Scheduling (LNMB Master Course)

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Time       Monday 13.00-14.45
           January 24 - March 21 and April 4 - April 18

Location   De Uithof Utrecht, Princetonplein 5,
           Buys Ballot Laboratorium, Room 106
Information on the web:

http://www.math.utwente.nl/~hurinkjl/sched/

• references
• pdf- and ps-files of the slides of the lectures
• subjects of the course
• news
• . . .
Goals

main goals of the course 'Scheduling':

1. get knowledge on basic models in scheduling
2. get knowledge on basic solution techniques for scheduling models
3. learn about applications of scheduling models
Material


- handout
## Planning of the subjects (temp.)

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Structure

• Lectures
  – models
  – methods and algorithms
  – examples
  – applications

• Examination: take home problems
  – will be given on the web-page
  – are updated frequently
  – two series; first to be delivered by 11.03.2005; second by 29.04.2005

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What is Scheduling?

- decision making in manufacturing and service industries
- allocation of scarce resources to tasks over time

Two main areas of application

- manufacturing models
- service models

Remark: we only consider deterministic models
Examples: Paper Bag Factory

- factory producing paper bags for different goods
- raw material: rolls of paper
- 3-stage production process
  - printing the logo
  - gluing the sides of the bag
  - sewing one or both ends of the bag
- at each stage several machines for processing
- set of production orders specified by
  - quantity and type of bag
  - committed delivery date
Examples: Paper Bag Factory

- processing times proportional to the quantities
- late delivery leads to a penalty, magnitude depends on
  - importance of the client
  - tardiness of the delivery
- switching on a machine from production of one bag-type to another, leads to setup time
- objectives:
  - minimize total penalty costs
  - minimize total time spent on setups
Examples: Routing and Scheduling of Airplanes

- An airline has a fleet of different aircrafts.
- Given a set of flights characterized by:
  - Origin and destination
  - Scheduled departure and arrival time
  - Customer demand (predicted by the marketing department)
- Assigning a particular type of aircraft to a specific flight leg leads to an estimated profit (based on demand)
• problem: combine different flight legs to round-trips and assign an aircraft to them

• constraints:
  – turn around time at an airport
  – law regulation on duration of a crew duty
  – . . .

• goal: maximize profit
Scheduling Function in an Enterprise

- the scheduling function interacts with many other functions
- interactions are system-dependent
- often take place in an enterprise-wide information system; enterprise resource planning (ERP) system
- often scheduling is done interactively with a decision support system linked to the ERP system
Scheduling in Manufacturing

- Schedule performance
- Scheduling and rescheduling
- Schedule
- Dispatching

Detailed Scheduling
Scheduling in Manufacturing

Production planning
master scheduling

Quantities, due dates

Material requirement, planning
capacity planning

Material requirements

Shop orders, release dates

Scheduling and rescheduling

Schedule

Dispatching

Orders, demands, forecasts

Capacity status

Scheduling constraints

Schedule performance

Detailed Scheduling
Scheduling in Manufacturing

Capacity status

Production planning
master scheduling

Quantities, due dates

Material requirement, planning
capacity planning

Material requirements

Shop orders, release dates

Scheduling and rescheduling

Schedule

Detailed Scheduling

Schedule performance

Dispatching

Shop status

Shopfloor management

Data collection

Job loading

Shopfloor
Scheduling in Services

Remark: scheduling function in service organization is much more diverse than in manufacturing

Diagram:

- Database
- Status (history)
- Forecasting
- Prices rules
- Yield management
- Scheduling
- Data
- Accept/reject (conditions)
- Place orders, make reservations
- Customer
- Forecasts
Scheduling models (manufacturing)

- scheduling concerns optimal allocation or assignment of resources, over time, to a set of tasks or activities
  - \( m \) machines \( M_1, \ldots, M_m \)
  - \( n \) jobs \( J_1, \ldots, J_n \)

- schedule may be represented by Gantt charts
Classification of Scheduling Problems

General Notations:

- $m$ machines 1, \ldots, $m$
- $n$ jobs 1, \ldots, $n$
- $(i, j)$ processing of job $j$ on machine $i$ (called an operation)
- data for jobs:
  - $p_{ij}$: processing time of operation $(i, j)$
  - if a job need to be processed only on one machine or has only one operation:
    - $p_j$: processing time of job $j$
  - $r_j$: release date of job $j$ (earliest starting time)
  - $d_j$: due date of job $j$ (committed completion time)
  - $w_j$: weight of job $j$ (importance)
Classification of Scheduling Problems

