Information Management in Production Systems

Production Planning and Scheduling

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Overview

- **Tasks and levels of production planning and scheduling**
- **Problems and methods**
  - Production planning — Linear Programming, Integer Programming
  - Scheduling — MIP, Constraint Programming
  - CAPP — Constraint Programming
- **Model building and solution**
- **Optimization Programming Language (OPL)**
  - OPL Studio
  - www.ilog.com — free trial version

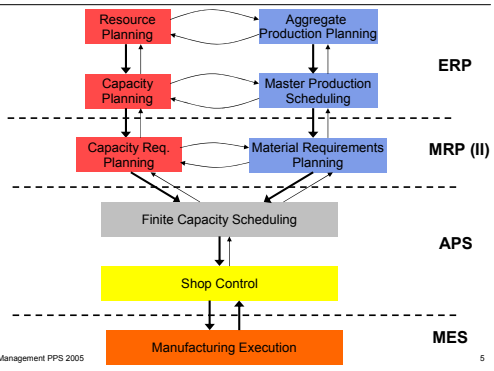
Production

- **Internal environment**
  - Resources
    - Tools, machines, equipment
    - Labour
    - Material
    - (Capital, financial resources)
  - Production technology
    - Discrete
    - Needs various resources
  - Organizational structure
- **External environment**
  - Orders
  - Resources (subcontractors, supply net partners)
  - Criteria
- **Task:** Matching capabilities and requirements
  - In the future
  - From time to time

Principles

- **Information flood and uncertainty → aggregation**
  - Production goals
  - Products
  - Time unit and horizon
  - Resources
  - Closer to actual production, more and more details, shorter horizon, more feedback
- **Complexity → decomposition and relaxation**
  - Production planning with infinite capacities
  - Capacity planning with given production load
  - Iterative improvement
  - Far from being optimal
  - We cannot plan with much details ahead of a long period – but it is not worth, too

The complete picture



Aggregate Production Planning

- **Problem statement**
  - Determine long/term load of a factory
  - On the level of product families/groups
- **Input data**
  - Business plan
  - Market forecast
  - Orders
- **Result**
  - Profit- and cost-oriented aggregate production plan

Resource Planning

- **Problem statement**
  - Determine the capacities required for executing the long-term production plan
- **Input data**
  - Long-term aggregate production plan
  - Aggregated resource capacities
  - Financial resources
- **Results**
  - Extra capacity needs
  - Investment decisions
  - Plan for deploying capacities
    - Plants, layouts
- **Issues**
  - Company without borders
    - *Supply chain, cooperative manufacturing, extended, virtual enterprise*
  - Capacity – production planning
    - Chicken-egg problem, on all levels

Master Production Scheduling

- **Problem statement**
  - How much to produce from given products in each period, in medium-term horizon
  - What to do in each time period on products with long lead time.
- **Input data**
  - Aggregated production plan
  - Capacity requirements of products
  - Resource calendar for each time period
- **Results**
  - *Master production schedule*
    - What products to work on (and complete) in each time period.
    - For complex products, project plans.

Master Production Scheduling (2)

DATA ITEM	Period 1	Period 2	Period 3	Period 4
Forecast Demand	250	340	400	450
Initial Number of Employee	10	10	10	10
Regular Time Capacity in Hour per Employee	35	35	35	35
Regular Time Cost per Hour	15	15	15	15
Undertime Cost per Hour				
Overtime Capacity in Hour per Employee	10	10	10	10
Overtime Cost per Hour	25	25	25	25
Hiring Cost per Employee	500	500	500	500
Dismissal Cost per Employee	2000	2000	2000	2000
Maximum Number of Employee Allowed	M	M	M	M
Minimum Number of Employee Allowed	8	8	8	8
Initial Inventory (+) or Backorder (-)				
Maximum Ending Inventory Allowed	M	M	M	M
Minimum Ending Inventory (Safety Stock)				
Unit Inventory Holding Cost	3	3	3	3
Maximum Subcontracting Allowed	M	M	M	M
Unit Subcontracting Cost	60	60	60	60
Maximum Backorder Allowed	M	M	M	M
Unit Backorder Cost	M	M	M	M
Other Unit Production Cost				
Capacity Requirement in Hour per Unit	2	2	2	2

