Industrial Excellence
KPP319 – Product and Process Development

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An individual reflection on future development regarding simulation as a tool within production and logistics management. In a brief PM (max 5 p), reflect and discuss upon following key topics for the future of discrete event simulation:

1. Model size and complexity
2. Verification and validation techniques
3. Optimization
4. Parallel and distributed simulation
5. Internet based simulation
6. Human behavior and uncertainty modeling
7. Integration with ERP, PLM etc.

Search and refer to sources by your self!
PM – physical hand in and presentation 2011-10-04
Max 5 pages reflections and discussion.
Project

The participants perform in a group of 3-4 persons a project. A simulation-based study of an industrial production process, complemented by advanced production system analysis methods.

- A production system analysis focusing an aspect of industrial excellence
- Logic model as well as visualized model of the object that is analyzed
- Simulation in Extend and Visual Components
- Valid and relevant modeling and analysis to the objective of study.

Expected results:
- Simulation model – present at presentation
- Project report – hand in 2011-12-06
- Group presentation 2011-12-06 and 2011-12-13 (backup 2011-12-20)
Projects

Topics linked to the build-up of the Virtual lab at MDH.

Examples on possible studies are:

- Hardening plant at Volvo CE
  - 3D animation of hardening plant VCE (Visual Components). Internal flow / External flow
  - Discrete event simulation of hardening plant (Extend). Internal material flow / External material flow.
- Robot cell within a assembly flow at Haldex – animation as well as simulation.
- Build upon previous RTT (Robot Till Tusen) studies

Will be further presented and decided in lecture 2011-09-13.
<table>
<thead>
<tr>
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To-dos

- Fill in project team and project / company (if any)
- Fill in date to participate in Lab
Lecture 2 – 2011-09-06

Industrial Excellence - resumé

- The production system
- Production system design
- Design process
- Req´s – Alt´s – Eval
Production decisions have impact on the overall performance of the company

”.. what appears to be routine manufacturing decisions frequently come to limit the corporation’s strategic options, binding it with facilities, equipment, personnel, basic controls and policies to a non-competitive posture, which may take years to turn around.”

Skinner (1969)
The production system

Transformation of "input" to products, from supplier to customer
Industrial excellence

Production system design

Production system operations

Decisions, plans, guidelines

Competences, Tools, Methods, Processes

Experience, knowledge, data

Competences, Tools, Methods, Processes
Oloigesailie
Ponte e Torri Arsenale di Venezia nel XVI secolo. Canaletto (1697-1768)
Putting out system (Tonya in Japan)
Globally increasing manufacturing activity

A world wide 42% increase in manufacturing activity (at constant prices) 1998-2008. 36% increase in GDP world wide 1998-2008.

Production and processes

Future Manufacturing Technologies - Manufacture

The manufacturing sector in Europe today faces intense and growing competitive pressure on several fronts. In the high-tech sector, other developed economies pose the greatest threat. In more mature traditional sectors, manufacturing is increasingly migrating to low-wage countries such as China and India. Moreover, additional challenges such as the shortening life cycle of enabling technologies, environmental and sustainability issues, the socio-economic environment and the regulatory climate put further pressure on European manufacturing.

Key documents


Strategic Research Agenda - 2006

“MANUFACTURE - Assuring the Future of Manufacturing in Europe. Strategic Research Agenda”
By Edward Burtynsky. Deda Chicken Processing Plant, Dehui City, Jilin Province, 2005.
Design: David Benqué, Royal College of Arts
Industrial Excellence - resumé

The production system

- Production system design
- Design process
- Req´s – Alt´s – Eval
Process and layout types

- Project processes
- Jobbing processes
- Batch processes
- Mass processes
- Continuous processes

Manufacturing process types:
- Project processes
- Jobbing processes
- Batch processes
- Mass processes
- Continuous processes

Basic layout types:
- Fixed-position layout
- Process layout
- Cell layout
- Product layout

Slack et al. (1998)
Typical cost functions

- Fixed position
- Functional layout / process layout
- Cell layout / Flow group
- Product layout
- Continuous flow

But, big uncertainties in the cost functions! – What else influences choice of principle?
Typical manufacturing site

Parts manufacturing → Surface treatment / hardening → Assembly

Parts Supplier → Material Supplier → Material Supplier → Parts Supplier → Material Supplier
Typical manufacturing site

Challenges, e.g.
- Lot sizes
- Materials handling
- Order principles

Solutions, e.g.
- Supply sequencing
- Manufacturing process development
- Manufacturing control
## Variant flora in production systems…

