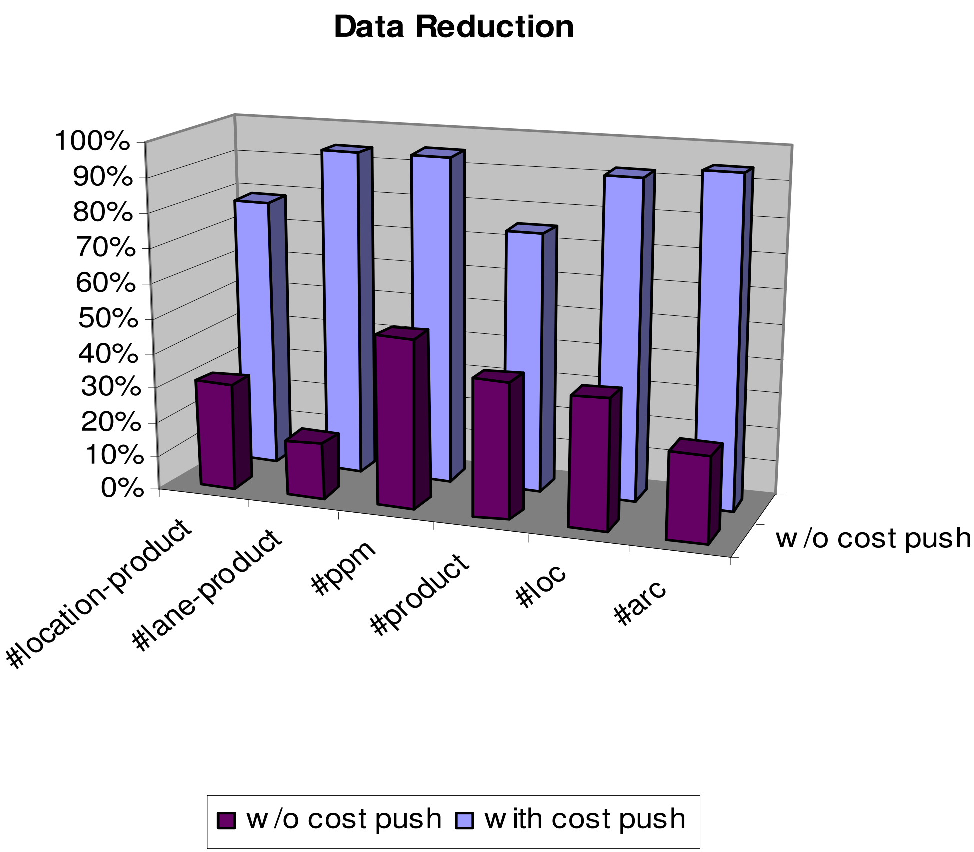
- Eliminate location-products not required for demand- or safety stock satisfaction, min resource utilization, or not involved in cost push
- Eliminate all dependent lane-products, lanes and locations
- Eliminate all dependent activities (procurement, transport, PPM)

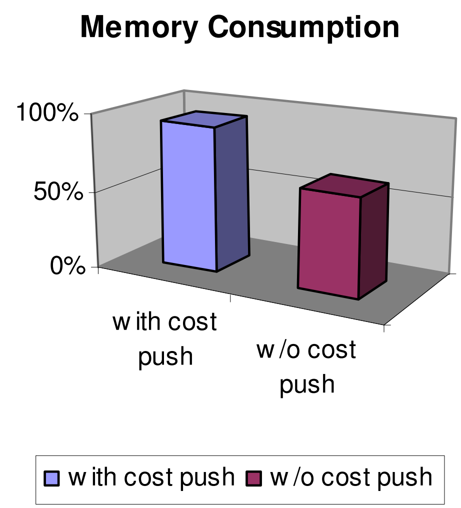
Computational Tests: Pharma Industry

Problem characteristics

#buckets	#loc-products	#lane-products	#ppm	#products	#locations	#lanes	#ineq	#vars	memory consumption
24	8.788	2.647	10.680	5.644	64	207	201.327	524.578	994.050.048

