Fundamentals of Business Information Systems

Information Systems for design, planning and control of value-adding processes

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MMag. Haeussler, PhD

Content

- Introduction to information systems for planning and control of value-adding processes
- Introduction to quantitative methods of Operations Management/Research
- Practical case: Master Planning - Sales and Operations Planning

Team Production and Logistics Management

- Research topics:
  - Production planning and control,
  - Inventory Control,
  - Behavioral Operations Management (BOM).
- Application and analysis of quantitative models within business administration – operations managment/operations research:
  - Optimization models,
  - Discrete event simulation and queueing models
  - Regression models,
  - Forecasting,
  - Experimental research.

Courses

- Introduction to Management for students with a degree in Computer Science: "Value-Adding Processes in Organizations" (Haeussler/Missbauer)
- **Operations Management Track**:
  - Elective Course – summer term:
    "**Operations Management I**: IT-supported Production and Supply Chain Planning – Concepts, Methods and Software" (Haeussler/Missbauer)
  - Elective Course – winter term:
    "**Operations Management II**: Applying Methods of Operations Managements - Optimization, Simulation and Analytics" (Haeussler/Missbauer)

Master theses

In cooperation with companies and theoretical theses, e.g.:

- Der operative Beschaffungsprozess der **HILTI AG**
- Erarbeitung eines zeitoptimalen Bereitstellungskonzeptes für die separate Türenmontage bei der **BMW Group**
- Vorstudie zur Erstellung einer Wertstromanalyse für den logistischen Gesamtprozess am Beispiel der **Lufthansa** Cargo Centers
- Lot size optimization at **Swarovski**
- Decision Support Tool for material sequencing of different types of heating furnaces running in parallel mode
- Production planning using dynamic planned lead times: A machine learning approach
- Literature Review on Practical Implementations of the Workload Control (WLC) Concept

Definitions

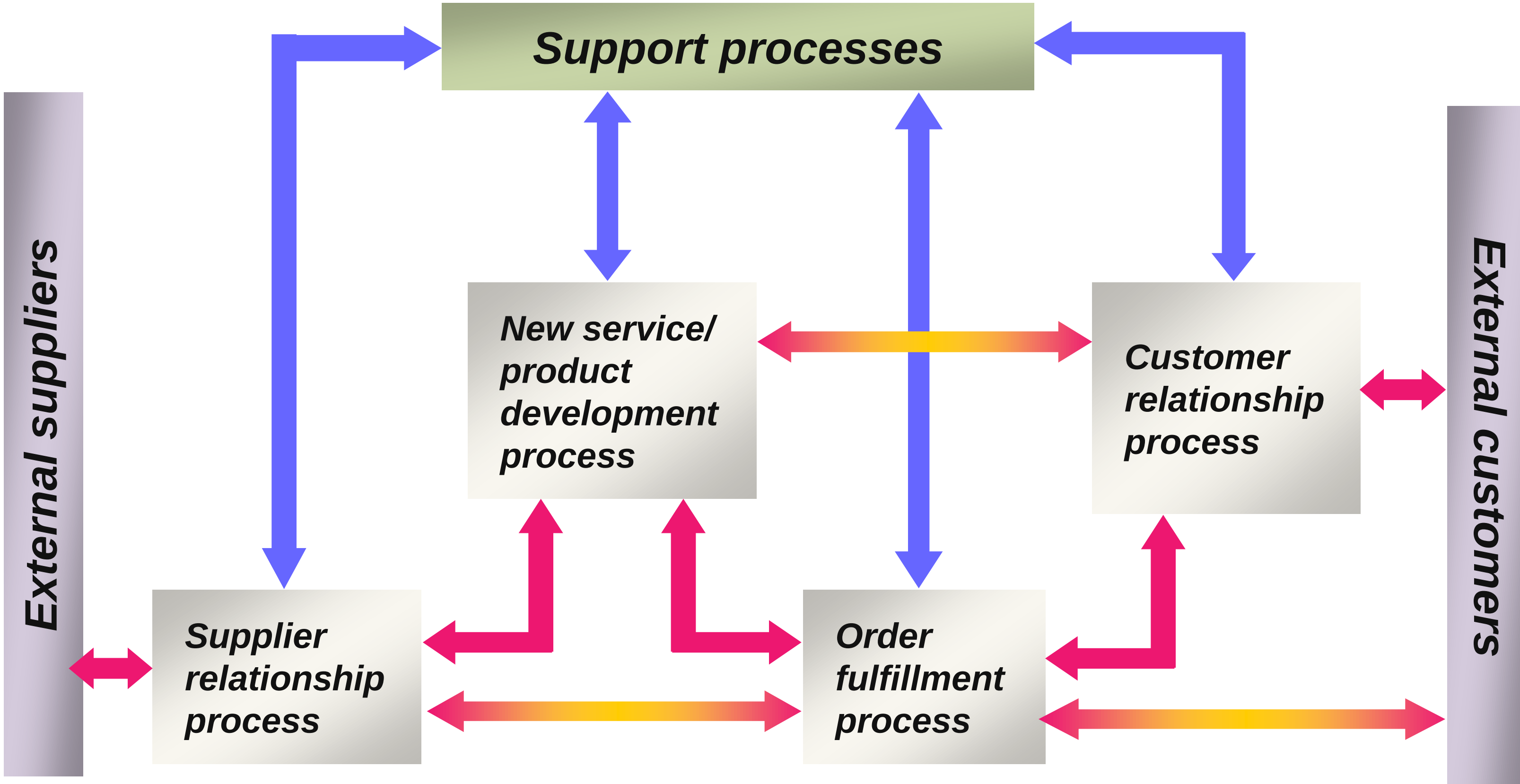
Source: Krajewski/Ritzman 2007, p. 8 f.

- The **value chain** is “the interrelated series of processes that produces a service or product to the satisfaction of the customer.”
- “A **core process** is a chain of activities that deliver value to external customers …”
- **A support process** provides vital resources and inputs for the core processes …”

Value-chain linkages showing work and information flows

Source: Krajewski/Ritzman 2007, Chapter 1 (support material)

Firms have many processes that support the core processes.

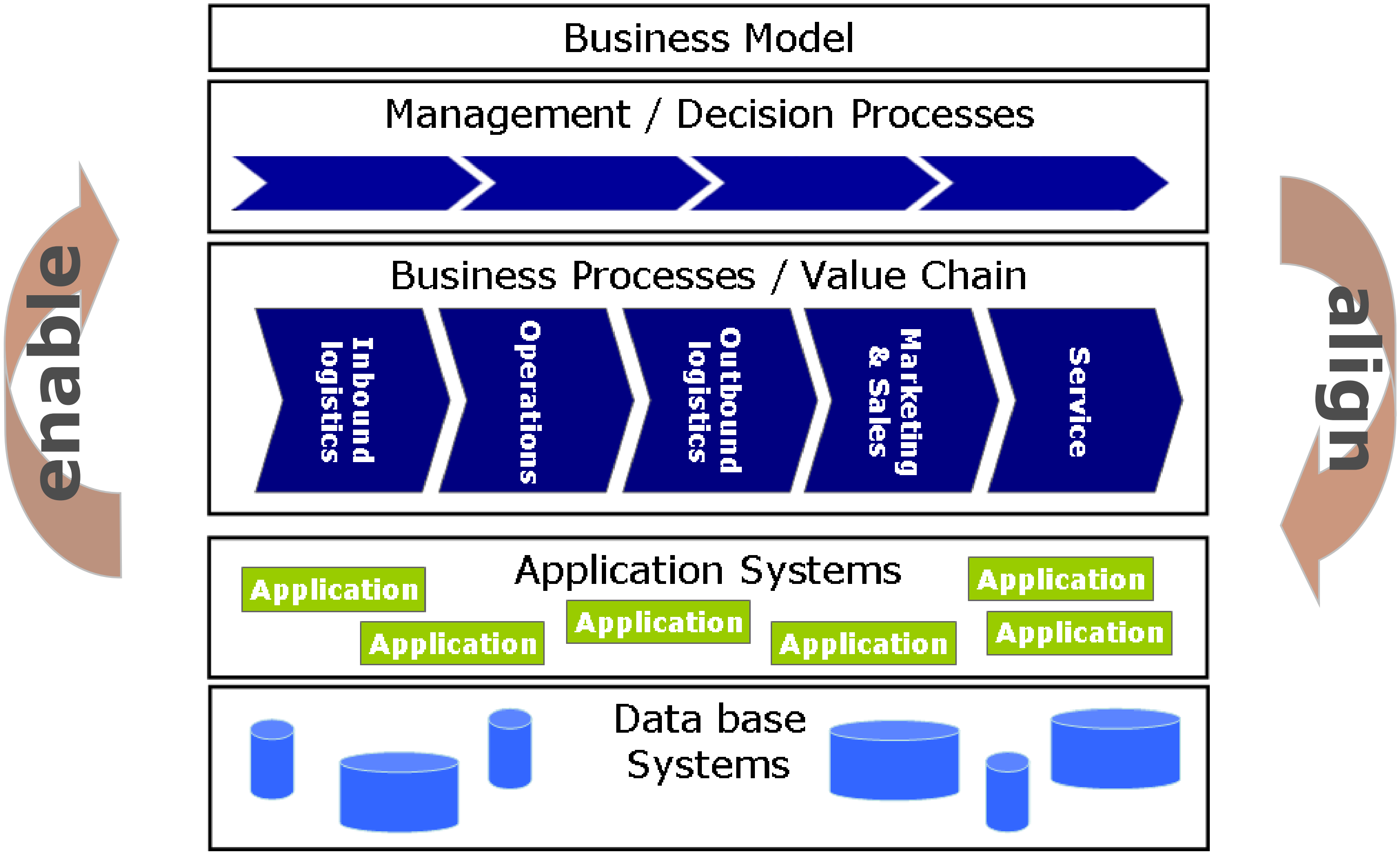


Core processes

Source: Krajewski/Ritzman 2007, Chapter 1 (support material)

1. **Customer relationship processes**
   Identify, attract, and build relationships with external customers and facilitate the placement of orders.
2. **New service/product development processes**
   Design and develop new services or products from inputs received from external customer specifications.
3. **Order fulfillment processes**
   The activities required to produce and deliver the service or product to the external customers.
4. **Supplier relationship processes**
   Select suppliers of services, materials and information and facilitate the timely and efficient flow of these items into the firm.