Capacity Planning

- **Problem statement**
  - Check whether *master production schedule* can be executed
  - Determine the "bottleneck" of production
- **Input data**
  - *MPS*
  - Resource calendar
- **Results**
  - yes/no answer
  - Aggregate machine and labor capacities, for each period
  - Subcontractors
- **Issue**
  - Does not deal with material availability

Materials Requirements Planning

- **Problem statement**
  - Departing from detailed product and technology information, determine what operations to do in each period
- **Input data**
  - Master production schedule
    - Production plan for end-items
  - Bill of Materials (BOM)
  - Routings
  - Inventory
  - Estimated lead times
- **Method**
  - Exploding the BOM
  - Forward/backward planning
  - Without respecting capacities
- **Results**
  - Material requirements plan: what operations to make in each period
  - Order plan

Capacity Requirements Planning

- **Problem statement**
  - Check feasibility of mat. req. plans
    - For machines and groups of machines
    - For groups of labor
  - Determine eventual extra capacities
- **Input data**
  - Machines
  - Labor
  - Calendar
  - *Material Requirements Plan*
    - What operations to make ion each period
- **Results**
  - Yes/no answer
  - Extra capacity requirements, for each period
    - machinehour
    - manhour

Finite-Capacity Scheduling

- **Allocate resources in time to accomplish a set of tasks**
  - Executable schedules → constraints must be observed
  - Get the best from alternative solutions → optimization
- **„Clear" sequencing**
  - Determine start and end time of tasks
- **„Clear" resource alllocation**
  - Assign resources for tasks
- **Joint problem**
  - Tasks compete for scarce resources.

Shop Control

- **Problem statement**
  - In a given instant, assign resources to operations
- **Input data**
  - Schedule
  - Current state of the shop floor
- **Method**
  - Using many kinds of knowledge,
  - Prompt decision are needed
  - Made by man (dispatcher)
  - Support: *dispatching rules*
  - No need to automate
    - Manless factory: dream → nightmare

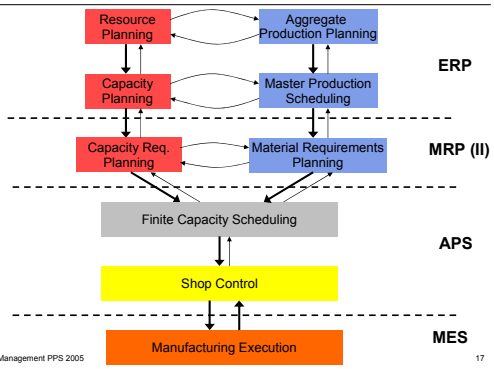
Manufacturing Execution

- **Following the production**
- **Comparing schedules with actual performance**
- **Continuous data collection**
  - Analysis
  - Reporting
- **Feedback for scheduling and planning**
- **Issues**
  - Technical
  - Human
  - But not computational (no hard decision problem)
- **First step toward automation production**

Process Planning (CAPP)

- **See previous lecture**

The complete picture, again



Model and solution

- **Declarative model building**
  - Separating the description of the problem, asking and answering of questions
  - Model + solver algorithm
- **Model and data separation**
- **Solution**
  - One (first)
  - All
  - Optimal
  - Pareto optimal (several criteria, not dominated)
- **Solution approach**
  - Properties: (non)complete, (non)optimal
  - Generic vs. heuristic methods
  - Complexity

Complexity and size

- **Problem complexity**
  - In the worst case how much time – how many steps – are needed to find solution.
- **Complexity classes**
  - **Deterministic polinon (P)**
  - **Nondeterministic polinom (NP)**
    - Trial and check
    - Check is in P
  - **NP complete**
    - NP and
    - Would P exist, then it would solve all the NP problems