<table>
<thead>
<tr>
<th>System Characteristic</th>
<th>Example</th>
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<tr>
<td>Flow pattern</td>
<td>* Single straight line</td>
</tr>
<tr>
<td></td>
<td>* Parallel lines</td>
</tr>
<tr>
<td></td>
<td>* U-shaped cells</td>
</tr>
<tr>
<td></td>
<td>* Dendritic flow</td>
</tr>
<tr>
<td>Cycle time</td>
<td>* Parallel operations leading to long cycle times</td>
</tr>
<tr>
<td></td>
<td>* Single line leading to short cycle times</td>
</tr>
<tr>
<td>Product movement device</td>
<td>* Belt</td>
</tr>
<tr>
<td></td>
<td>* Roller conveyor</td>
</tr>
<tr>
<td></td>
<td>* Overhead crane</td>
</tr>
<tr>
<td></td>
<td>* AGV</td>
</tr>
<tr>
<td>Pacing</td>
<td>* Manual</td>
</tr>
<tr>
<td></td>
<td>* Mechanical</td>
</tr>
<tr>
<td>Product mix</td>
<td>* One product</td>
</tr>
<tr>
<td></td>
<td>* Multiple products (in separate batches)</td>
</tr>
<tr>
<td></td>
<td>* Mixed products (simultaneously)</td>
</tr>
<tr>
<td>Banking</td>
<td>* Various removability of products</td>
</tr>
<tr>
<td>Work-station equipment</td>
<td>* Manual</td>
</tr>
<tr>
<td></td>
<td>* Mechanical</td>
</tr>
<tr>
<td></td>
<td>* Automatic</td>
</tr>
<tr>
<td>Work-station characteristics</td>
<td>* Workers may sit, stand, walk with a line or ride a line</td>
</tr>
<tr>
<td></td>
<td>* Size/Length of station/line: Few or many workers</td>
</tr>
<tr>
<td></td>
<td>* Worker density: Number of workers working at the same object</td>
</tr>
</tbody>
</table>
Industrial Excellence - resumé
The production system

Production system design
Design process
Req´s – Alt´s – Eval
What is a production system?

Hubka & Eder, 1996

Porter, 1985
Reasons for design of production systems

Internal reasons
Product development
Idea / need of renewal
Cost cut
Structural rationalisation

External reasons
Market footprint
Customer preferences
Volume increase
Available technology
Change of principle
Changing offering
Supply chain structure
Regulation / legislation

Hubka & Eder, 1996
Focusing on production development, we are moving from a sequential scheme to a parallel one.
Principal product realization process
However, the problem occurs if the production system can’t cope with the new product.
Tied-up cost in production development project

Cost

100%

50%

Freedom of action

Tied-up share of the total cost

Actual cash-flow

Study phase  Project phase  Detailed design  Implementation  Running phase  Time
Concurrent engineering of product and production system

Traditional product and production system development

Concurrent engineering of product and production system

Time reduction
However, Concurrent Engineering poses a number of challenges as well.
A complex task to develop production systems!

- Freedom of action
- Tied-up share of the total cost
- Actual cash-flow

Cost vs. Time

- Study phase
- Project phase
- Detailed design
- Implementation
- Running phase

- Product development
- Production system development

- Traditional product and production system development
- Concurrent engineering of product and production system

Time reduction

- Production

To sum up: Today is "production system design"...

A layout project

An investment project

Part of a product development project

Development of production principles

Netz and Wiktorsson, 2009

Muther, 1974

Ohno, 1988
- Industrial Excellence - resumé
- The production system
- Production system design

**Design process**
- Req´s – Alt´s – Eval
The design paradox

“How can you decide the whole, without knowing the parts? The parts depend in turn on the whole.”
Developments of the general model of the design process

- (problem) analysis
- (solution) synthesis
- (solution) evaluation
- (problem) analysis
- (solution) synthesis
- (solution) evaluation
- (problem) analysis
- (solution) synthesis
- (solution) evaluation

Rosell, 1990
Design as a reduction process

- Choice and evaluation screens
- Large number of design options
- Uncertainty regarding the final design
- One design
- Certainty regarding the final design
- Final design specification

Slack et al., 1998
The hierarchy of systems

Energy Materials Signals

Overall function

Sub-function

Energy’ Materials’ Signals’

Complexity

Pahl and Beitz, 1996
Steps of the planning and design process

Task: Market, Company, Economy

Plan and clarify the task:
- Analyse the market and the company situation
- Find and select product ideas
- Formulate a product proposal
- Clarify the task
- Elaborate a requirements list

