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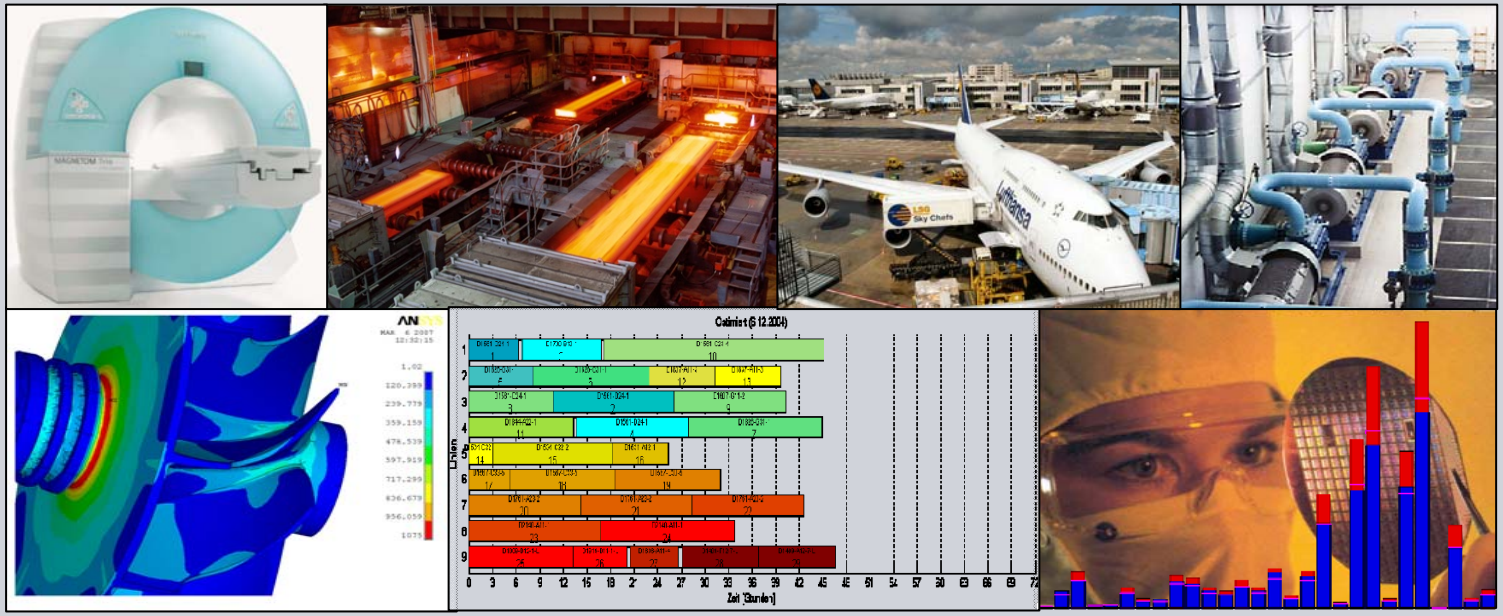
Corporate Technology

Mathematical Optimization at Siemens

Michael Hofmeister

Siemens AG Munich, Corporate Technology



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Outline

- Siemens Company – a short introduction
- Mathematics at Siemens Corporate Technology
- Assembly of printed circuit boards
- Water supply network planning
- The internet of things
- Outlook

Siemens Company

Siemens' innovations have changed the world

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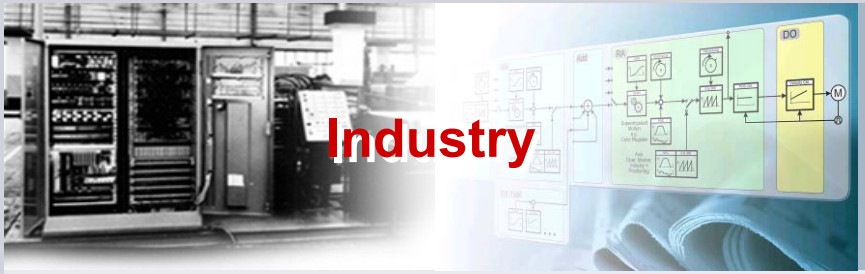
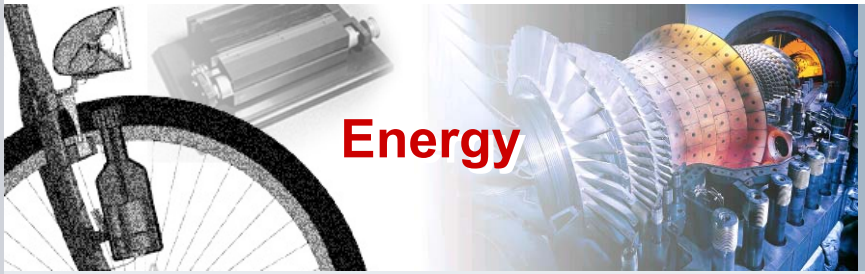


From the first electronic controls –
to fully automated factories



From the invention of the dynamo –
to the world's most efficient gas turbines

From the first interior view of the body –
to full-body 3D scans

Siemens Company
Milestones for Three Centuries

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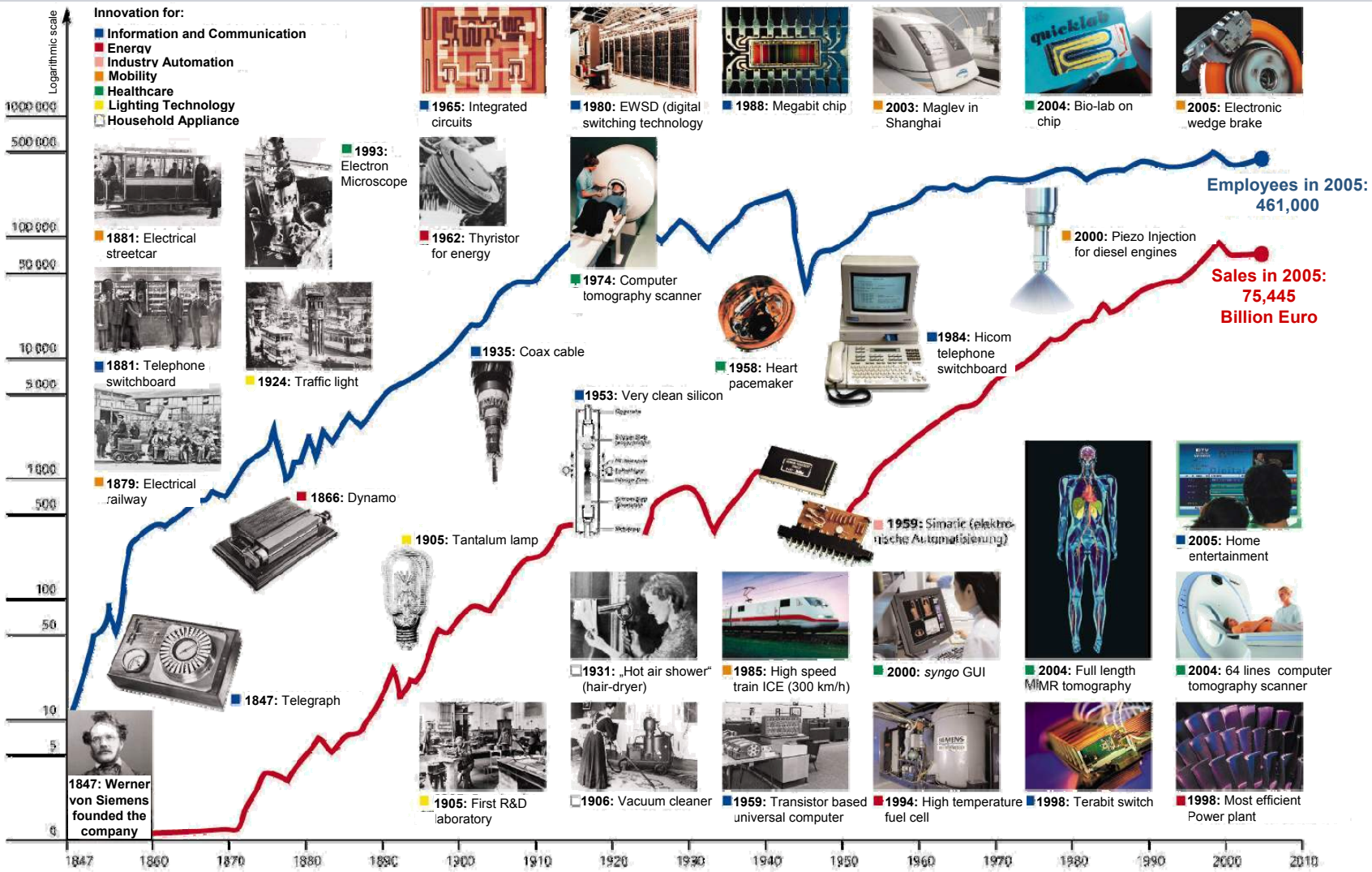

Siemens Company

Almost 50.000 R&D Employees at 150 Locations

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Corporate Technology
Innovation Network of the Integrated Company

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Customers

Chief Technology Officer (CTO)

- Evaluation of innovation strategy
- Technology based support of synergies
- assurance of innovative power
- Evaluation of technologies
- Guidance

Sectors / Divisions

Industry

Energy

Healthcare

Regions

Siemens IT Solutions and Services (SIS)
Siemens Financial Services (SFS)

Chief Technology Office (CT O)

- Direct support of CTO

Corporate Research and Technologies (CT T)

- Global Technology Fields with multiple impact
- Pictures of the Future
- Accelerators for new business opportunities

Corporate Intellectual Property and Functions (CT I)

- Intellectual Property Services & Strategy
- Standardization, Environmental Affairs
- Global Information Research

Corporate Technology (CT)