Overview


Business Model
Management / Decision Processes
Business Processes / Value Chain
Inbound logistics
Operations
Outbound logistics
Marketing & Sales
Service
Application Systems
Application
Application
Application
Application
Application
Application
Data base Systems
enable
align

IS along the value chain – software categories 1/2

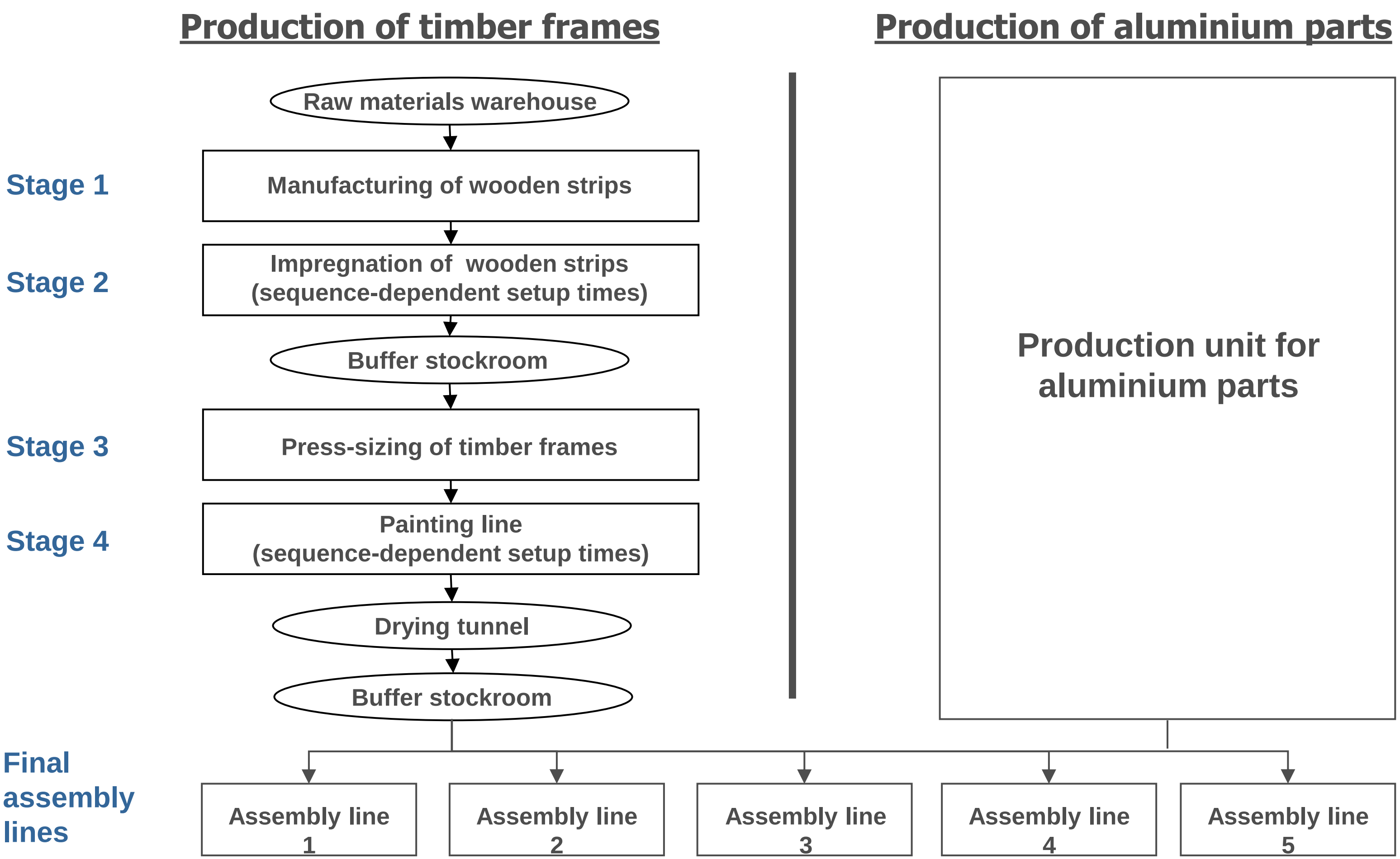
- **Manufacturing planning and control (MPC) systems**
  "… concerned with planning and controlling all aspects of manufacturing, including managing materials, scheduling machines and people, and coordinating suppliers and key customers". (Vollmann et al. 2005, p. 1).
- **Enterprise Resource Planning (ERP) systems**
  Modules on production planning, material/inventory management, purchasing, quality management, etc.
- **Advanced Planning Systems (APS)**
  based on ERP data; integral planning of the supply chain; optimization methods are implemented.
- **Manufacturing Execution Systems (MES)**
  support manufacturing execution; perform detailed production scheduling, shop-floor data collection and various other functions.

IS along the value chain – software categories 2/2

- **Computer Aided Engineering (CAE)/Design (CAD)/Process Planning (CA(P)P)**
  => 3-D Printing originally for "Rapid Prototyping".
- **Engineering Data Management (EDM) and Product Lifecycle Management (PLM) systems**
- **Numerical control of machines,** robots, Automated Guided Vehicles, etc.
- **Process monitoring**
- **Booking and Revenue Management systems** (e.g., for airlines, hotels, cruises)
- **Software for specific tasks** (e.g., vehicle routing, cutting optimization, assembly line balancing, timetabling, staff scheduling and rostering)
- **Software for specific industries** (e.g., steel industry)

→ Examples see next slides

Production system of a window manufacturer



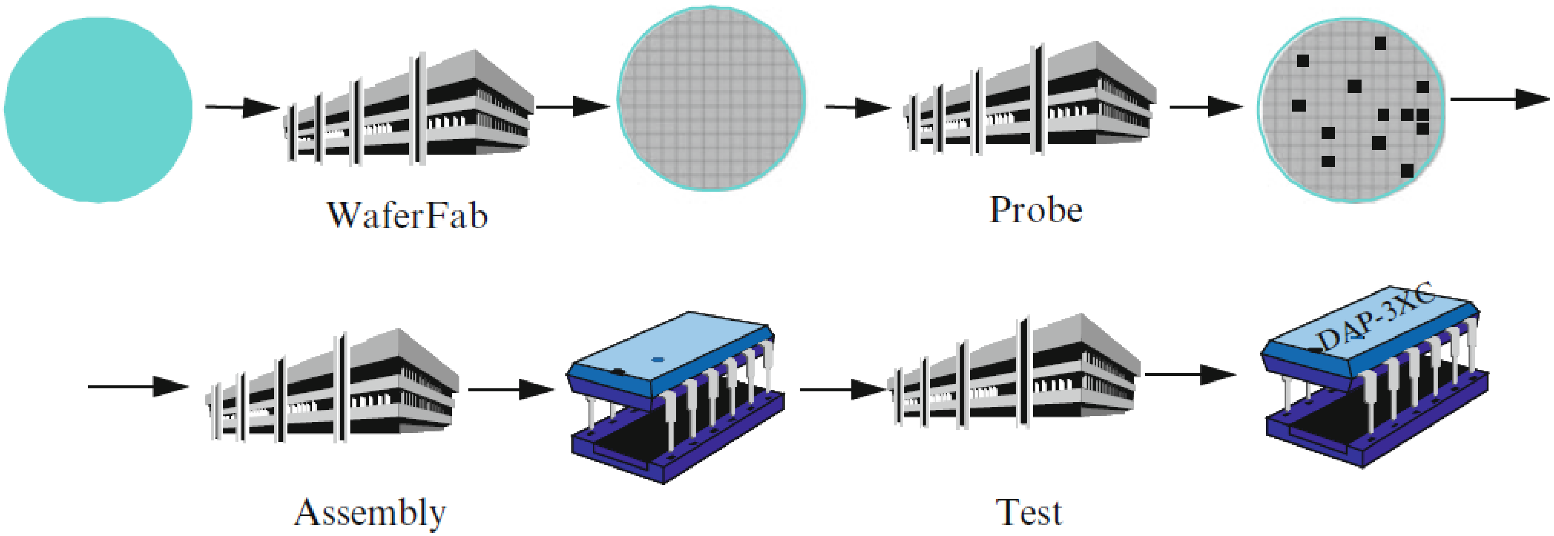
Production system of a window manufacturer

Videos:

- Wood window production in Belgium:
  https://www.youtube.com/watch?v=pnvS_vnAKQo
- Austrian window producer:
  https://www.youtube.com/watch?v=5imyXu96ca0

Stages of semiconductor manufacturing

Source: Mönch, L. et al.: Production Planning and Control for Semiconductor Wafer Fabrication Facilities: Modeling, Analysis, and Systems. Springer 2013 (available electronically)



Stages of the fab operation in semiconductor manufacturing

- Cleaning: Removal of particulate matter from the wafer before a layer of circuitry is produced.
- Oxidation, deposition, metallization: A layer of material is grown or deposited on the surface of the cleaned wafer.
- Lithography: This is the most complex operation requiring greatest precision. A photoresistant liquid is deposited onto the wafer and the circuitry defined using photography. The photoresist is first deposited and baked. It is then exposed to ultraviolet light through a mask that contains the pattern of the circuit. Finally the exposed wafer is developed and baked.
- Etching: In order to define the circuits, the exposed material is etched away.
- Ion Implantation: Selected impurities are introduced in a controlled fashion to change the electrical properties of the exposed portion of the layer.
- Photoresist Strip: The photoresist remaining on the wafer is removed.
- Inspection and Measurement of the in order to identify defects and guide future operations.