Level of redundancy





Computational Tests: Consumer Products

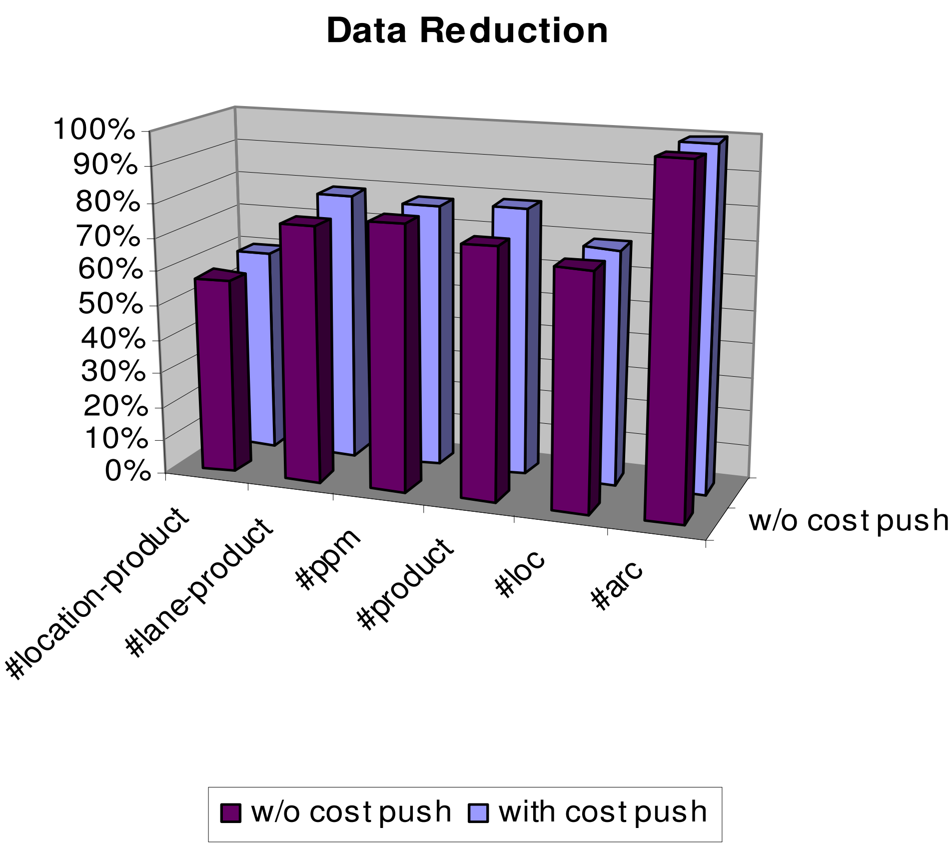
Problem characteristics

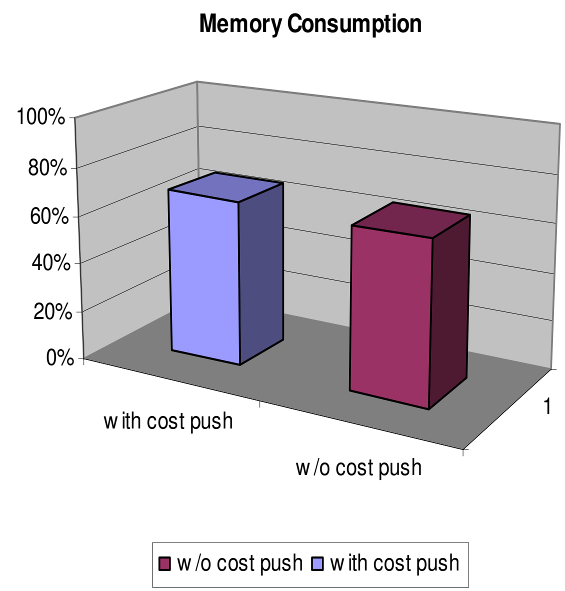
#buckets	#loc-products	#lane-products	#ppm	#products	#locations	#lanes
33	5.092	23.107	1.169	260	32	146

#ineq	#vars
201.327	524.578

memory consumption
1.569.828.864

Level of redundancy





Report of Solution Quality

Key Indicators

- Resource utilization
  - Setup time
  - Idle time
- Stock
  - Safety
  - Range of coverage
- Demand
  - Backlog
  - Delay (Percentage of volume, average of delay in days, priorities)
  - Non Deliveries

Aggregation – Drill Down

- Location
- Product

Advanced solution analysis

Explanation

- Non deliveries
- Delay
- Missed safety stock

Easier Optimizer Customizing

- Preconfigured optimizer profiles
- Support for generating cost parameters

Summary – Acceptance of Optimization in Practice

Acceptance by OR-Specialist

- Evolutionary algorithms are also optimization algorithms

→ Bridging the gap between Local Search and MILP

Acceptance by IT-department / „Decider of the investment“

- Solution completeness, Integration, Openness to Enhancements

→ Component Architecture (SAP Netweaver)

Acceptance by Consultant

- Know How, References, Best Practices, Quality guarantees

→ Optimization as “commodity” needs patience

Acceptance by End user

- Explanation Tools
- Semi-automatic optimizer configuration

Reallocate Orders using aggregated level (SNP)

Problem

Scheduling a late order or Solving a machine break down

Solving on same location and same production process model

- Re-optimize in detailed scheduling

Change location or production model

- Remove orders overlapping machine break down
- Resolve problem on aggregate level (SNP)
  - Selecting appropriate location and/or alternative PPM
- Release order to detailed scheduling
- Re-optimize detailed scheduling
- ONLY APPLICABLE: Inside overlapping horizon of SNP and PP/DS

SNP considers setup in PP/DS

Setup for each bucket

Enhancing PP/DS orders by SNP orders