Corporate Technology
Modeling, Simulation, Optimization

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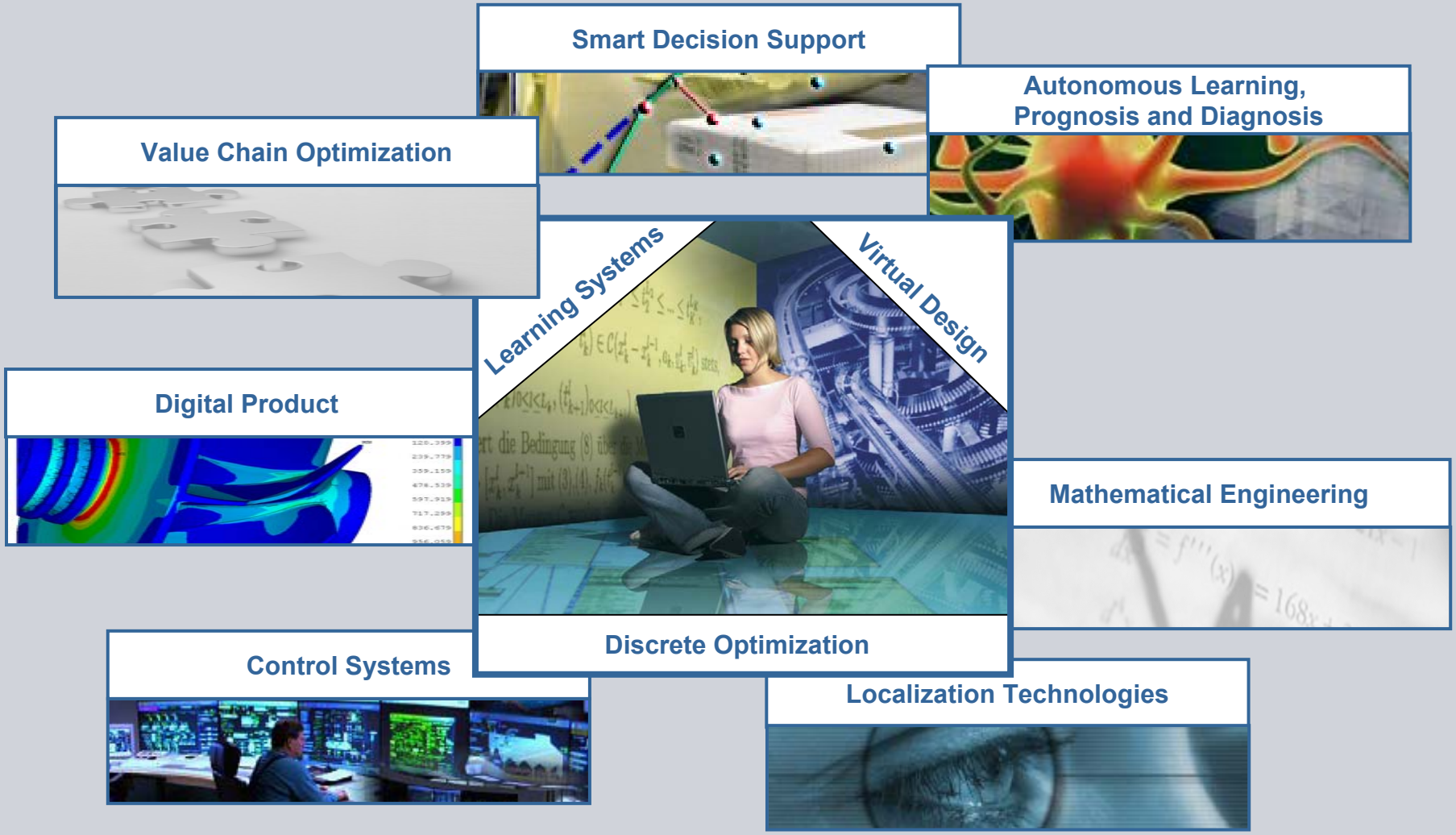

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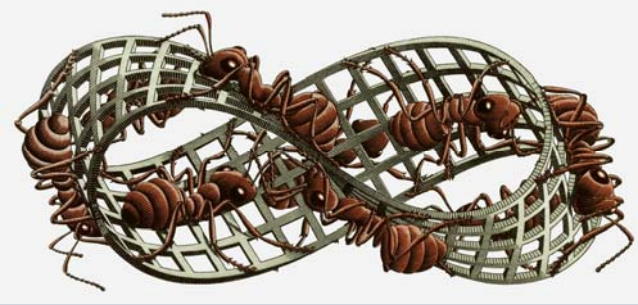
Mathematics



Maid?

Queen?

Mathematics evolves its impact most effectively if it appears as a <u>PARTNER</u> together with other sciences and technologies

Research and Innovation
The Mindset

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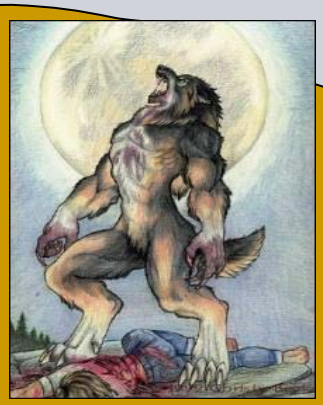

Giants …

- GUI
- 100k LOC
- Middleware
- Incorrect inputs
- External systems
- Data base
- Operating system
- Bug Fixing
- Commissioning
- Interfaces
- Software Engineering

Dwarfs and elves

- Modeling
- Theorems and proofs
- Algorithms

… and Dragons

Research and Innovation
From Modeling to Application

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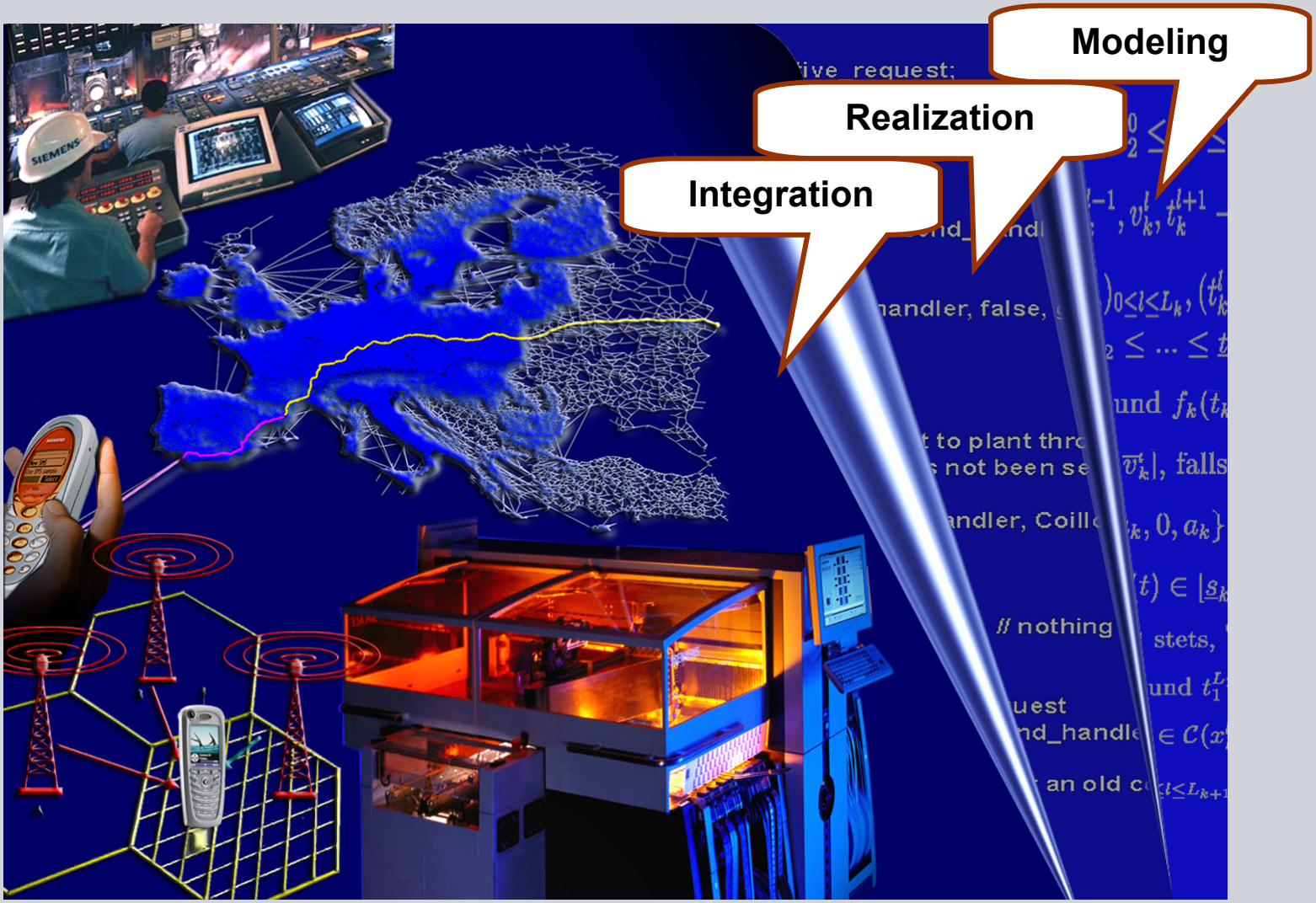

Assembly of Printed Circuit Boards

Optimizing the automaton

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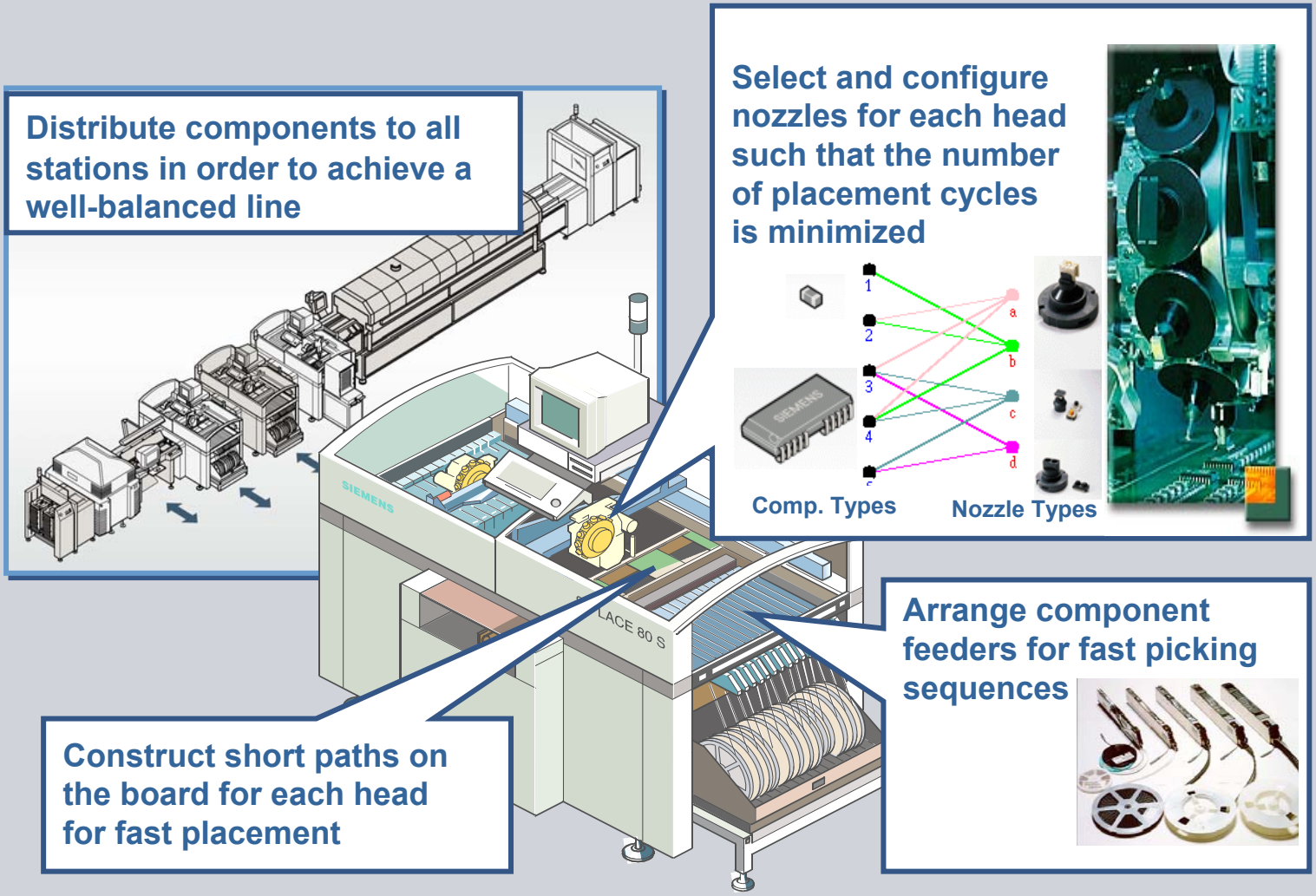