The is sequence of operations is repeated, with variations, for each layer of circuitry on the wafer.

Source: Missbauer, H. and Uzsoy, R.: Production Planning with Capacitated Resources and Congestion. Springer, forthcoming; following Uzsoy et al. 1992.

Stages of semiconductor manufacturing

Source: Mönch, L. et al.: Production Planning and Control for Semiconductor Wafer Fabrication Facilities: Modeling, Analysis, and Systems. Springer 2013 (available electronically)

Video of semiconductor plant (until 3:40):

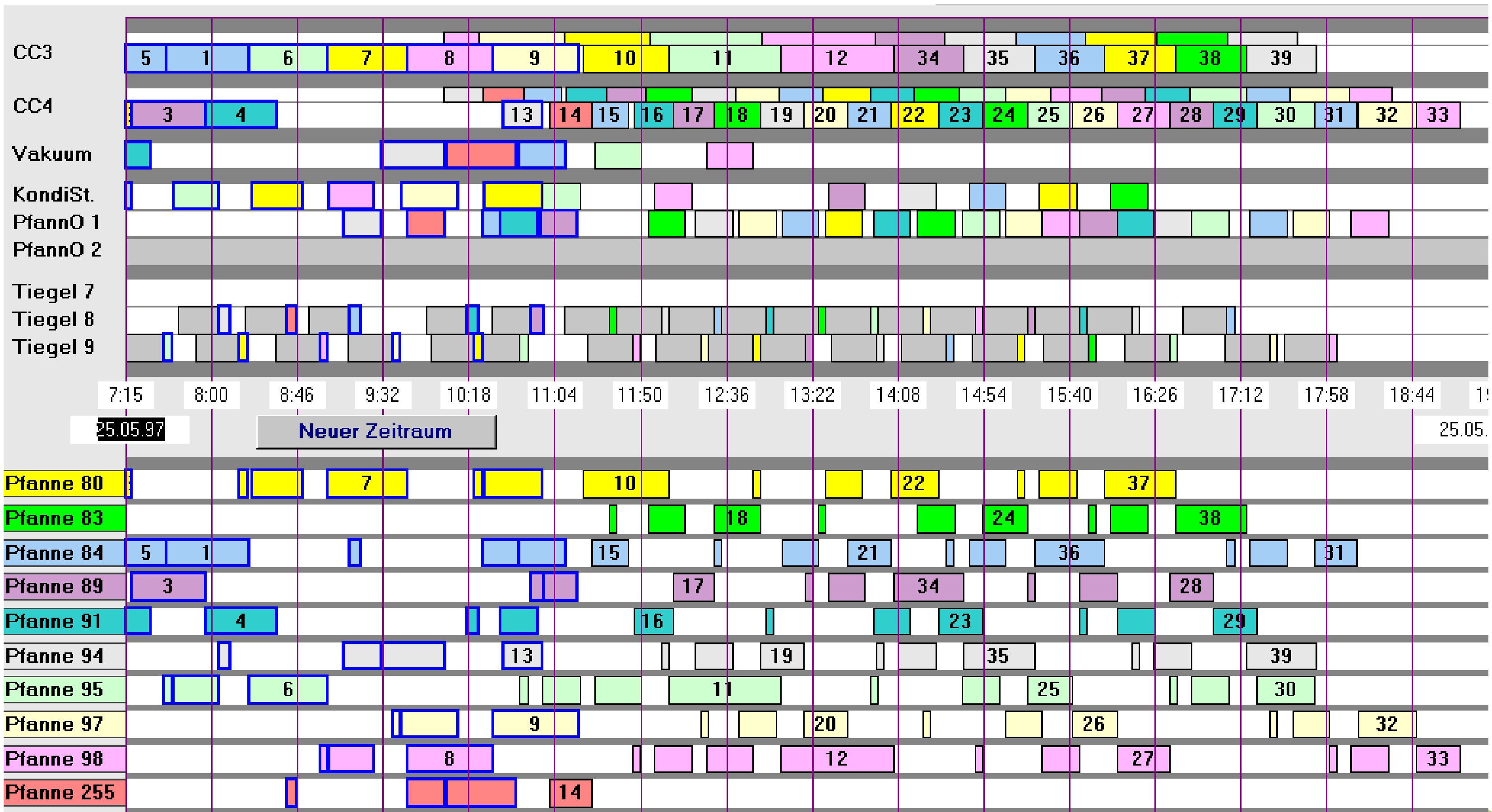
https://youtu.be/clpEw69-7jk?t=156

(if time, until 7:45)

https://youtu.be/clpEw69-7jk?t=408

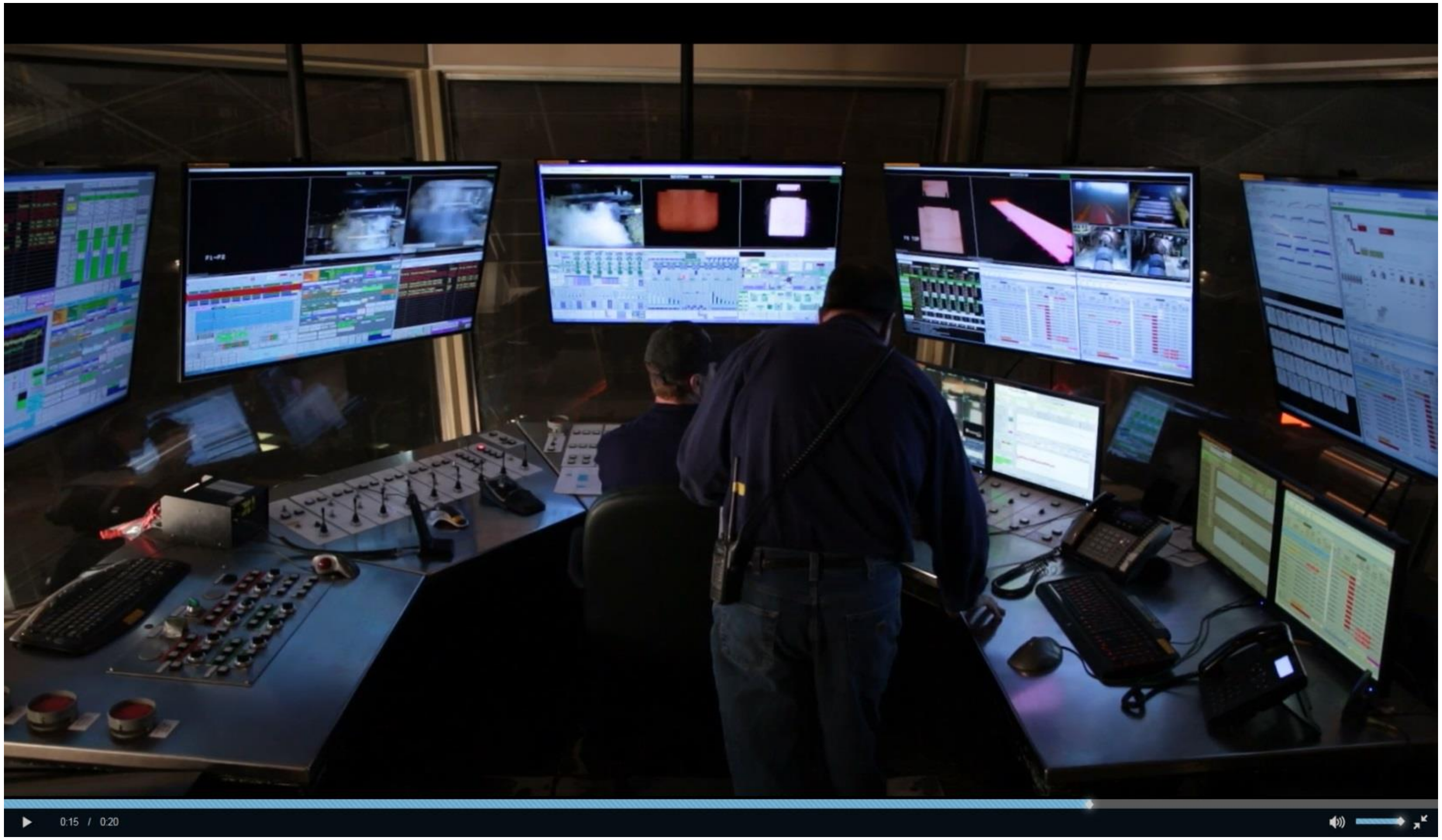
Software for specific tasks:

Production scheduling in the steel industry (steelmaking - continuous casting)



Process monitoring in a steel plant

Source: world steel association, http://images.worldsteel.org/picture/worldsteel_nucor_north-america_people-of-steel_1/category/production-process/people-of-steel; retrieved 28-Feb-17



Software for specific tasks:

Production schedule in the steel industry (continuous casting)

Video continuos casting (short):

https://www.youtube.com/watch?v=d-72gc6I-_E

Steel production:

https://youtu.be/hTw9LVMBLns?t=29

Proposed view on information systems for planning and control of value-adding processes

- **Tasks** to be fulfilled
  - Planning & Control
  - Execution
- **Data**
  - **Master data:** describe the entities of the value chain (products, materials, processes, resources, customers, suppliers, etc.)
  - **Transaction data:** represent current state and the operation of the value chain (inventory levels, material requirements, production orders and their state, etc.) -> Collecting, analyzing & utilizing "Big Data"!
- **Methods**

  such as: algorithms for execution, statistical analyses, „What-if"-analyses, event-oriented simulation, models/algorithms for decision making; e.g., math programming
- **Concepts** for planning & control, coordination, e.g.
  - hierarchical vs. centralized („monolithic") planning
  - coordination concepts for supply chains (e.g., hierarchical vs. heterarchical vs. autonomous decision making with centralized information)

Operations management/research

- "The term **operations management** refers to the systematic design, direction, and control of processes that transform inputs into services and products for internal, as well as external, customers." (Krajewski/Ritzman 2007, p. 4).
- **Operations research** is the application of the *methods* of science to *complex problems* arising in the direction and management of large system of men, machines, materials and money in industry, business, government, and defence. The distinctive approach is to develop a *scientific model* of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls. The purpose is to help management determine its policy and actions scientifically. (OR Society)

  OR is an interdisciplinary field: Mathematics, Engineering, Information systems, Economics and Business Administration

Quantitative models in OM - Basics

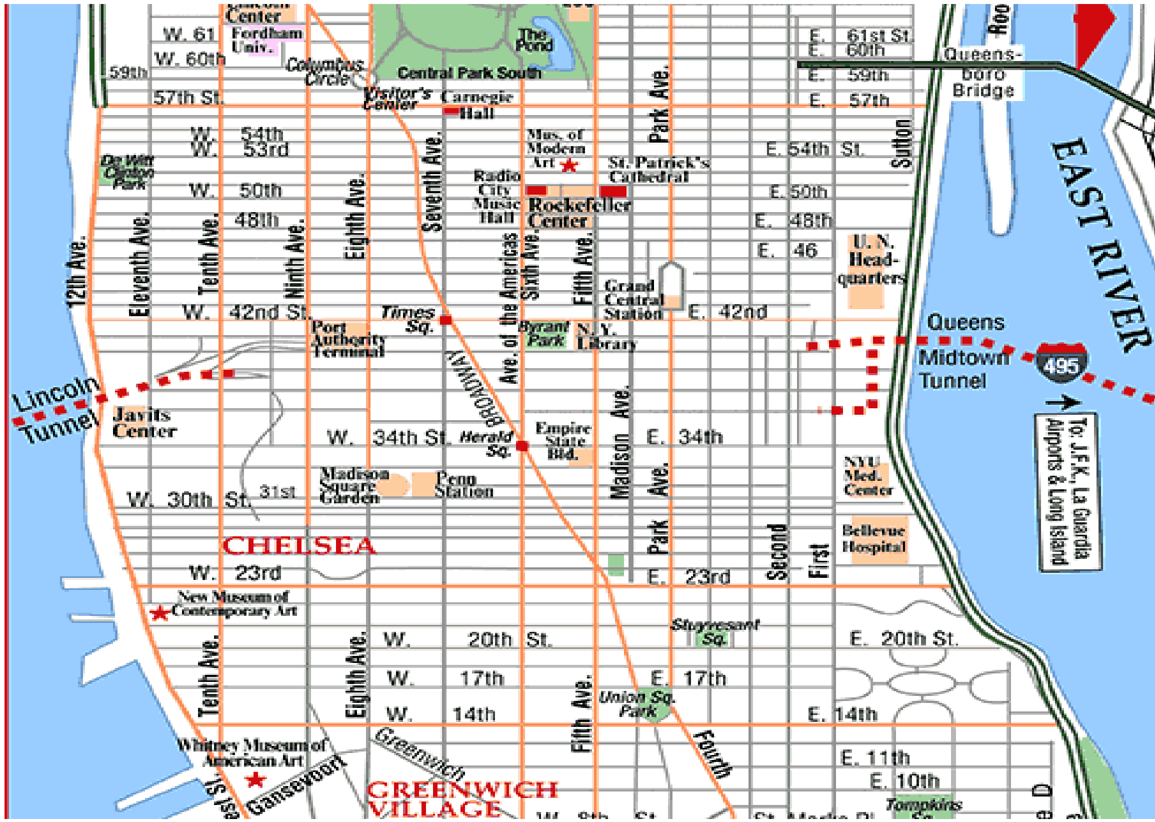
- Complexity and solution approaches illustrated on the example of the Traveling Salesman Problem
- Forecasting
- Linear optimization
- Excursus: Simulation

Mainly repetition of bachelor-program, please be aware of the following concepts.

Interesting brainteaser:

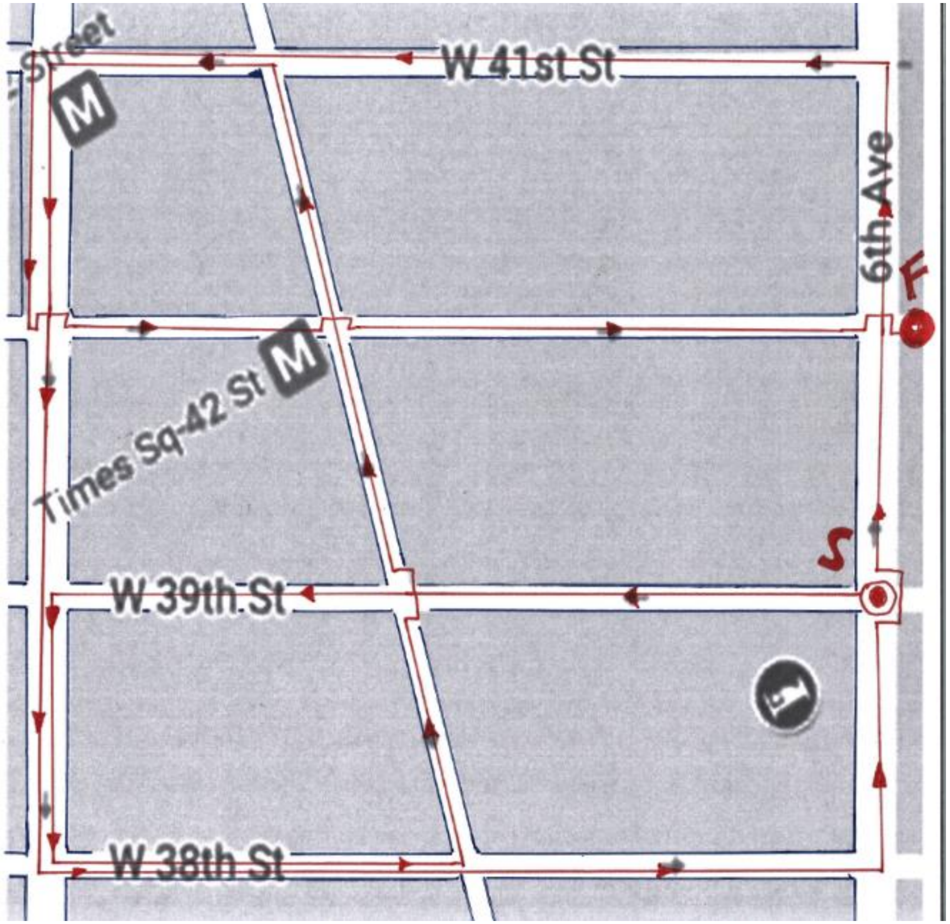
Shortest path through the streets and avenues of midtown Manhattan (Chinese Postman Problem)

Source: http://www.aaccessmaps.com/show/map/us/ny/manhattan, 22.10.2015



Perhaps this way?
Optimal route through a part of Midtown Manhattan

(Calculated by Quirin Ilmer)



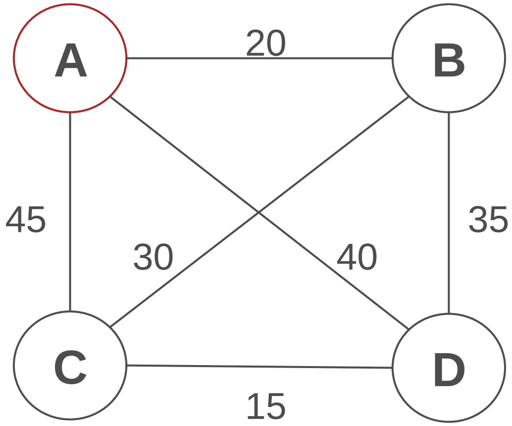
Other example: Optimal hiking tour through Austria (starting in Vienna):
http://www.math.uwaterloo.ca/tsp/road/austria.html

Traveling Salesman Problem (TSP)

- Given a list of **cities** and the **distances** between each pair of cities, find the **shortest route** that visits each city and returns to the starting point.
- Standard Operations Reserach Problem with several applications, e.g.,:
  - Vehicle routing (standard)
  - Microchips manufacturing (drilling of printed circuit boards) – here „cities" are soldering points
  - Sequencing of production orders at a machine with sequence-dependent setup times – here „cities" are the setup states of the machine
  - ...