Aggregate production planning: 1. example

- **Problem**
  - Internal capacities are limited.
  - Products need certain capacities.
  - Demand is known for each product.
  - Products are made either internally, or at external subcontractors.
  - External capacities are unlimited.
  - Internal and external capacities have different costs.
  - Time does not matter.
- **Question**
  How much to make from each product internally and externally to meet all demand?
- **Formulation: linear program**
  - Model: prodPlan1.mod
  - Data: prodPlan1.dat

Linear programming

- **Class of problems**
  - Real-valued variables, linear constraints, linear optimization criteria
- **Problem formulation**
  - Decision variables and their domains
  - Constraints
  - Criteria (goal)

$$\min cx \quad \text{s.t.} \quad \mathbf{A}x \geq b \quad i = 1..n, \quad x_i \text{ limited}$$

- **Solution**
  - Feasible values: n-dimensional body
  - Optimal solution in one of the vertices
- **Methods**
  - Simplex (Dantzig, 1940-50)
  - Internal points (Karmarkar, 1984)
  - Applicable to large-size problems ($n \approx 10^5$)
  - Successful applications

Master Production Scheduling: 2. ex.

- **Problem**
  - As before, plus
  - Time as new dimension
  - Producing more than the demand → building up inventory
  - Inventory costs
- **Modeling time**
  - Discrete units – time buckets
    - Demand and produced quantities change in time
- **Question**
  What and where to do so that to meet demand and minimize total costs?
- **Formulation: linear program** ProdPlan2.mod/.dat

Capacity and production planning: 3. ex.

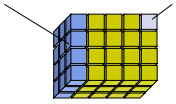
- **Task**
  - Given resources: labor and material
  - Each product requires certain resources
  - Profit is known for each product
  - Products can be made on certain machines
  - Machine can be leased, at certain cost
- **Questions**
  - What machines to lease,
  - How much to produce from each product so that
  - Profit be maximal.
- **Formulation: integer program**
  - Variables: 0-1 valued (Boolean)
  - fixed.mod/.dat

Integer programming

- **Problem class**
  - Optimize linear function
  - Integer variables (options from a finite set)
  - Under linear constraints
- **Complexity**
  - Much harder to solve than linear problems
  - Only smaller problems can be solved
  - Relaxation
    - Happy with real-valued solutions, too
    - Omitting some constraints
  - Heuristics
- **Solution method**
  - Enumeration
    - Bit: 100 binary variable→ $2^{100} \approx 10^{30}$ combinations
  - Search for solutions

Search

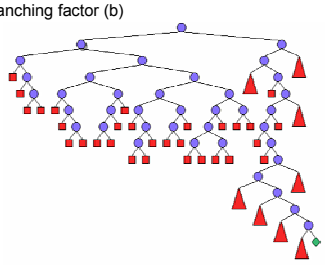
- **Methodical trial and error**
- **On partial or complete solutions**



- **Methods**
  - Constructive
  - Stochastic
- **Iterative improvement**
- **Safe – complete– optimal**
- **Complexity**
  - Time
  - Memory

Constructive search

- **Search tree**
  - **Nodes**: decisions + variables with actual domains
  - **Edges**: narrowing the domain of a variable, assigning value
  - **Leafs**: all variables with assigned value
  - Sizes: depth (d), branching factor (b)
- **How to traverse?**



Capacity and production planning: 4. ex.

- **Problem**
  - See 1. example, plus
  - Leasing of machines incurs costs
  - Production needs leasing of machines
- **Question**
  - Which machines to lease,
  - How much to make from each product externally and internally so as to
  - Meet demand and
  - Minimize total cost?
- **Formulation: mixed program**
  - Selection: 0-1 valued (Boole) variables
  - prodPlan3.mod/.dat

Mixed integer program

- **Class of problems**
  - Linear program, with some integer variables
- **Solution**
  - Uses search
  - Branching: along values of integer variables
  - Estimates where to proceed