Assembly of Printed Circuit Boards
Coherence in Systems Hierarchy

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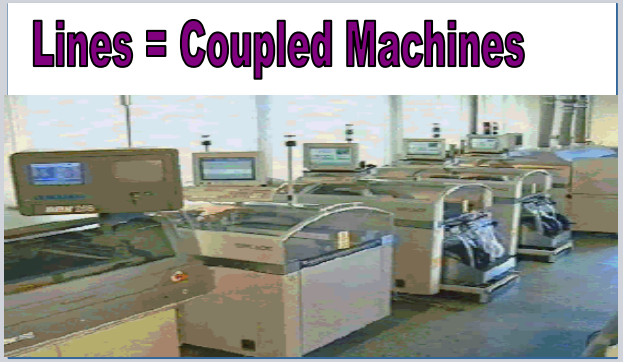

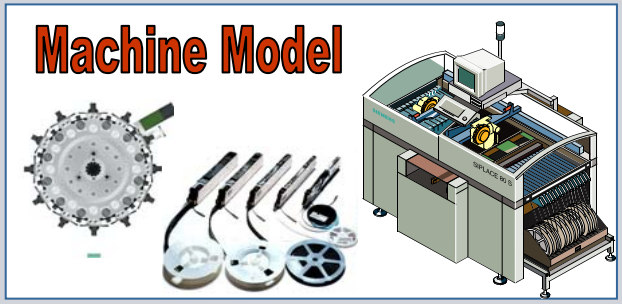

Coherence of Models ↔ Semantic Coupling

Factory
- Layout
- Dispatching and scheduling
- Staff assignment
- Material supply
- Maintenance planning

Production Lines
- Matched line configuration of machines
- Optimum component feed along the line
- Trade-off between set-up times and processing times

Machine Level
- Timing and spatial constraints of single machines
- Necessary resources behavior
- Availability

Assembly of Printed Circuit Boards
Nozzle Selection

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Given:

- **Bipartite Graph** $G = (U \cup V, E)$ **such that**

$$(u,v) \in E \quad \Leftrightarrow$$

Component type u **may be placed through nozzle type** v

- **For every node** $u \in U$ **a component number** b_u
- **For every edge** $(u,v) \in E$ **an integer variable** y_{uv}
- **For every node** $v \in V$ **an integer variable** x_v
- $k =$ **Number of nozzle positions at the placement head**
- **Variable** $z =$ **Number of placement cycles**

Nonlinear model:

$$\min \; z$$

such that

$$\forall u \in U : \sum_{v:(u,v)\in E} y_{uv} = b_u$$

$$\forall v \in V : \sum_{u:(u,v)\in E} y_{uv} \le z x_v$$

$$\sum_{v \in V} x_v \le k$$

All variables nonegative integers

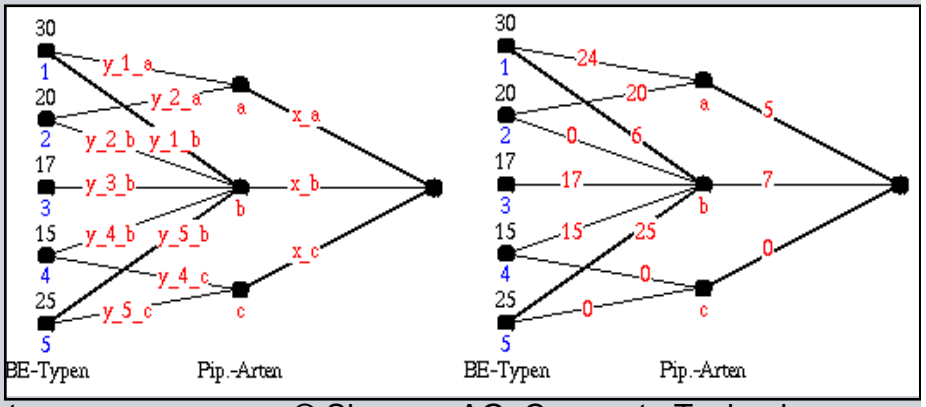
Minimize no. of placement cycles

All components have to be placed

Set up a sufficient number of nozzles at placement head

Upper limit for nozzle segments

Runtime requirement: At most 5 ms!



Water Supply Network Planning
A Simple Network

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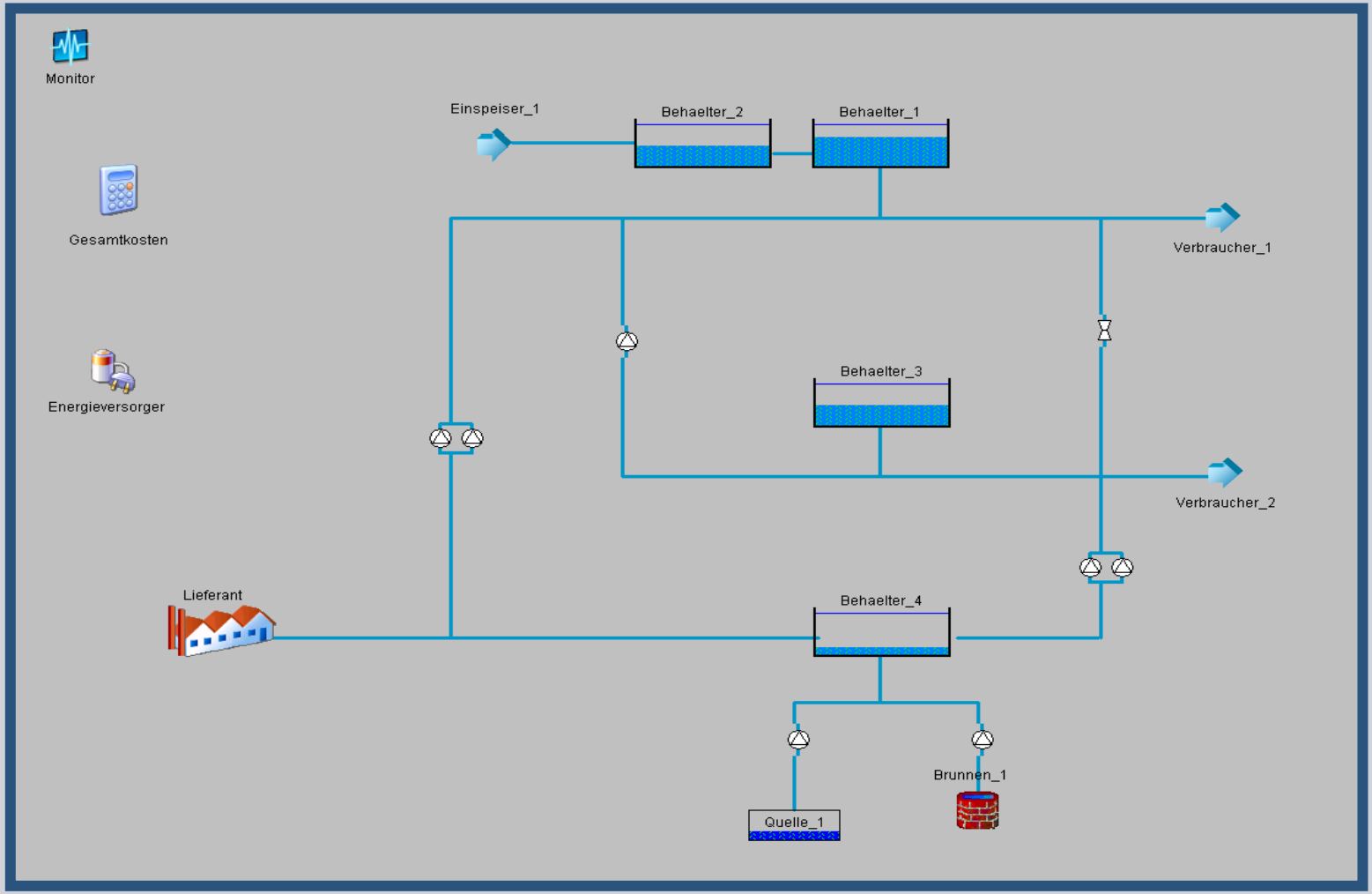

Water Supply Network Planning
Inputs and Goals

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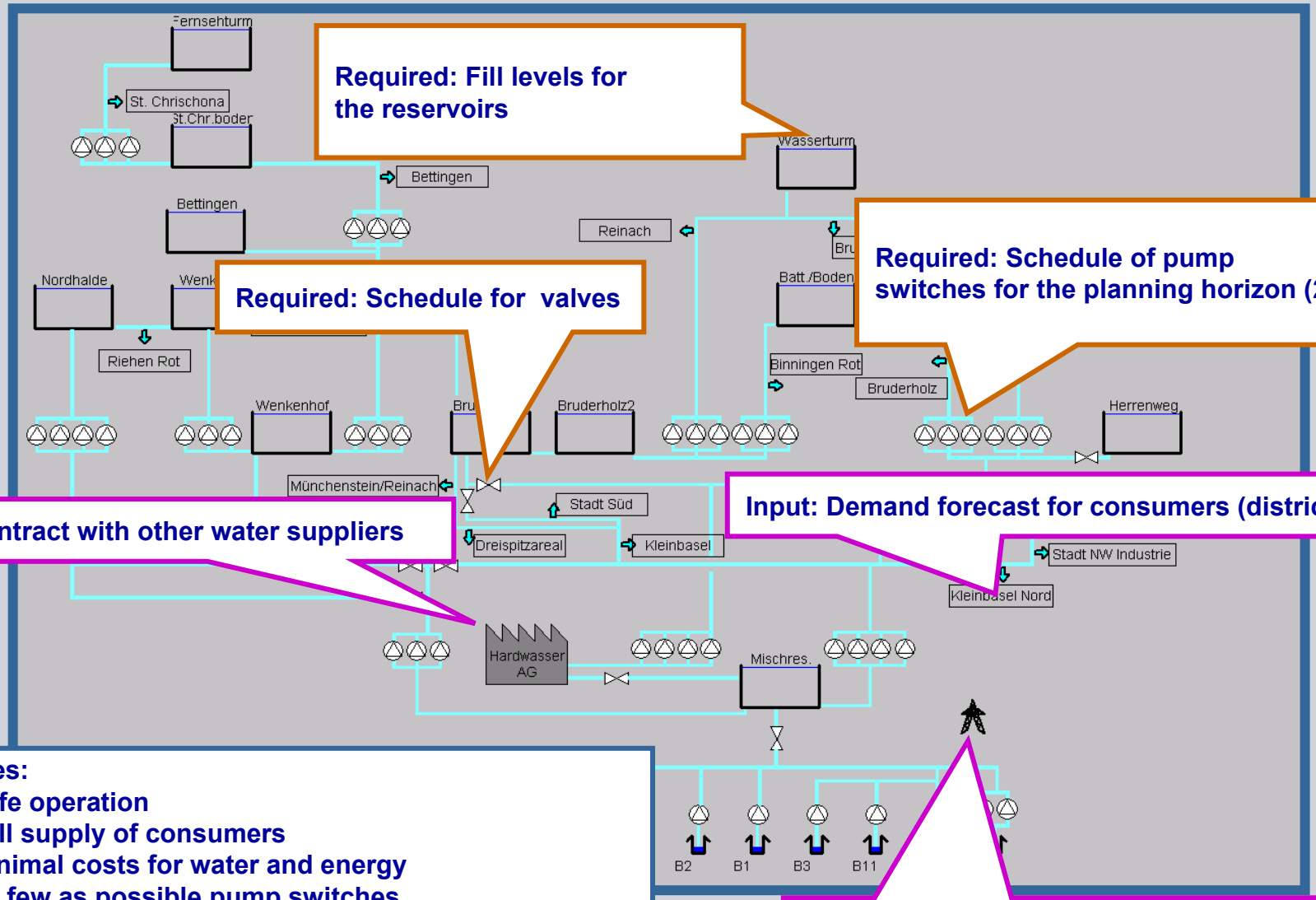

Required: Fill levels for the reservoirs

Required: Schedule for valves

Required: Schedule of pump switches for the planning horizon (24h)