Traveling Salesman Problem (TSP)

- Combinatoric problem often modelled as a graph:
  - **nodes** represent cities (e.g., A to D),
  - **edges** (c_{ij}) define the distances between nodes (e.g., c_{AB}=20)
- Simplest form is a symmetric TSP:
  → same distance in both directions
- Asymmetric TSP



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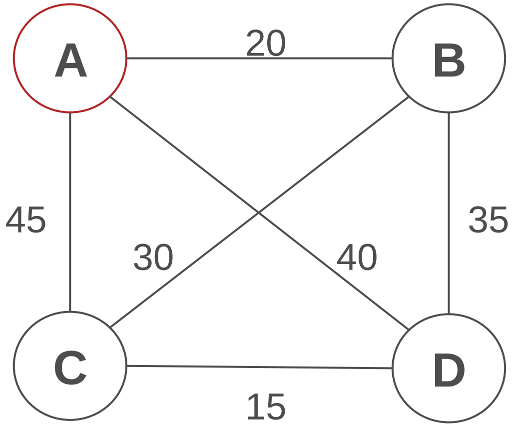

→ Complexity: Number of soultions (S):

- asymmetric TSP: $S = (n-1)!$
- symmetric TSP : $S = \frac{(n-1)!}{2}$
- **Calculate for: n=4, 10, 25**

n ... number of nodes including start node

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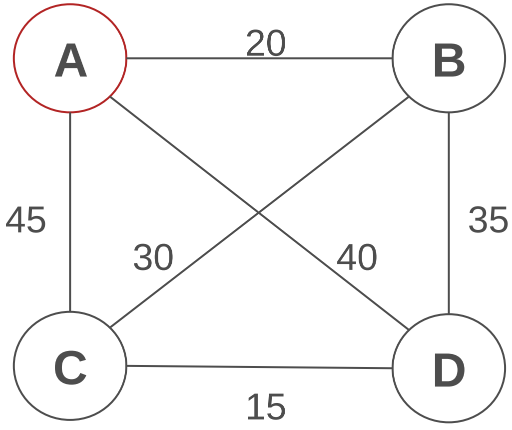

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TSP is a NP hard problem!

Solving the Traveling Salesman Problem (TSP)

- **Exact solution:**
  - Brute force search: try all permutations (see above – NP hard)
  - Optimization algorithms (integer linear programming: branch-and-bound, branch-and-cut)

    → current record: solve TSP with 85900 cities

    http://www.math.uwaterloo.ca/tsp/optimal/index.html
- **Construction heuristics:**

  e.g., Nearest neighbor, Insertion heuristic

  http://www-m9.ma.tum.de/Allgemeines/GraphAlgorithmen (in German)
- **Improvements heuristics - Metaheuristics:**

  e.g., Hill-climbing, simulated annealing, genetic algorithms, ant colony, particle swarm optimization, …

Lessons learned

- Complexity vs. Optimality

  → reflects the relation btw. academia vs. practice;

  recall def. of OR: „…*application* of *methods of science* to complex problems… to *help management* determine its policy and actions scientifically."

  → decision support (understanding vs. sophisticated solutions)

- Our teaching approach in our *Operations Management track* - Quantitative methods to provide decision support to managers:
  - Summer term: Operations Management I: IT-supported Production and Supply Chain Planning – Concepts, Methods and Software
  - Winter term: Operations Management II: Applying Methods of Operations Management – Optimization, Simulation and Analytics

Forecasting

Forecasting

- Why forecasting?
  → Uncertainty
- Applied in many areas:
  - Weather forecasts
  - Stock exchange
  - Demand/Sales planning

- Basic Forecasting Approaches:
  - Statistical Techniques (quantitative):
    - time-series-analysis
    - causal models
  - Judgmental Forecasting (e.g. Promotions)
  - Collaborative Forecasting (consensus based)

Time series forecasting

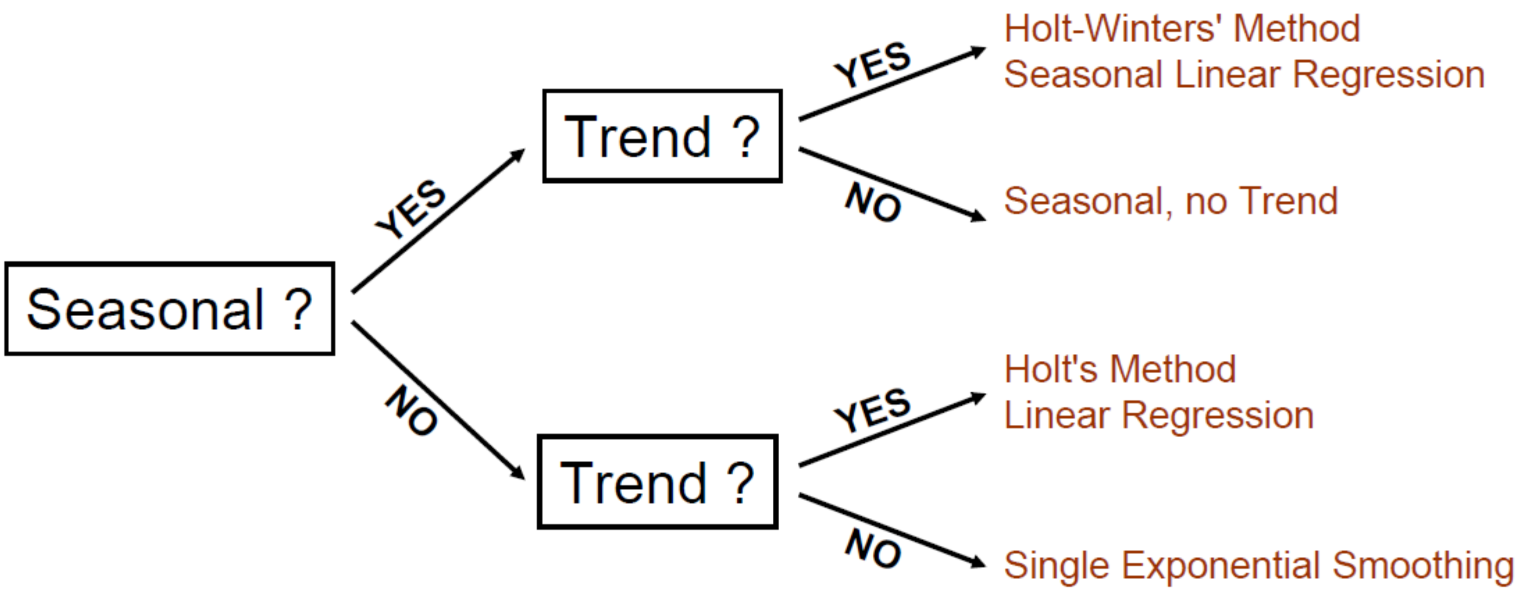
- **Univariate Analysis** (e.g., time series)
  - **Constant demand** varies very little from a stable mean value
  - Trend demand falls or rises constantly over a long period of time with only occasional deviations
  - **Seasonal demand** periodically recurring peaks and troughs differ significantly from a stable mean value
  - **Seasonal trend** periodically recurring peaks and troughs, but with a continual increase or decrease in the mean value
  - **Intermittent demand**

- **Multivariate** linear regression (analyze the relationship between a single dependent variable and several independent variables)

Forecasting Process

1. Initial **data analysis** and **preparation**
2. Set a **forecasting model** and method for testing
3. Determine **initial values** of the forecasting method
4. Set **parameters** of the forecasting method
5. Analyze forecasting **quality**
6. **Monitor** forecasts (if necessary go back to step 2)

Decision tree for selecting a forecasting method



Notation

t … period

T… period in which forecasting takes place

$\hat{x}_{T+i}$… forecasted demand for period $T + i$

x_t … realization of object in period t

n… sufficient amount of periods

a … demand level

$\hat{a}$ … forecasted demand level

α… smoothing parameter, (0 < a < 1)

Level Demand

Relationship applied by Level Demand Models $E(X_t) = a$

- Method **Moving Averages**

  Forecast for a future period: $\hat{x}_{T+1} = \hat{a} = \frac{1}{n} \cdot \sum_{t=T-n+1}^{T} x_t$

- Method **Single Exponential Smoothing** (SES):

  Forecast for a future period: $\hat{x}_{T+1} = \alpha \cdot x_T + (1-\alpha)\ \hat{x}_T$

Additive trend

Relationship applied by Level Demand Models $E(X_t) = a + b \cdot t$

- Additional notation

  b... constant trend slope

  $\hat{b}_T$... forecasted trend slope in period t

  β... smoothing parameter, (0 < β < 1)

- Method of **Holt** (SES with two parameters)