(Many) Scheduling problems can be described by a three field notation $\alpha|\beta|\gamma$, where

- $\alpha$ describes the machine environment
- $\beta$ describes the job characteristics, and
- $\gamma$ describes the objective criterion to be minimized

Remark: A field may contain more than one entry but may also be empty.
Classification - Machine environment

- Single machine ($\alpha = 1$)
- Identical parallel machines ($\alpha = P$ or $Pm$)
  - $m$ identical machines;
    - if $\alpha = P$, the value $m$ is part of the input and if $\alpha = Pm$, the value is considered as a constant (complexity theory)
  - each job consist of a single operation and this may be processed by any of the machines for $p_j$ time units
- Uniform parallel machines ($\alpha = Q$ or $Qm$)
  - $m$ parallel machines with different speeds $s_1, \ldots, s_m$
  - $p_{ij} = p_j/s_i$
  - each job has to be processed by one of the machines
  - if equal speeds: same situation as for identical machines
Classification - Machine environment

- **Unrelated parallel machines** ($\alpha = R$ or $Rm$)
  - $m$ different machines in parallel
  - $p_{ij} = p_j/s_{ij}$, where $s_{ij}$ is speed of job $j$ on machine $i$
  - each job has to be processed by one of the machines

- **Flow Shop** ($\alpha = F$ or $Fm$)
  - $m$ machines in series
  - each job has to be processed on each machine
  - all jobs follow the same route: first machine 1, then machine 2, etc
  - if the jobs have to be processed in the same order on all machines, we have a **permutation** flow shop
Classification - Machine environment

- Flexible Flow Shop ($\alpha = FF$ or $FFm$)
  - a flow shop with $m$ stages in series
  - at each stage a number of machines in parallel

- Job Shop ($\alpha = J$ or $Jm$)
  - each job has its individual predetermined route to follow
  - a job does not have to be processed on each machine
  - if a job can visit machines more than once, this is called recirculation or reentrance

- Flexible Job Shop ($\alpha = FJ$ or $FJm$)
  - machines replaced by work centers with parallel identical machines
Classification - Machine environment

- Open Shop (α = O or Om)
  - each job has to be processed on each machine once
  - processing times may be 0
  - no routing restrictions (this is a scheduling decision)
Classification - Job characteristics

- release dates ($r_j$ is contained in $\beta$ field)
  - if $r_j$ is not in $\beta$ field, jobs may start at any time
  - if $r_j$ is in $\beta$ field, jobs may not start processing before their release date $r_j$

- preemption ($pmtn$ or $prmp$ is contained in $\beta$ field)
  - processing of a job on a machine may be interrupted and resumed at a later time even on a different machine
  - the already processed amount is not lost

- unit processing times ($p_j = 1$ or $p_{ij} = 1$ in $\beta$ field)
  - each job (operation) has unit processing times

- other 'obvious' specifications (i.e. $d_j = d$)
Classification - Job characteristics

- precedence constraints ($prec$ in $\beta$ field)
  - between jobs precedence relations are given: a job may not start its processing before another job has been finished
  - may be represented by an acyclic graph (vertices = jobs, arcs = precedence relations)
  - special forms of the precedences are possible: if the graph is a chain, intree or outtree, $prec$ is replaced by $chain$, $intree$ or $outtree$
Classification - Objective criterion

Notations:

- $C_{ij}$: completion time of operation $(i, j)$
- $C_j$: completion time of job $j$ (＝ completion time of last operation)
- $L_j = C_j - d_j$: lateness of job $j$
- $T_j = \max\{C_j - d_j, 0\}$: tardiness of job $j$
- $U_j = \begin{cases} 
  1 & \text{if } C_j > d_j \\
  0 & \text{otherwise}
\end{cases}$: unit penalty
Classification - Objective criterion

- Makespan ($\gamma = C_{\text{max}}$)
  
  $C_{\text{max}} = \max\{C_1, \ldots, C_n\}$

- Maximum lateness ($\gamma = L_{\text{max}}$)
  
  $L_{\text{max}} = \max\{L_1, \ldots, L_n\}$

- Total completion time ($\gamma = \sum C_j$)
  
  - can be used to measure the Work-In-Progress (WIP)

- Total weighted completion time ($\gamma = \sum w_j C_j$)
  
  - represents the weighted flow times of the jobs

- Total (weighted) tardiness ($\gamma = \sum (w_j)T_j$)

- (weighted) number of tardy jobs ($\gamma = \sum (w_j)U_j$)
Remark: the mentioned classification gives only an overview of the basic models; lots of further extensions can be found in the literature!