Input: Contract with other water suppliers

Input: Demand forecast for consumers (districts)

Input: Contract with energy supplier

Objectives:

1. **Safe operation**
2. **Full supply of consumers**
3. **Minimal costs for water and energy**
4. **As few as possible pump switches**

Water Supply Network Planning
Inputs and Goals

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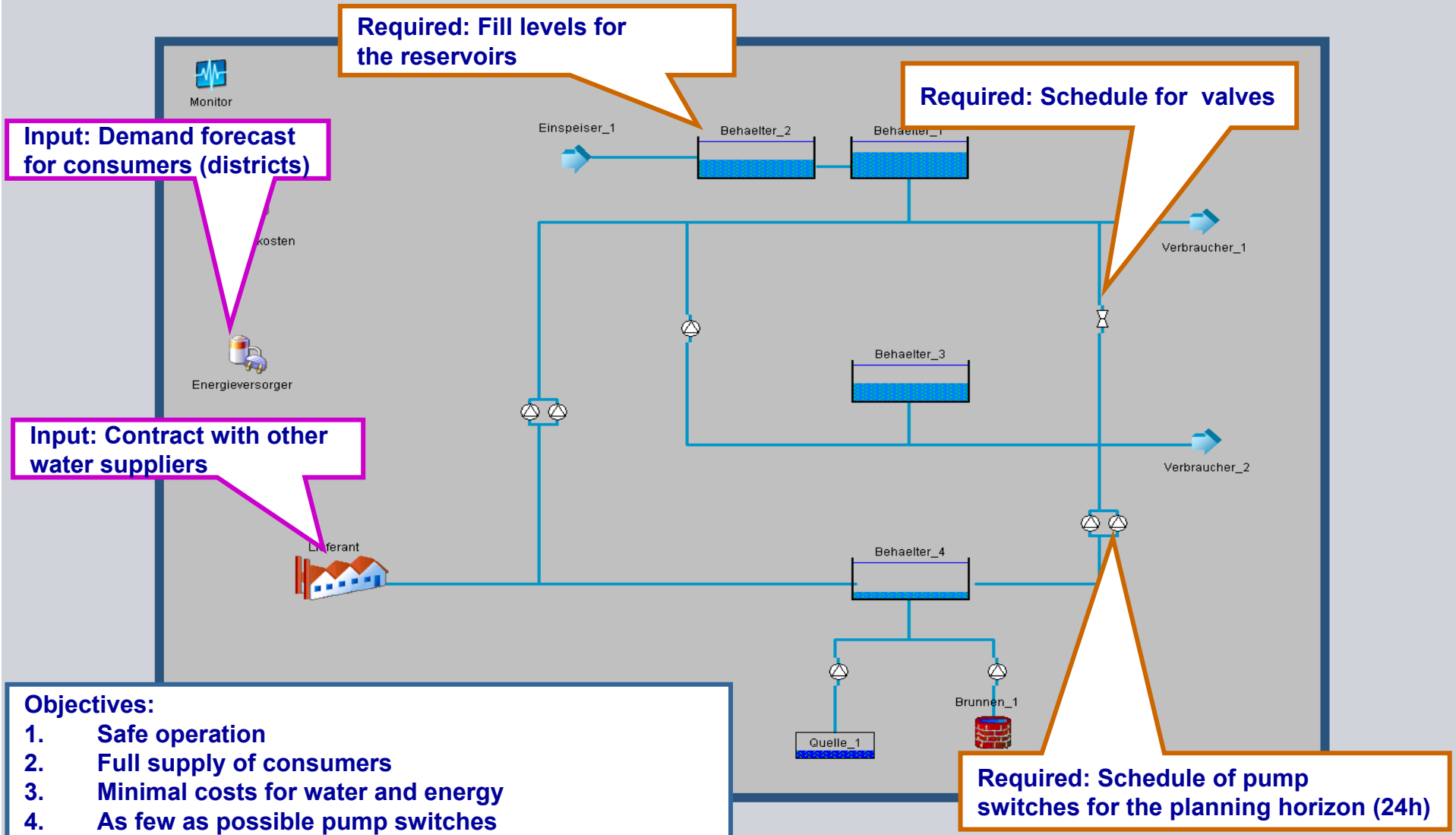

Objectives:

1. **Safe operation**
2. **Full supply of consumers**
3. **Minimal costs for water and energy**
4. **As few as possible pump switches**

Water Supply Network Planning
General Setting for Optimization

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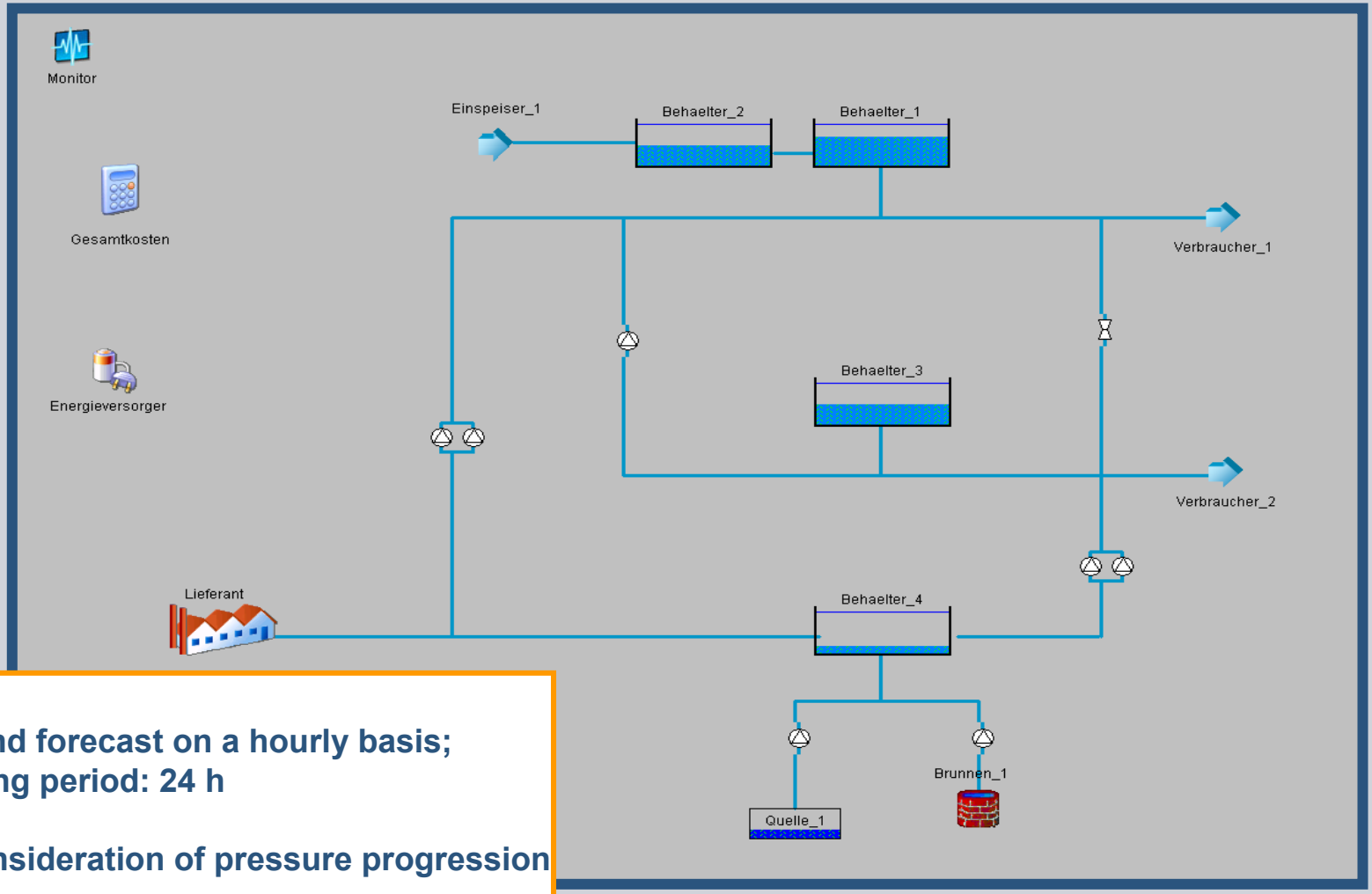

- **Demand forecast on a hourly basis; Planning period: 24 h**
- **No consideration of pressure progression**

Water Supply Network Planning
Subnets

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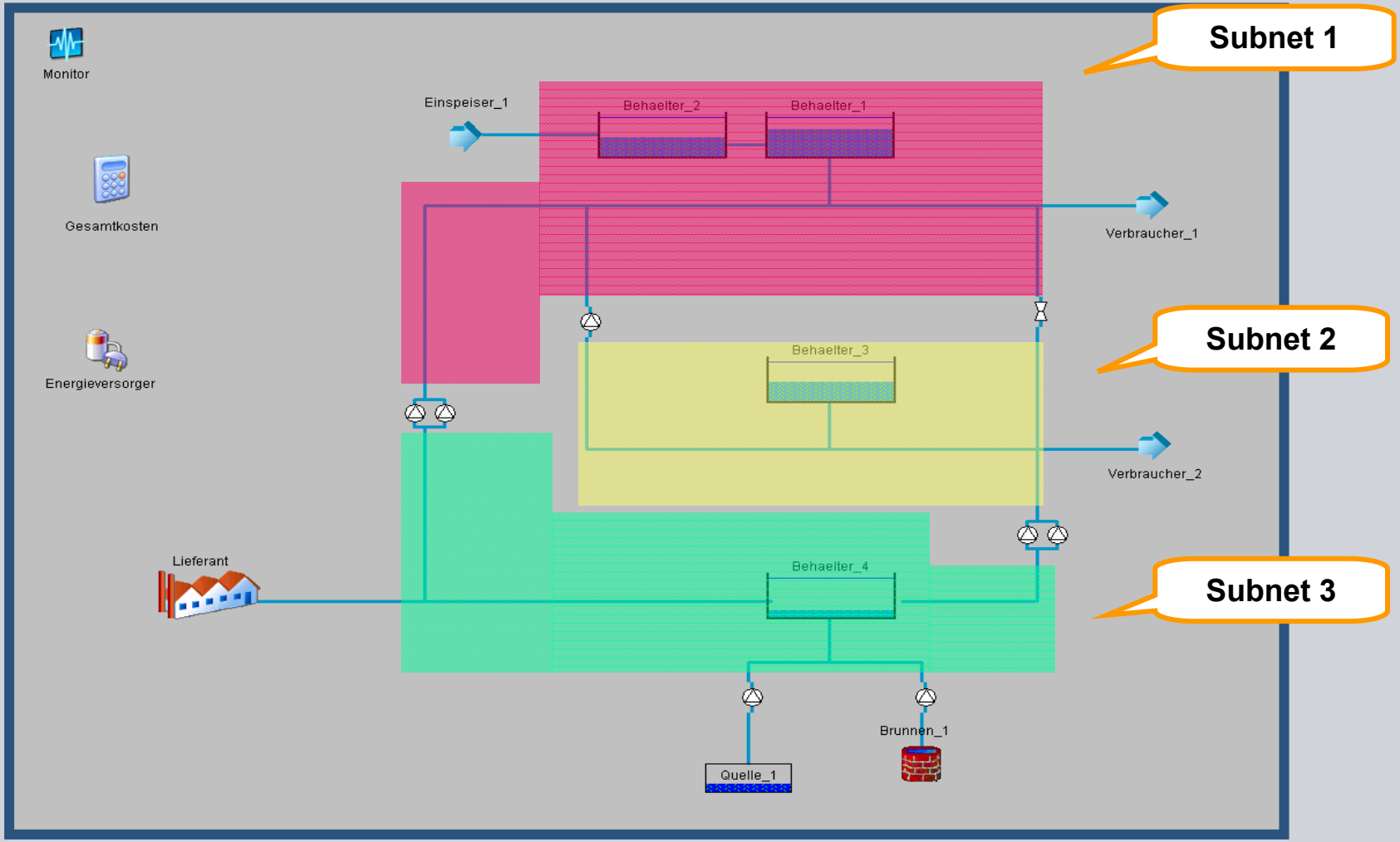