  Smoothing $\hat{a}$ and $\hat{b}$ separately by two parameters α and β

$$\hat{a}_T = \alpha \cdot x_T + (1-\alpha) \cdot \left(\hat{a}_{T-1} + \hat{b}_{T-1} \right)$$

$$\hat{b}_T = \beta \cdot (\hat{a}_T - \hat{a}_{T-1}) + (1-\beta) \cdot \hat{b}_{T-1}$$

Forecast: $\hat{x}_{T+i} = \hat{a}_T + \hat{b}_T \cdot i$

Measuring the Forecast Quality

Forecast Error $e_t = x_t - \hat{x}_t$

- Quality Measures of the structure $\text{quality measure} := \frac{1}{K} \sum_{k=t-K+1}^{t} f(k).$
  - Mean absolute deviation "MAD" $f(k) := |e_k|$
  - Mean squared error "MSE" $f(k) := (e_k)^2$
  - Root mean squared error "RMSE" $RMSE := \sqrt{MSE}$
  - Mean Average Percentage Error „MAPE“ $f(k) := 100 \cdot \frac{|e_k|}{x_k}$
- Continuously Quality Measure with Error tracking signal „SIG“:

$$SIG := \frac{ME}{MAD}$$

ME…Mean Error

Linear programming

- Mathematical model with:
  - **linear objective** function and
  - **linear constraints**
  - **real-valued variables** (implied by linear constraints)
- If feasible, the linear programming algorithm (e.g., simplex) finds the optimal point of the formulated linear program.
- Mostly calculated with a software package: Excel, Lingo, Cplex, Gurobi,…
- Browser-based application (in German):

  http://www2.wiwi.uni-jena.de/Entscheidung/tenor/

One period model

A company produces **several product** types ($j \in J$) which are manufactured on a few **machines** ($r \in R$) which may become a bottleneck. Available **capacities** c_r of the machines, the **processing times** of each product on each machine p_{jr} and **contribution margins** of each product cm_j are known.

Aim: Find **production quantities** X_j of the products that **maximize** the contribution margin.

$$\underset{X_j}{Max}\ O^* = \sum_{j=1}^{J} cm_j \cdot X_j$$

subject to

$$\sum_{j=1}^{J} p_{jr} X_j \leq c_r$$

Assumptions:

- Only one period is considered.
- Production quantities may take real values
- Setup times and costs are negligible.

Numerical example

$$\underset{X_j}{Max}\ O^* = \sum_{j=1}^{J} cm_j \cdot X_j$$

subject to

$$\sum_{j=1}^{J} p_{jr} X_j \le c_r$$

$cm_1=400$; $cm_2=450$

$c_1 = 120$; $c_2 = 105$; $c_3 = 50$

$p_{11} = 1$; $p_{12} = 1.4$

$p_{21} = 2$; $p_{22} = 1$; $p_{23} = 1$

$$O^* = \max_{x_1, x_2}\ 400\ x_1 + 450\ x_2$$

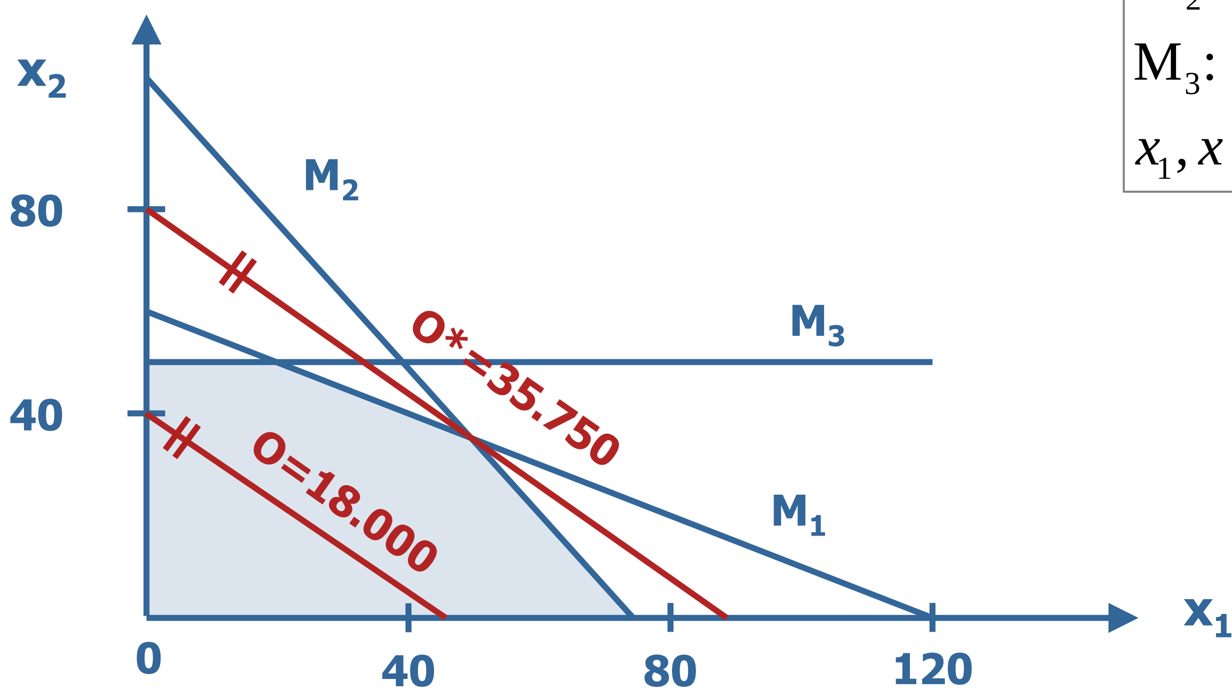
$s.t.$

$M_1: \quad x_1 + 2\ x_2 \le 120$

$M_2: 1.4\ x_1 + x_2 \le 105$

$M_3: \quad x_2 \le 50$

$x_1, x_2 \ge 0$



Excursus: Simulation

What‘s simulation?

- A simulation is the **imitation** of the operation of a **real-world** process or system over time.
- The behavior of the system is studied by developing a **simulation model** based on assumption concerning the operation of the system.
- A simulation model is used to investigate a wide variety of **‚what if‘** questions about the real-world system and compares these scenarios **quantitatively**.
- Software packages: e.g., Witness, Simul8, Arena, Vissim, Flexsim…

Videos von Herrn Wanner (Vissim):

- showreel.avi (Verkehrsimulation - Bergiselschanze)
- Untertunnelung Kresiverkehr.avi (Untertunnelung Grassmayrkreuzung)

Video (Flexsim): https://www.youtube.com/watch?v=veAEnbWaAGo

Why simulation? (1/2)

Alternatives:

- **Trial and error**

  Experiments with the real system might be:

  → not possible (e.g., impact of climate change)

  → dangerous (e.g., flight simulator)

  → very expensive (e.g., build a new site)

- **Analytics**
  - Define the whole system mathematically (e.g., queueing theory).
  - Very complex if stochastic processes and complex systems.

    → again: complexity vs. understanding (academia vs. practice)

Why simulation? (2/2)

When to **use** simulation?

- **Verifying** an **analytical solution**
- **Experiments within the real system** are not possible:
  - Impossible to build a new site
  - Expenses for testing are to high
  - Dangerous (flight simulator)
- **Reality** should be analyzed **beforehand** with high significance
- Analysis of the **dynamic behavior** of the system
- **Structure of the systems is too complex** for analytical calculations

Pro and Cons of simulation

Pro

- only approach for **complex systems**
- takes **random factors** into account
- no negative effects on real system
- cheaper than experiments with real system
- quick analysis of "what-if" scenarios
- working on the simulation model **increases** the **understanding** of the system tremendously (for all participants)!

Cons

- **Time consuming** and **expensive w.r.t:**
  - acquisition/learning of software
  - high effort for building the model
  - computation times
- **No exact representation** of **reality**
- **No exact solution** (intervals, means)
- Gathering of **huge amount of data** (data overload)
- **Validation** (no test on 100% validity)
- **Evaluation of given alternatives** and thus **no optimization**!

Now you know essential mathematical techniques in OM …

….. such as

- Demand forecasting for various demand patterns (constant, linear, trend-seasonal)
- Discrete-event simulation of manufacturing and service systems
- Linear programming models to optimize production quantities.

for small, stylized problems.