Requirements list (Design spec)

Develop the principle solution:
- Identify the essential problems
- Establish function structures
- Search for working principles and working structures
- Combine and firm up into concept variants
- Evaluate against technical and economic criteria

Concept (Principle solution)

Develop the construction structure:
- Preliminary form design, materials selection and calculation
- Select best preliminary layouts
- Evaluate against technical and economic criteria

Preliminary layout

Define the construction layout:
- Eliminate weak spots
- Check for errors, disturbing influences and minimum costs
- Prepare the preliminary parts list and production and assembly document

Definitive layout

Prepare production and operating documents:
- Elaborate detail drawings and parts lists
- Complete production, assembly, transport and operation instructions
- Check all documents

Product documentation

Solution

Pahl and Beitz, 1996
Task: Market, Company, Economy

Plan and clarify the task:
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Concept (Principle solution)

Develop the construction structure:
- Preliminary form design, materials selection and calculation
- Select best preliminary layouts
- Evaluate against technical and economic criteria

Upgrade and Improve:
- Information: Adapt the requirements list

Plan & clarify the task

Conceptual design

Visions / Objective

Requirements

Pre-conditions

Propositions

Evaluation

Rosell, 1990

Hubka & Eder, 1996

Pahl and Beitz, 1996
One example on design process for production systems

1. Identifying the required manufacturing functions needed.
2. Make vs. buy decisions.
3. Input/output-diagrams (IOD) of a number of Business System Options (BSOs) fulfilling the requirements of the desired, physical system.
4. Convert the physical IOD to including control models.
5. Refine control specific aspects within the different BSOs

(Wu, 1994)
Method for planning the assembly system design process

Bellgran, 1998
• Industrial Excellence - resumé
• The production system
• Production system design
• Design process

Req’s – Alt’s – Eval
What to evaluate?

Basically:
- **Time**,  
- **Cost** and  
- **Quality**.

**Req´s - Alt´s - Eval.**
- **Quality**,  
- **Speed**,  
- **Dependability**,  
- **Flexibility** and  
- **Cost**

...links the operation strategy to the performance of the production system.
Slack et al. (1998)

- **Cost**,  
- **Delivery reliability**,  
- **Delivery speed**,  
- **Quality**,  
- **Flexibility**,  
- **Environmental friendliness** and  
- **Employee relationships**

... parameters as defining the manufacturing strategy (based on a review by Öhrström, 1997)

- **Cost**,  
- **Quality**,  
- **Time**,  
- **Efficiency**,  
- **Flexibility**,  
- **Risk** and  
- **Environmental effects**

... the seven "universal virtues" of DFX
Olesen (1992)
Goldratt and Fox (1986) defines three global economic measures:
- **net profit**
- **return on investment** and
- **cash flow**.

Translated into three parameters to be used in operations,
- **Throughput**: the rate at which the system generates money through sales.
- **Inventory**: all the money the system invests in purchasing things the system intends to sell.
- **Operating expense**: all the money the system spends in turning inventory into throughput.

Troxler and Blank (1989) defines a **manufacturing system value** (MSV) as a combination of:
- **Suitability**, based on factors such as: investment, growth, technology and market position, employee relations, workforce composition, organisation structure and operations management.
- **Capability**, based on factors such as: design, function, reliability, availability, flexibility, human factors and technical feasibility.
- **Performance** based on factors such as: throughput, quality, inventory, information, and capital utilisation.
- **Productivity**, based on factors such as: economic infrastructure, customer response and environmental influence.
Line performance as a function of line parameters

- Repair times
  - Number of workstations
  - Number of repairmen
  - Dispatching rule
- Interfailure times
  - Preventive maintenance
  - Engineering changes
  - Calibration / setup
  - Personal fatigue / delay
  - Lunch / break
- Workstation layout
  - Job complexity
- Tools
  - Skill level / discipline
- Parts Quality
  - Environment
- Assembly process
- Scheduling
  - Job dispatching
  - Parts availability
  - Layout / process
  - Material handling
- Waiting time
- Unscheduled downtime
- Reliability
- Scheduled downtime
- Availability
- Operation process time
- Capacity
- Yield
- Yield capacity
- Line performance