Water Supply Network Planning
Graph Model

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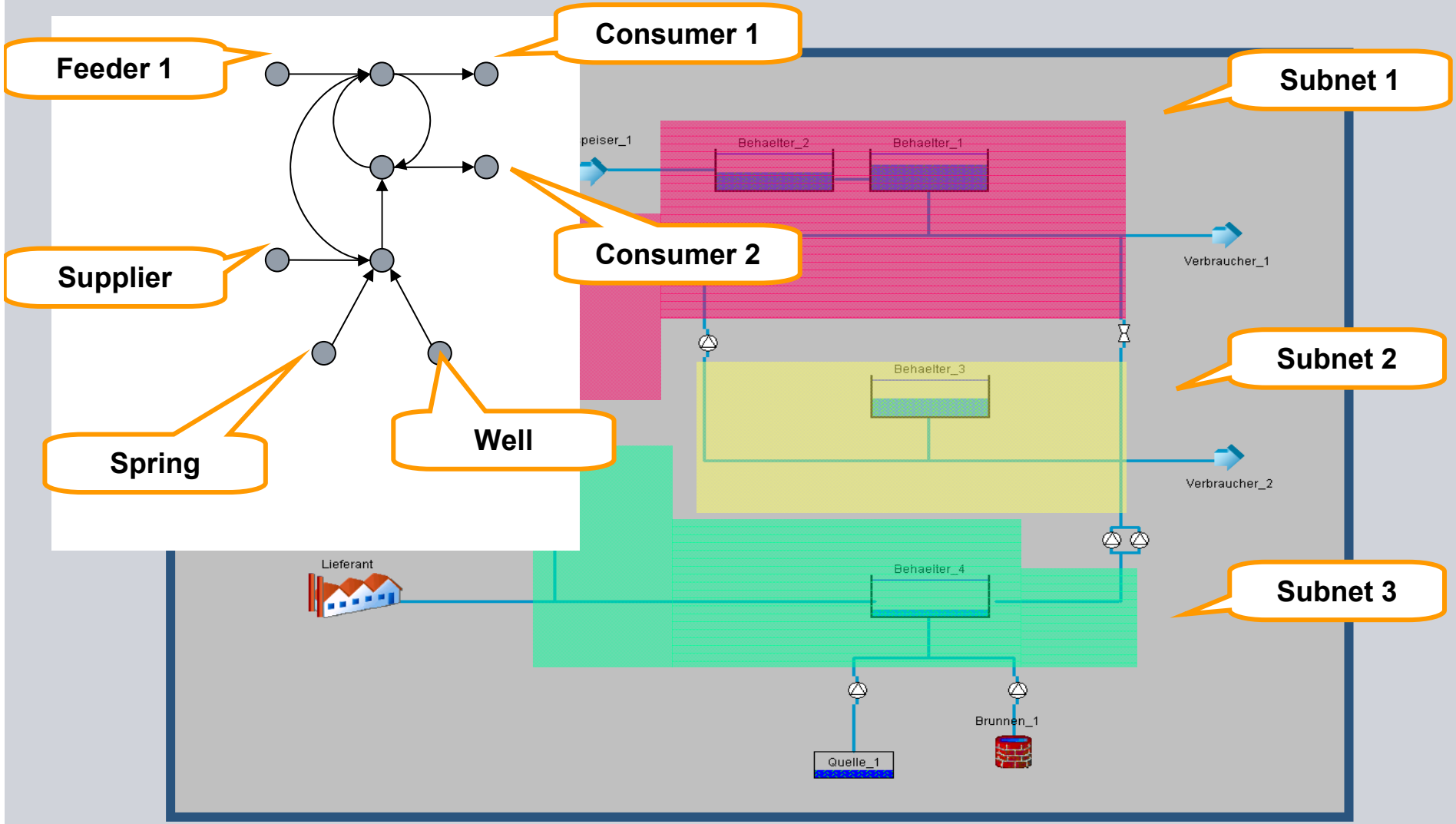

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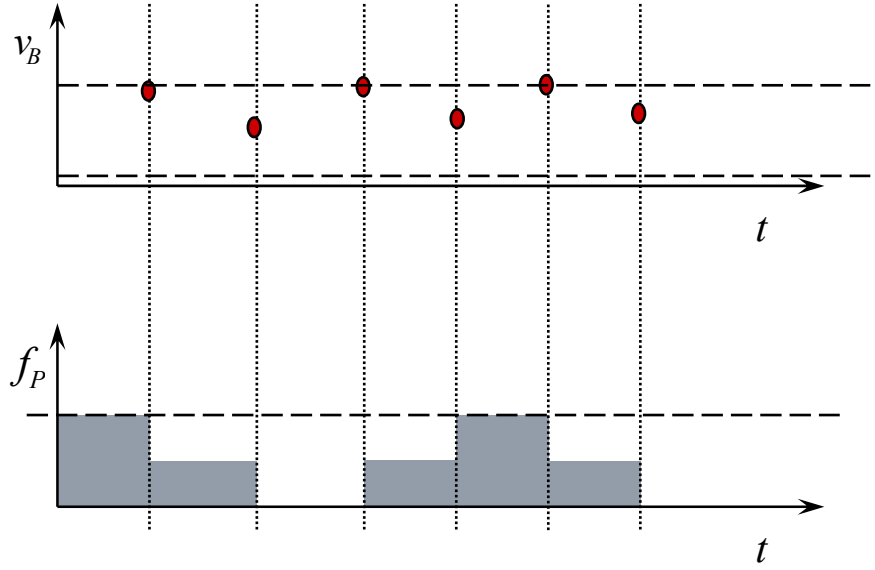
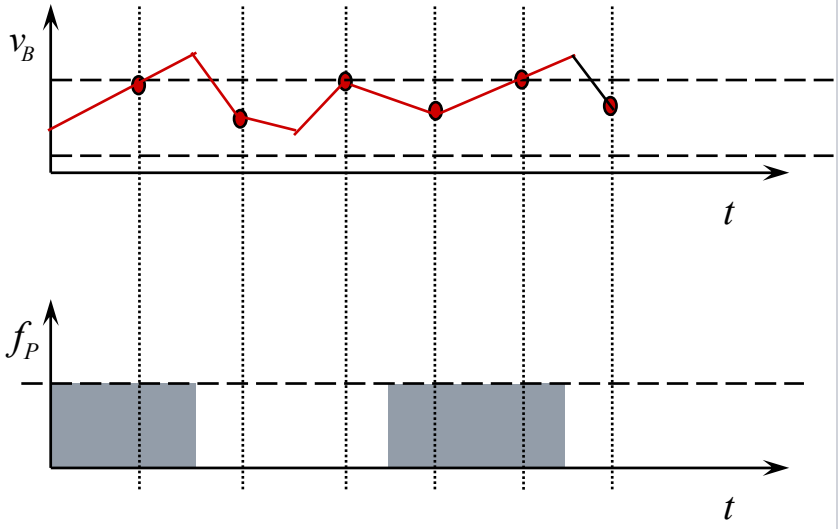
Min cost flow solutions



Solutions of the model have to be transformed into switching points of time for the pumps and fill level curves for the reservoirs

Schedules / fill levels



Water Supply Network Planning
The Real Planning Cycle

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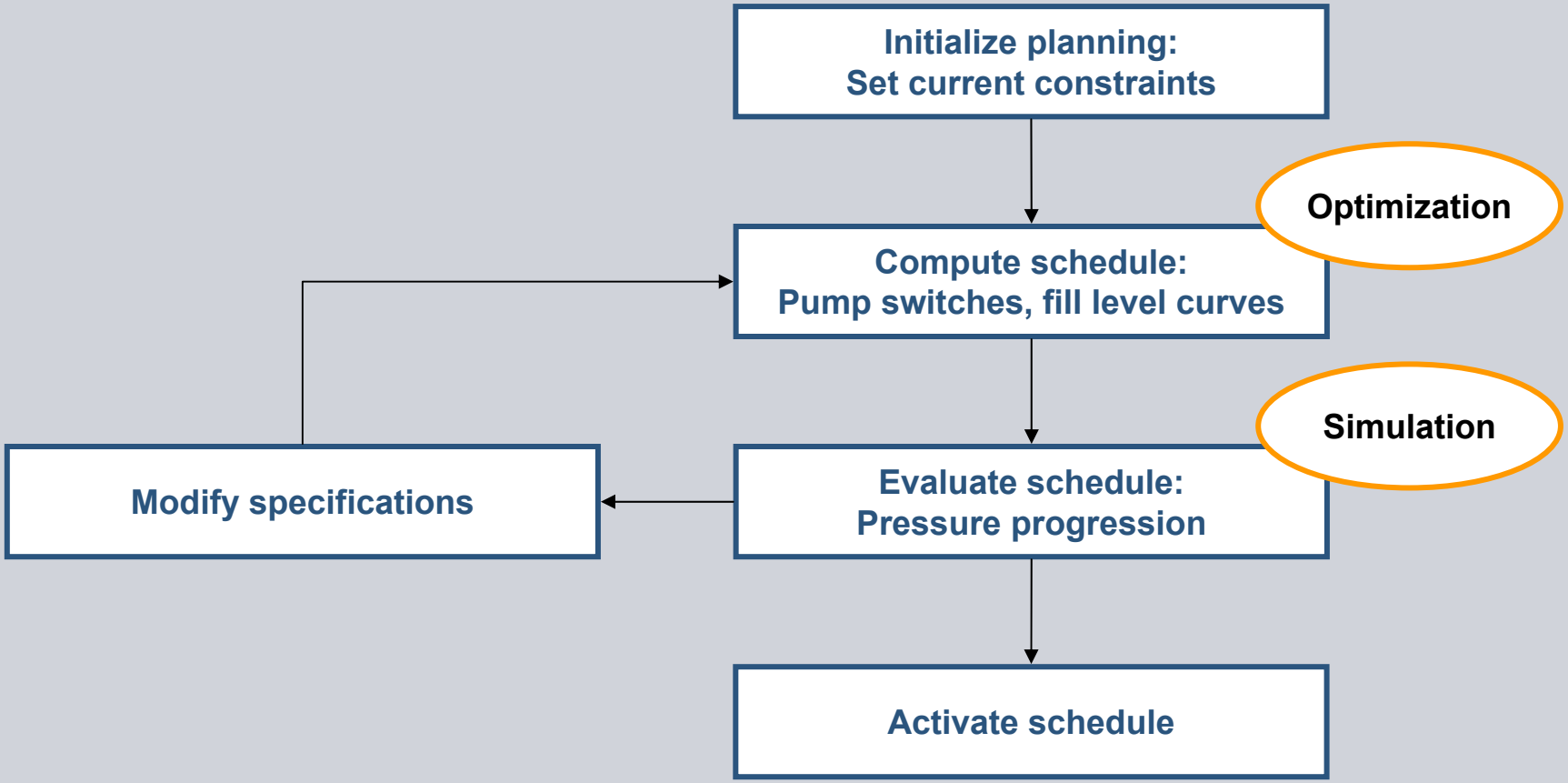

Water Supply Network Planning
The Toolset

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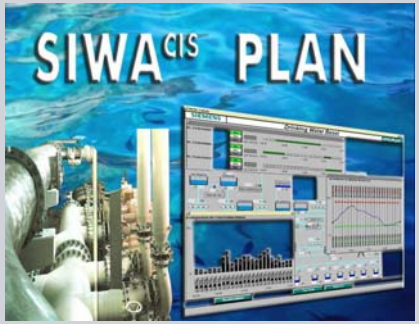
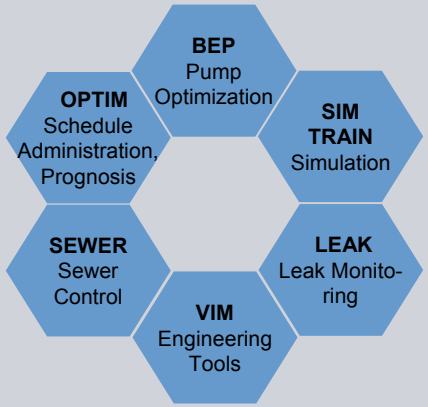
- Siwa-Plan is a toolset for the **management** of water supply networks, including planning and control functions.
- Using Siwa-Plan, the first step is the **engineering** of the water net under consideration.
- In addition to the implementation of optimization and simulation routines, the challenge is to **generate** an appropriate optimizer and simulator.