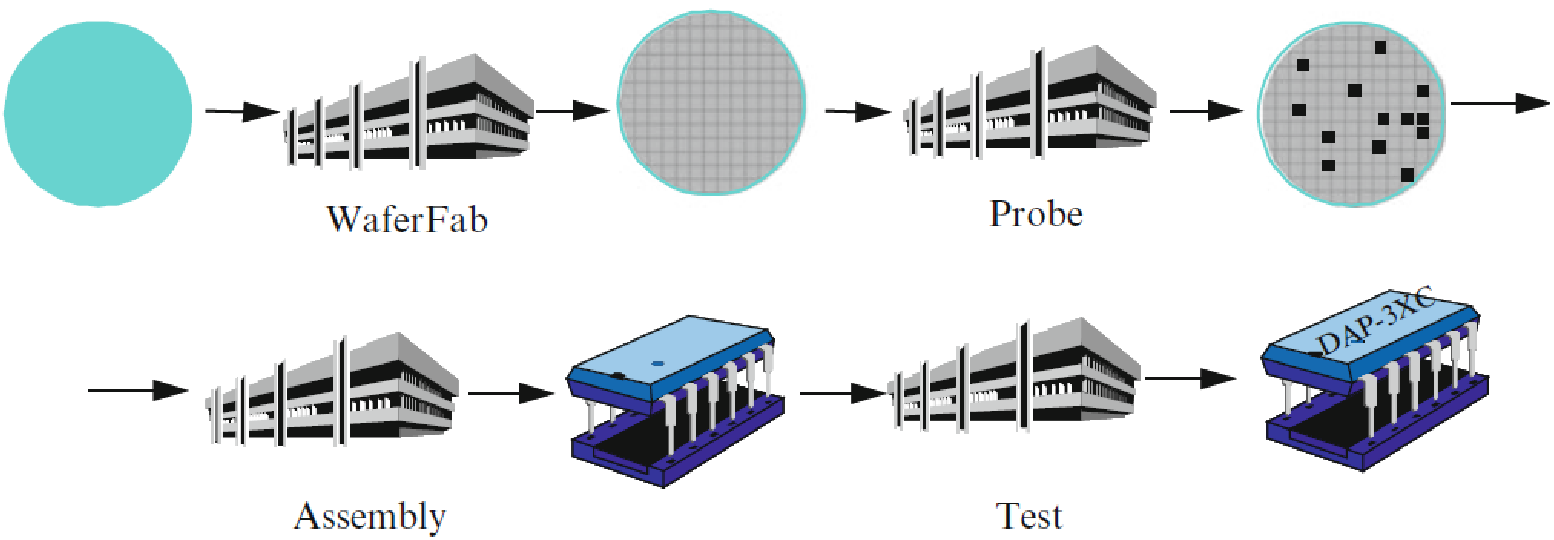
And now let‘s have a look at a typical problem in industry!

Quantitative models in OM – example:
Master Planning - Sales and Operations Planning

focusing on the semiconductor industry

Stages of semiconductor manufacturing (rep'd)

Source: Mönch, L. et al.: Production Planning and Control for Semiconductor Wafer Fabrication Facilities: Modeling, Analysis, and Systems. Springer 2013 (available electronically)



Master Planning – definition of the decision problem

"The main purpose of *Master Planning* is to synchronize the flow of materials along the entire supply chain. Master Planning supports mid-term decisions on the efficient utilization of production, transport, supply capacities, seasonal stock as well as on the balancing of supply and demand."

"Based on demand data from the Demand Planning module, Master Planning has to create an aggregated production and distribution plan for all supply chain entities. It is important to account for the available capacity and dependencies between the different production and distribution stages. Such a capacitated plan for the entire supply chain leads to a synchronized flow of materials without creating large buffers between these entities."

Source: Stadtler/Kilger, Supply Chain Management and Advanced Planning. 5th ed., Springer, 2015

Let's start step by step: Aggregate Production Planning for a single plant – problem formulation

- One single production stage (e.g., a plant) produces J products or families of similar products j=1,…., J.
- The planning horizon is divided into T planning periods t=1,…., T (e.g., months).
- Demand forecasts for each product family and periods, denoted D_{jt}, are available, we assume perfect forecasts. All demand must be satisified.
  Remark: Time-varying demand that exceeds capacity in certain periods is normal.
- Regular capacity of the plant, denoted C_t, is known for each period. Overtime (additional capacity) is possible up to a specified limit.
  Remark: Multiple capacities or time-dependent regular capacity can be added easily.
- Costs for overtime (per hour) and for holding finished goods inventory (FGI) (per product unit and period) are known.

Given these assumptions, calculate the **optimal production and inventory levels** and the **optimal total capacity** for all periods t=1,…., T.

Aggregate Production Planning for single-stage production: suggested notation

X_{jt}	Output of product j in period t
D_{jt}	Demand of product j in period t
I_{jt}	Inventory of product j at the end of period t
C_t	Regular capacity in period t
O_t	Overtime (additional capacity) in period t
$h_{jt,}$	Inventory holding costs per unit and period t for product j
$u_{t,}$	Overtime costs per unit in period t

Remark 1: For single-product models the index j can be omitted.

Remark 2: In our example capacity was measured in units of the product (all a_j=1).

Aggregate Production Planning for single-stage production: mathematical model

Objective function:

$$\sum_{j,t} h_{jt} I_{jt} + \sum_{t} u_t O_t \to Min!$$

Constraints

Inventory balance equations

$$I_{jt} = I_{j,t-1} + X_{jt} - D_{jt} \qquad \text{for all } j, t$$

Production capacity constraints

$$\sum_{j} a_j X_{jt} \le C_t + O_t \qquad \text{for all } t$$

with a_j the capacity required for producing one unit of product *j*.

Overtime constraints

$$O_t \le O_t^{Max} \qquad \text{for all } t$$

with O_t^{Max} the maximum possible overtime in period *t*.

Non-Negativity

$$X_{jt}, I_{jt}, C_t, O_t \ge 0 \qquad \text{for all } j, t$$

Aggregate Production Planning: Numerical example

- Company produces two products P1 and P2 (e.g., type of tires) in a single-stage production.
- Planning horizon are 12 periods (months).
- Regular capacity: 200 product units per months (the capacity requirements are the same for P1 and P2). Overtime is possible without relevant limitation.
- Planned sales per month for P1 and P2 (t=1,…,12): see spreadsheet.
- Inventory holding costs: 4.5 (money units per product unit and period) for P1, 5 for P2. Overtime costs: 20 money units per additional product unit.
- Initial inventory: 20 units P1, 80 units P2. Safety stock (=minimum planned inv.): 10 units P1, 20 units P2

Assignments (unofficial)

- What are the costs for a "chase" strategy? What is the maximum capacity required?
- What are the costs for a "level" strategy? What is the monthly production in this case?
- Try to find the optimal time-dependent production that minimizes the sum of costs for overtime and inventory.
- How would you determine appropriate safety stock levels if P1 and P2 are types or families of products?

Remark: Use a spreadsheet table; you can extend the table that is provided.

Aggregate Production Planning: extensions of the single-stage model

- Multiple capacities within the production stage.
- Costs assigned to flows (production, transportation).
- Planned sales as decision variables, not necessarily equal to planned demand.
  =>Revenues are an element of the objective function.
- Backordering is possible, backorder costs in the objective function.
- Discrete decisions, modelled as integer variables (e.g., number of trucks for transportation in a period).
- Nonlinear functions.
  Example: Transportation costs as a function of transportation volume can be nonlinear due to optimization of vehicle routing.
- And finally: Multiple production or distribution stages with SKU inventories in between. Flows through the stages and inventory levels of the SKUs over time are the essential decision variables .
  This is what we called Master Planning!

Master Planning by linear programming

See separate document

General structure of this type of mathematical programming models for production planning

"Following Hackman and Leachman (1989), we can view these models as containing three basic sets of constraints:

1. *Inventory or material balance equations*, which capture the flows of material through both space and time. These will also enforce the satisfaction of demand, which is viewed as a flow of material from the production system to an external demand source.
2. *Capacity constraints*, which model how the production activities capture and consume production resources.
3. *Domain-specific constraints* reflecting the special structure and requirements of the particular production environment being modeled."

Source: Missbauer, H., R. Uzsoy. 2011. Optimization models of production planning problems. Kempf, K. G., P. Keskinocak, R. Uzsoy, eds. Planning Production and Inventories in the Extended Enterprise: A State of the Art Handbook. Springer, Berlin 437-508.

Further reference:

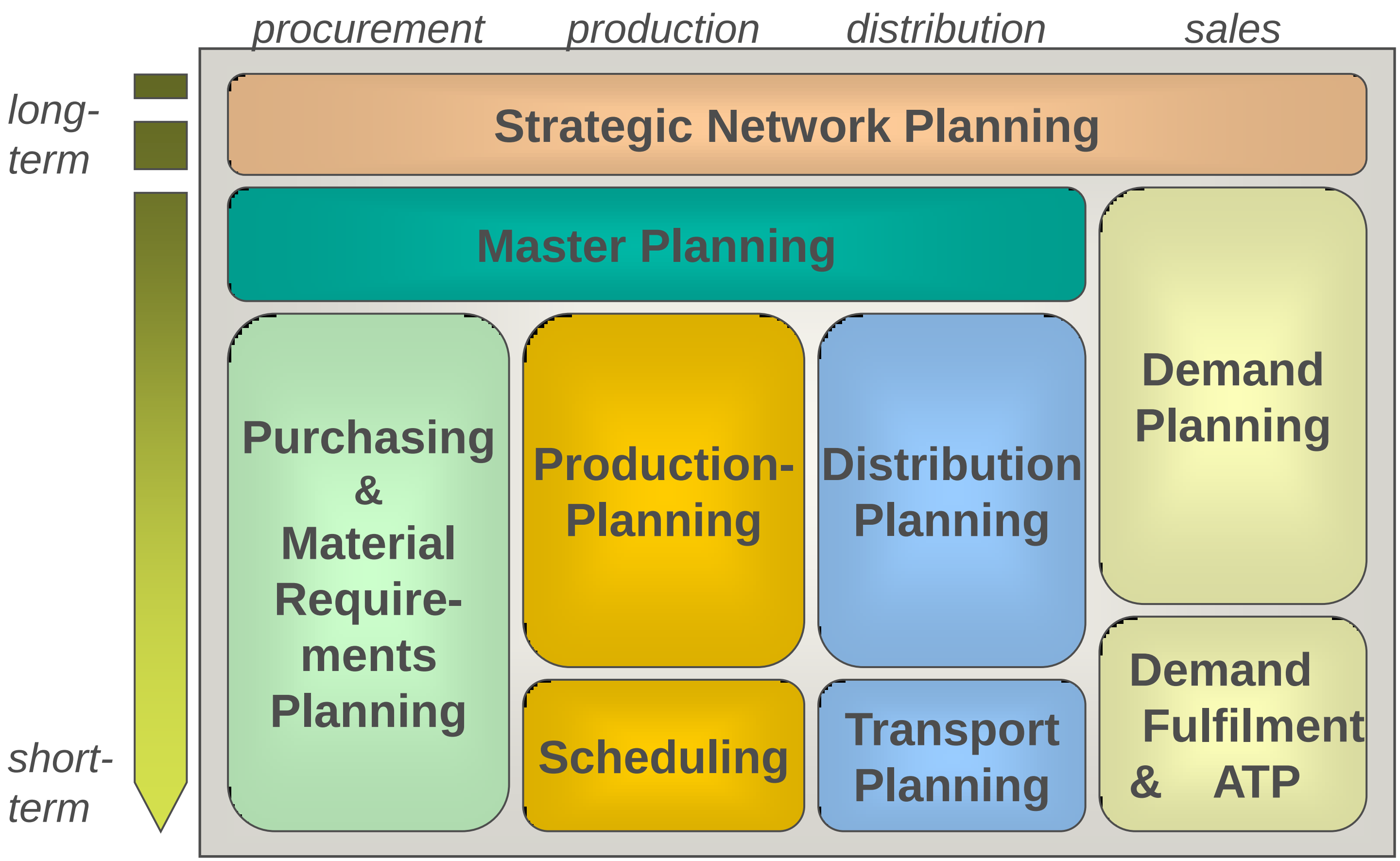
Hackman, S. T., R. C. Leachman. 1989. A general framework for modeling production. *Management Science* **35,** 478-495.