Water Supply Network Planning
Integration Into Control Equipment

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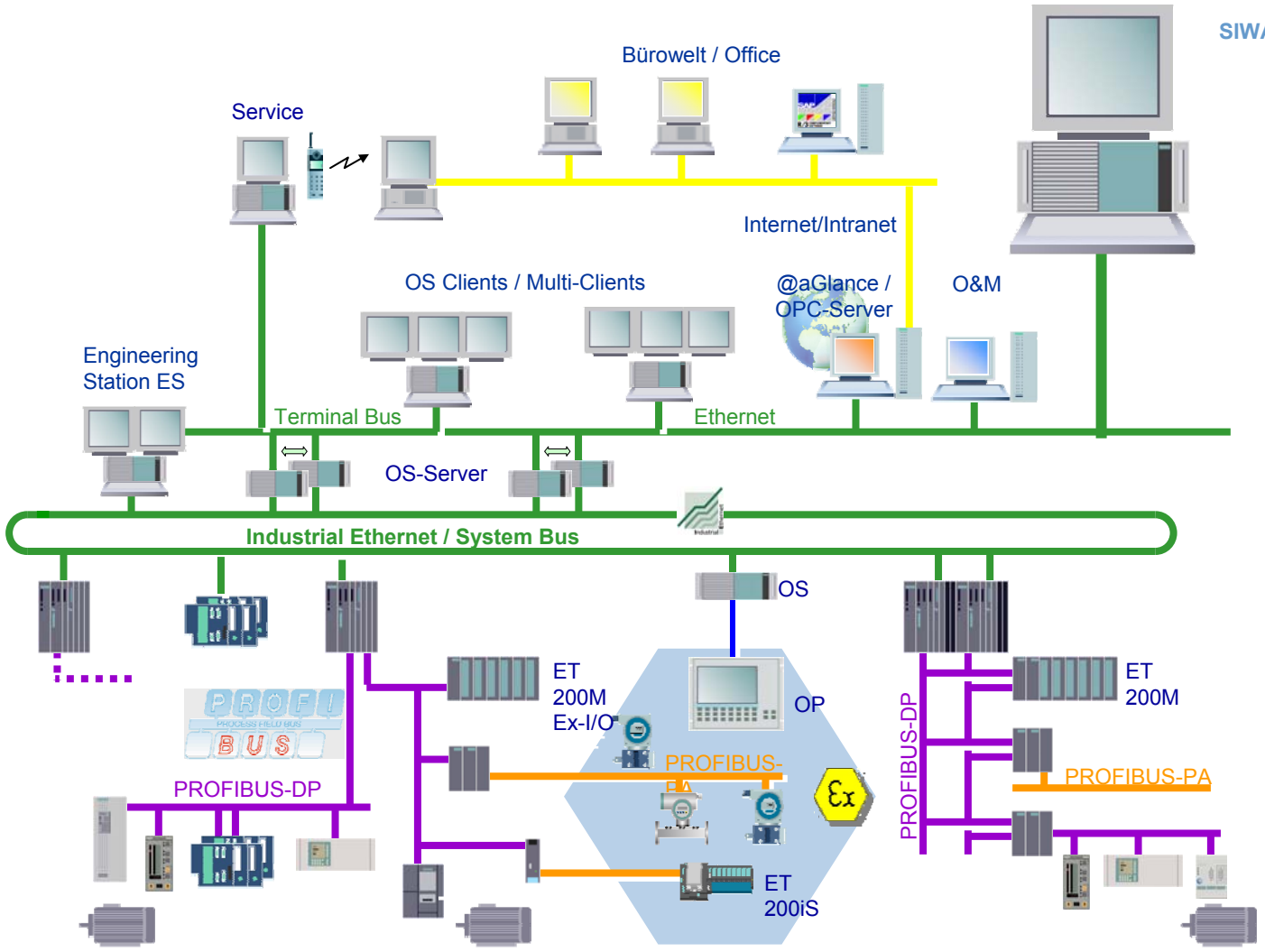

The Internet of Things
Routing Goods Like Data

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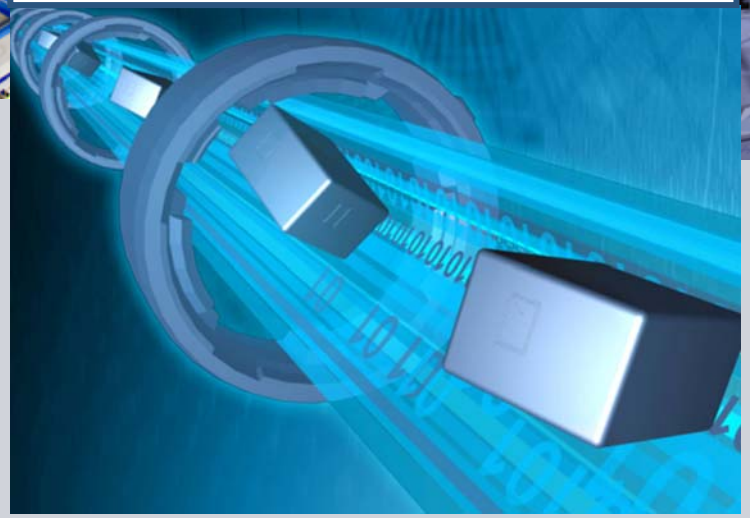
Baggage handling at Beijing airport

Mail distribution centers

The Internet of Things – A public funded project *)



*) German Federal Ministry of Education and Research

The Internet of Things

Hierarchical Structure of Commissioning Systems

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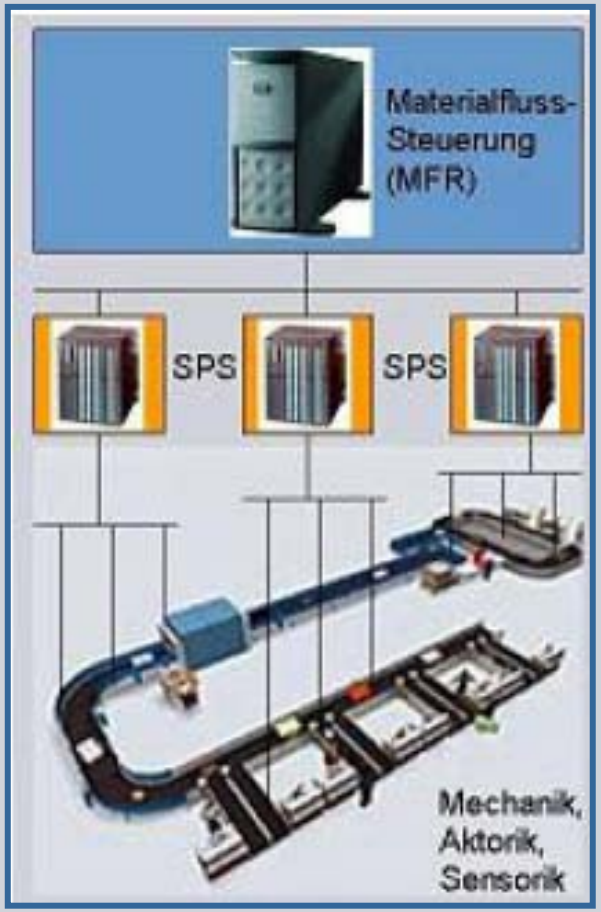
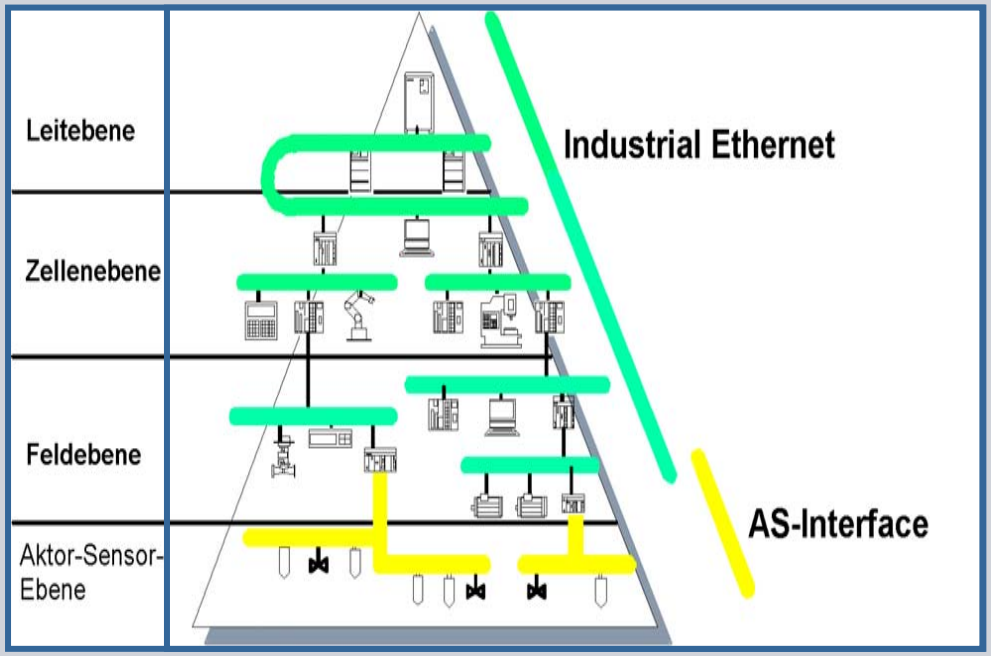
Hardware



IT-Structure



The Internet of Things
Basic Concepts

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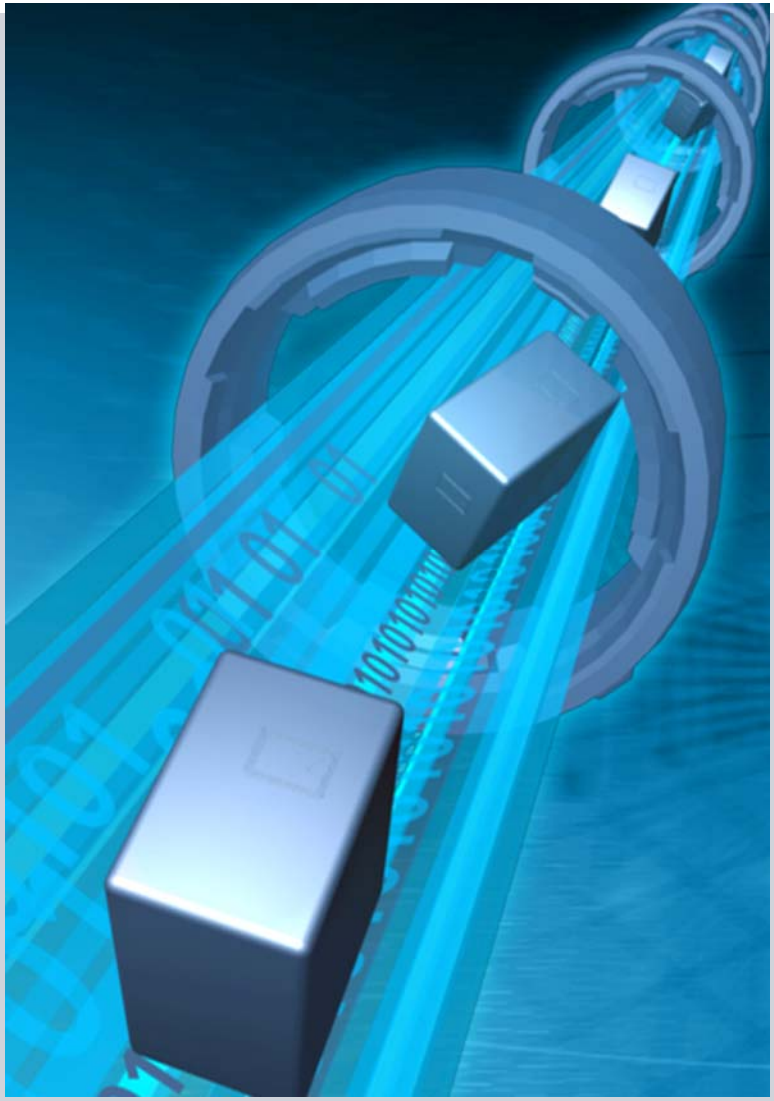
New controls architectures
- Migration of “Intelligence" to field level (e.g., "intelligent drives")
- Distributed controlling functions
- Vernetzung of devices at field level ("industrial ethernet")
- Web based services for the level of controls ("one homepage for every motor")

New systems architectures
- Distributed software systems
- Decentralized controls (e.g., agent technology)
- "Aware objects" (RFID, RF-based systems)
- Pervasive computing

New material flow strategies
- "Routing goods like data" (e.g., like e-mail)
- Methods of network management (e.g., IP routing) in physikal-logistic systems



The Internet of Things
Negotiations of Local Agents

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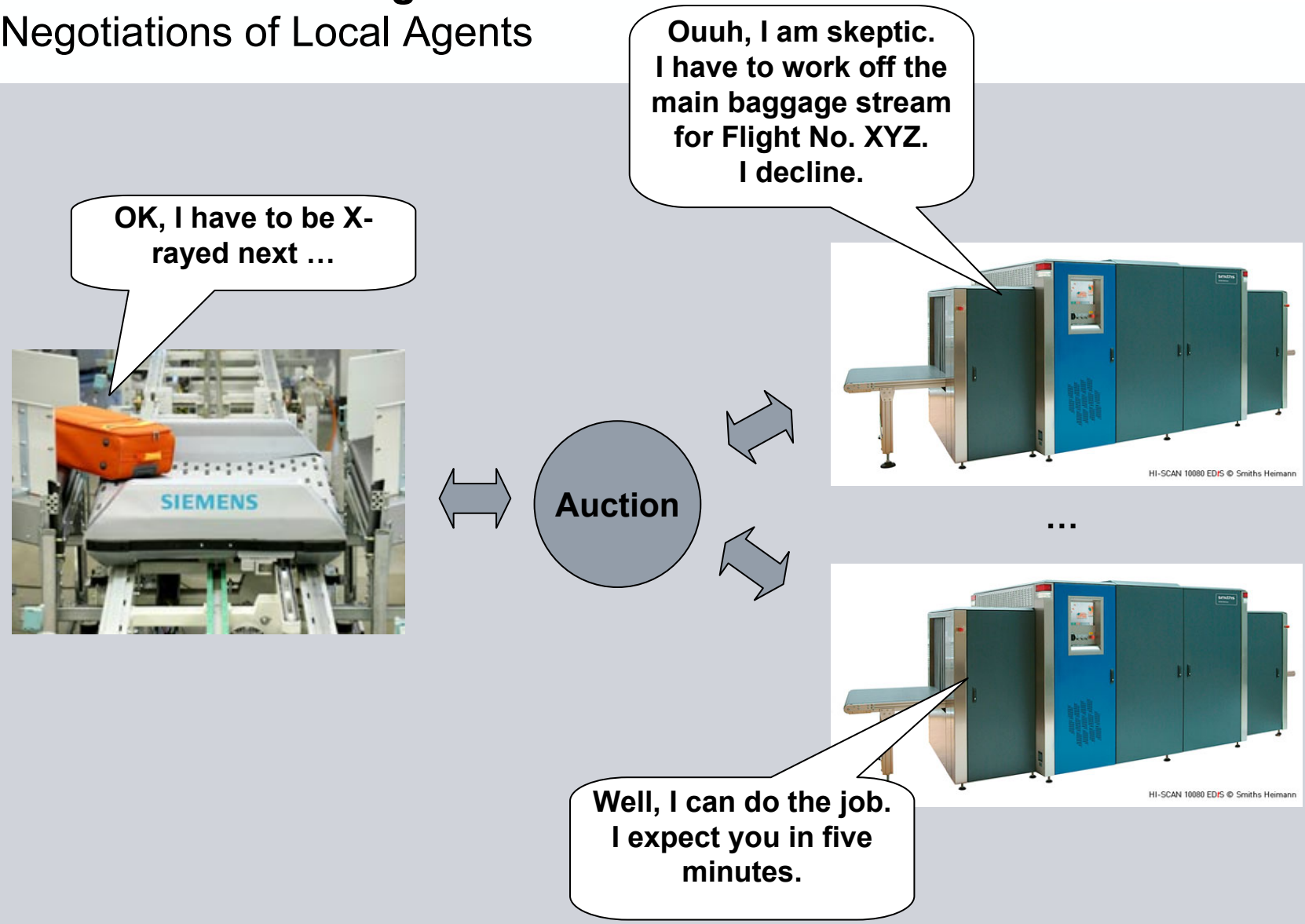

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Where to localize the agents?

- At the field modules
  - *Module agents have to manage their own workload in order to avoid congestion*

- At the material to be conveyed
  - *Baggage agents are responsible for their route through the net*

The Internet of Things
State Space of Agent Systems

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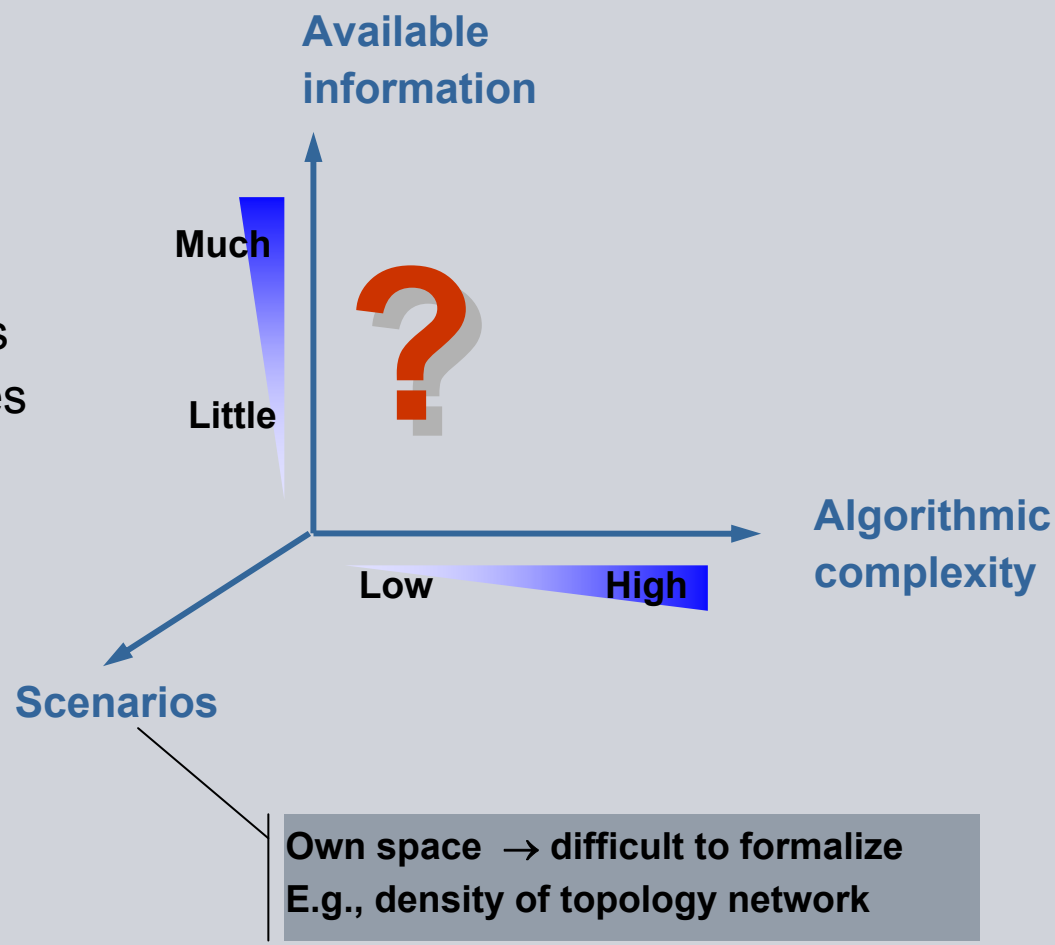
- **Available information**
  - Much: global, up-to-date
  - Little: local, out-of-date
- **Algorithmic complexity**
  - High: Complex computations
  - Low: Simple conditional rules
- **Scenarios**
  - Topology, dispatching, error handling, etc.