Implementation in standard software: Advanced Planning Systems (APS)

- „APS have been launched independently by different software companies at different points in time. Nevertheless, a common structure underlying most of the APS can be identified. APS typically consist of several *software modules* (eventually again comprising several software components), each of them covering a certain range of planning tasks (see Rohde et al. 2000)." (Stadtler et al. 2015, p. 99)
- APS can be considered as the most recent software products for planning and control of logistical processes. The most important properties:
  - Encompass the entire Supply Chain in order to support interorganzational collaboration.
  - Offer state-of-the-art decision support (optimization models for master planning, detailed production scheduling, lot sizing, etc.).
  - Encompass, at least conceptually, the design of the supply chain (e.g., location of plants; number and location of distribution centers).
- This common structure usually is depicted as *Supply Chain Planning Matrix*.
- Overview of the modules: Stadtler/Kilger/Meyr (2015), Ch. 5 (pp. 99-106) (available electronically).

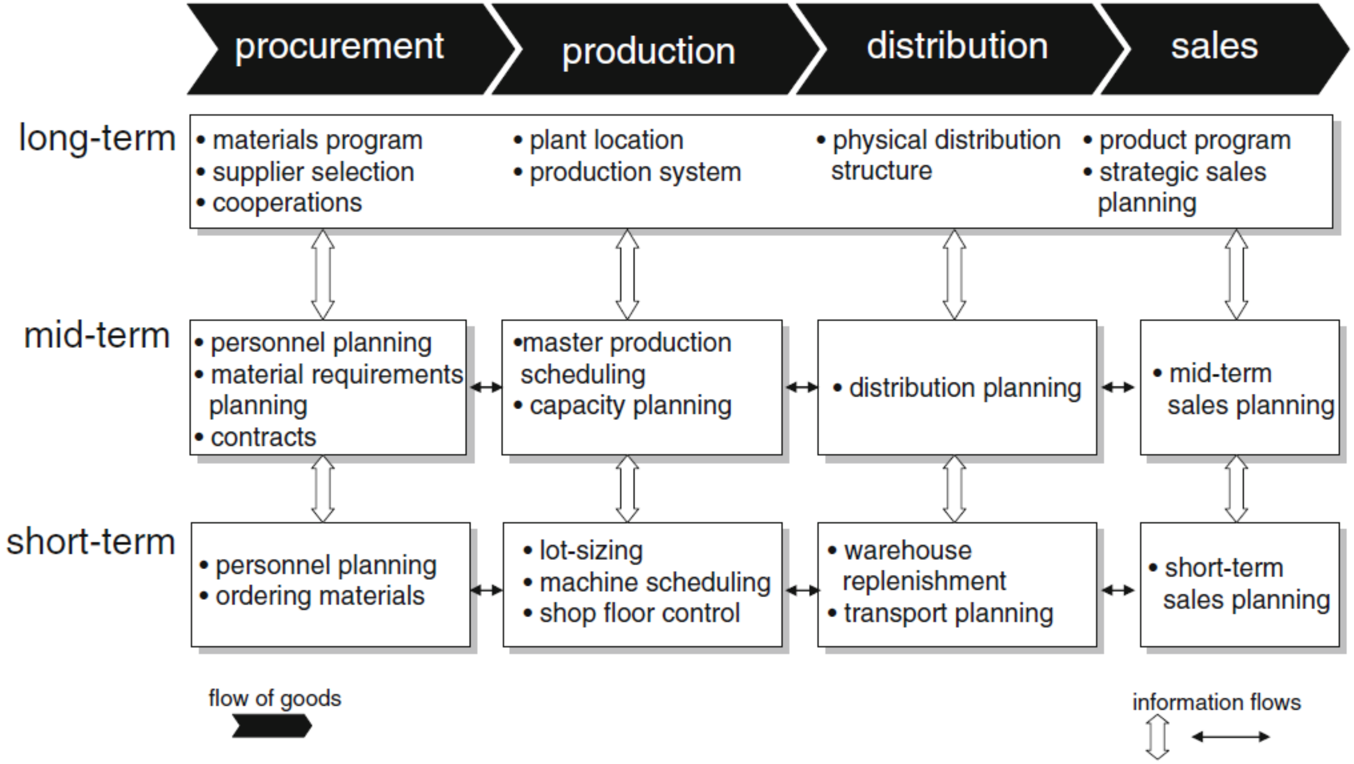
Architecture of APS: Supply Chain Planning Matrix

Following Meyr/Wagner/Rohde 2003; Source: Stadtler 2003



Architecture of APS: Supply Chain Planning Matrix

Source: Stadtler et al. 2015, p. 77



Lessons learned from the master planning example

- The **master planning problem** structure results from a specific planning concept, namely **hierarchical planning**.
  Philosophical question: is the master planning problem **discovered** or **created**?
- **Mathematical modeling** of the problem is well-established with a rich research tradition behind it.
- **Solving the model to optimality** can be easy (if linear) or quite tricky (if integer and/or non-linear).
  But: Making all the **relevant knowledge** available centrally might be difficult!
- Huge **impact on costs** possible!
  - Billions of € investment for one wafer fab.
  - Billions of € inventory value in a very large company.
  - Millions of tons annual throughput of a steel plant.
- **Software** for handling these models is powerful and user-friendly. **Data availability** and quality is often good and still improving.
- **Limitation:** The **experts** that understand the **problems**, know the **methods** and can select, implement and run the **IT-support**!

Current trends in IT *greatly* enhance our possibilities to improve value-assing processes!

Buzzwords: Digitization, Digital transformation, Industry 4.0

- Hardware and software closely linked both in products and manufacturing resources.
  Cyber-physical systems with easy data exchange (Internet of Things).
  “Smart products” produced by “smart machines”.
- **Monitoring** the current state of products and manufacturing resources is easy (RFID, sensors), even for products during use.
- Methods for **analyzing** the extensive data („Big data“, Analytics) are available.
- Sophisticated **decision support tools** based on these data: Operations Research, Artificial Intelligence.
- **Further automation** of both the manufacturing processes (e.g., sensitive robots) and decision processes (e.g., detailed scheduling: negotiation between autonomous “agents” such as products and machines).
- **Flexible structuring**, e.g., stations in a flow line as interchangeable modules.
- ….. and new **business models** based on this! E.g., predictive maintenance by the tool manufacturer as a service.

However, some limitations most likely will remain

- **Role of people** is considered important!
  -> “Augmented operator”
  -> Learning from human actions? E.g., case-based reasoning.
- „Optimal“ reaction to short-term events, based on most recent information? Most scheduling problems are **NP-hard** (Corsten & Gössinger 2016)!
- **Productivity** vs. **flexibility**: If it comes down to a new wave of **flexible automation**, it continues an ongoing development.
- Is utilizing the possibilities of IT to its maximum more efficient by definition (see Corsten & Gössinger 2016)?
  Economic assessment (ex ante) of the changes/investments remains an important and difficult task!

Exam

- Caluclations:
  - Solve TSP: with a heuristic (e.g., Nearest Neighbour or other greedy heuristic)
  - Forecast with methods presented in these slides
  - Model, solve and interpret a linear program (e.g. sensitivity analysis: dual prices, upper lower bound, see 'Excercises for the calculation part of the exam.pdf')
- All content of the slides and examples are relevant for the exam
- Additional excercises can be found (links are on OLAT):
  - https://link.springer.com/book/10.1007/978-3-319-11976-2
  - http://people.brunel.ac.uk/~mastjjb/jeb/or/morelp.html

No multiple choice, write whole sentences and argue conclusively!