The Internet of Things
A Simple Scenario

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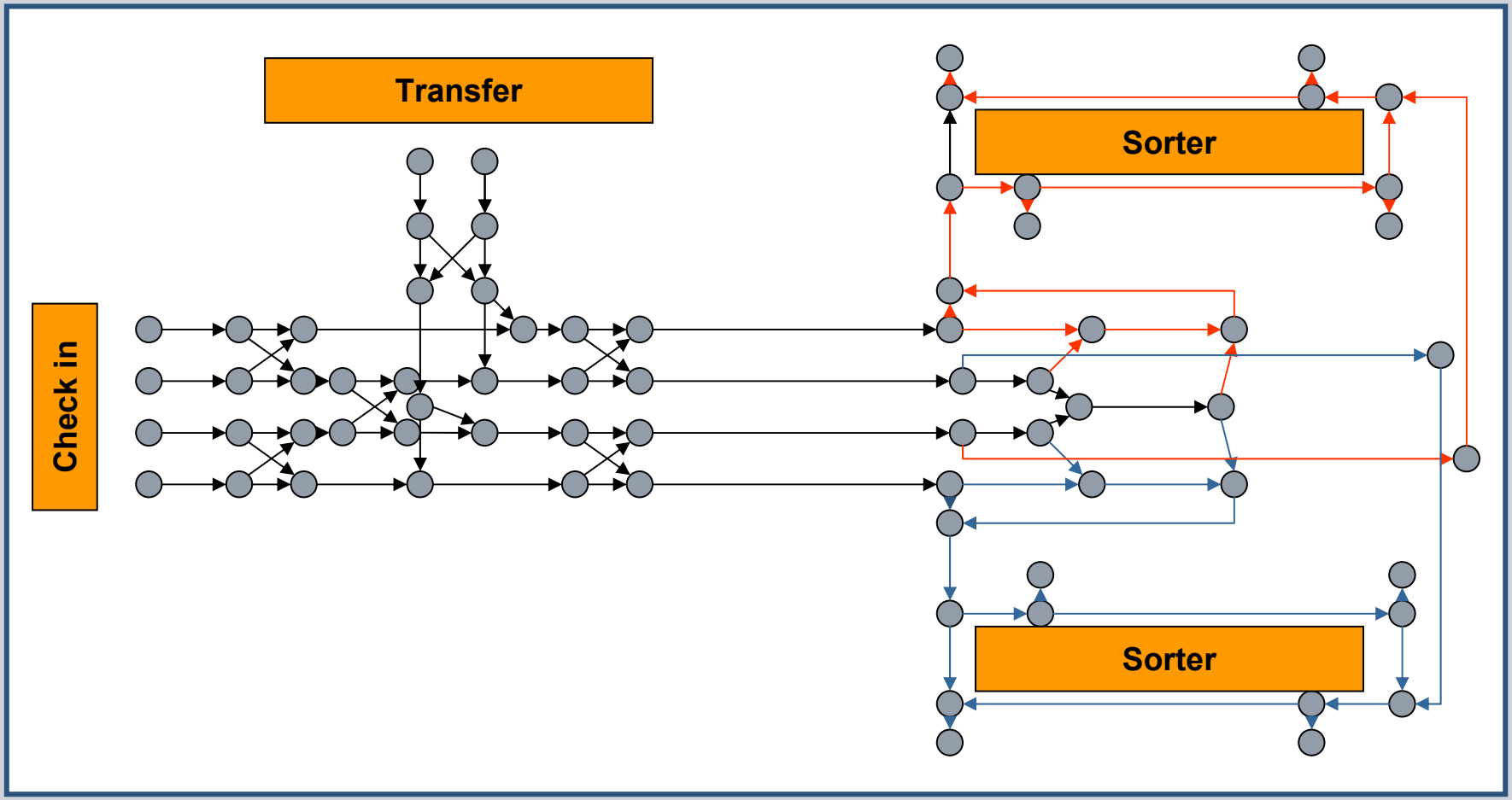

The Internet of Things
Three Scenarios

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For all scenarios: **Baggage agents plan their route exactly once, at Check In.**
Congested edges will be ignored.

Scenario name	Baggage agent	Conveyor agent	Communication
Stupid	Algorithm: Dijkstra Required edge information: ▪ Lengths of edges	Knowledge about itself: ▪ Length	B: What is your length? C: x meters
Up-to-date	Algorithm: Dijkstra Required edge information: ▪ Length of edges ▪ Current workload (-> **Penality cost**)	Knowledge about itself: ▪ Length ▪ Current workload	B: What is your length? C: x meters B: What is your current workload? C: y parcels
Anticipatory	Algorithm: Dijkstra Required edge information: ▪ Lengths of edges ▪ Expected workload at time t (-> **Dynamic penality cost**)	Knowledge about itself: ▪ Length ▪ Expected work load progression	B: What is your length? C: x meters B: What is your expected workload at time t_1? C: y parcels B: Expect me at time t_2! C: Well, I will update my forecast.

The Internet of Things

Stupid Routing – Situation Short After Dispatching

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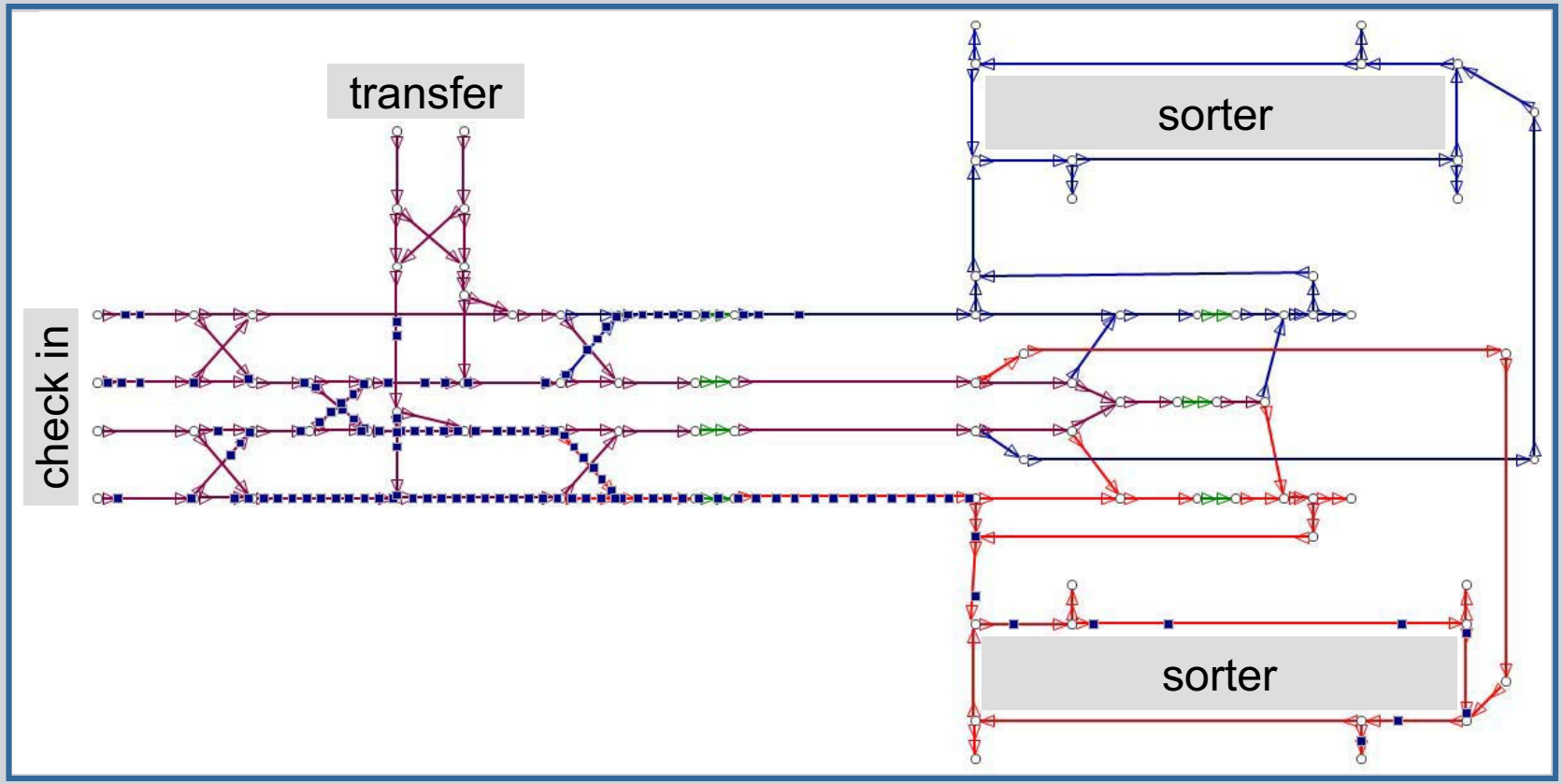

The Internet of Things

Anticipatory Routing – Situation Short After Dispatching

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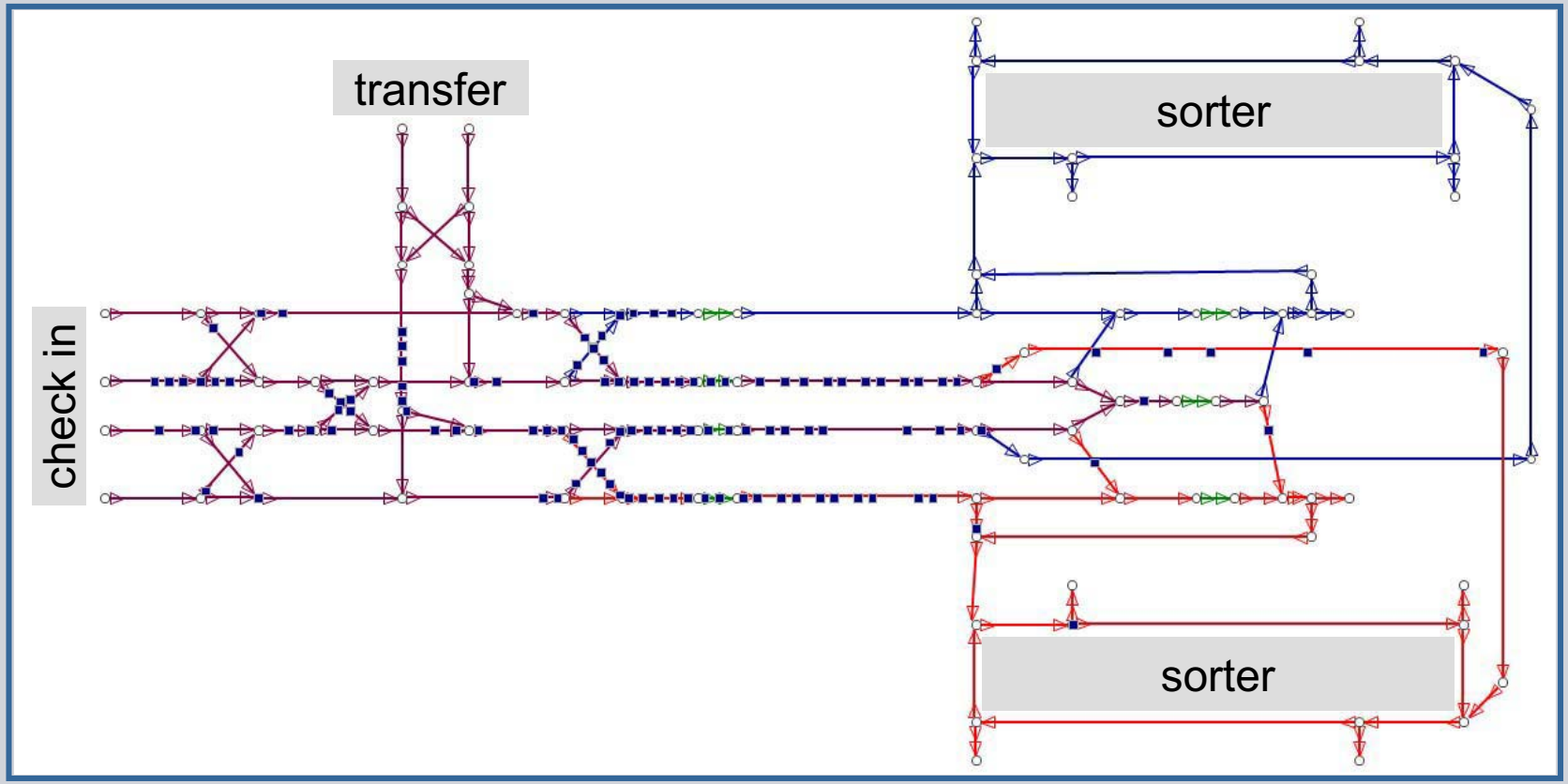

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Conclusion

- The rapid increasing complexity of industrial challenges requires usage of mathematical methods of modeling, simulation and optimization to a great extend.
- Mathematicians and computer scientists are invited,
  - To improve available tools and methods continuously, and
  - To assist usage of such methods within projects along the complete life cycle of products, plants and systems.
- The tight, project related collaboration with engineers and users is essential for the successful application of such methods.

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Thank you for your attention!

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