(Chow 1990)
# Three cases: Conditions

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<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
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<td>Truck industry</td>
<td>Truck industry</td>
<td>Car industry</td>
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<td><strong>Replacement or New?</strong></td>
<td>Replacement</td>
<td>Replacement</td>
<td>Replacement</td>
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<td><strong>Incentive for change</strong></td>
<td>New product</td>
<td>Volume shift</td>
<td>Space needed and work rationalisation</td>
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<tr>
<td><strong>Assembly capacity</strong></td>
<td>Tens</td>
<td>Tens</td>
<td>Hundreds</td>
</tr>
<tr>
<td>(thousands / year)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total no. handled</strong></td>
<td>Thousands</td>
<td>Thousands</td>
<td>Thousands</td>
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<tr>
<td><strong>components</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Components / product</strong></td>
<td>Hundreds</td>
<td>Hundreds</td>
<td>Some fifty to hundred</td>
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<td>Participant-observ. and archival</td>
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<td><strong>technique</strong></td>
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Wiktorsson, 2000
Case A. Requirements (R) and Aims (A)

(R1) Decrease of assembly cost with 10% due to product improvements
(R2) Decrease of assembly cost with 20% due to production improvements
(R3) Two parallel product programmes during 1,5 year
(R4) Verified quality on product/process before start of production
(R5) A technical capacity of X products/day (work during day time) + Y assembly-kits/day
(R6) Production design in accordance to a company-specific pre-defined production philosophy

(A1) Minimal losses in flow and no constraints in product mix. To be solved by:
- balancing on group level
- new assembly sequence
- flexible production layout

(A2) Fixed works done in the main flow
(A3) Optimisation of spaces
(A4) In the best way utilise the knowledge of production personnel and their management in order to avoid known problems concerning:
- quality
- ergonomic issues
- assembly sequence

Wiktorsson, 2000
Objectives (O1 - O4) and fundamental aspects (FA1 and FA2) in case B

(O1) A capacity of X products / day on two shifts (16 hours)
(O2) Y percent on a company-specific productivity measure
(O3) Z percent decrease in assembly time compared to today’s assembly system, on today’s products and mix
(O4) All pre-assembly should, where economically justifiable, be done by suppliers in order to have as little material handling as possible in the assembly system.

(FA1) Minimise the material handling. As complete components as possible should be delivered into the position at the line.

(FA2) Create a visual process. It should be seen and signalled, wherever and whenever the process is not working according to plan.

Wiktorsson, 2000
Aims (A), Secondary Aims (SA) and Prerequisites (P) for Case C

(A1) Reduce the used floor area in the assembly shop by a specific space.
(A2) Increase productivity by reducing man-hours.
(SA1) Simpler planning procedure
(SA2) Better ergonomics through job variety
(SA3) Possibility to introduce semi-automated assembly
(P1) No design changes on the product
(P2) Capacity of N products per year

Wiktorsson, 2000
Back to mathematics…

Generic optimization formula…

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<th>Maximise</th>
<th>( f(x) )</th>
<th>objective function</th>
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<td>( g_i(x) = 0 )</td>
<td>( i \in I )</td>
</tr>
<tr>
<td></td>
<td>( h_j(x) \geq 0 )</td>
<td>( j \in J )</td>
</tr>
<tr>
<td></td>
<td>( x \in S )</td>
<td>set constraints</td>
</tr>
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… applied on production system design

<table>
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<th>Maximise</th>
<th>( w(x) )</th>
<th></th>
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<tbody>
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<td>Subject to</td>
<td>( p_i(x) = R_i )</td>
<td>( i \in I )</td>
</tr>
<tr>
<td></td>
<td>( q_j(x) \geq R_j)</td>
<td>( j \in J )</td>
</tr>
<tr>
<td></td>
<td>( x \in C )</td>
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Where

<table>
<thead>
<tr>
<th>( x )</th>
<th>represents the production system design</th>
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</thead>
<tbody>
<tr>
<td>( w(x) )</td>
<td>represents the winning abilities</td>
</tr>
<tr>
<td>( p_i(x) = R_i )</td>
<td>represents the functional requirements: nominal values</td>
</tr>
<tr>
<td>( q_j(x) \geq R_j )</td>
<td>represents the functional requirements: threshold values</td>
</tr>
<tr>
<td>( x \in C )</td>
<td>represents the design constraints</td>
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Wiktorsson, 2000
## Possible spec’ structure for production system design

<table>
<thead>
<tr>
<th>Requirements on Function</th>
<th>Qualifying Levels</th>
<th>Constraints on Design solution due to:</th>
<th>Winning Abilities</th>
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<tr>
<td></td>
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<td>internal reasons</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>external reasons</td>
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### Examples
- Product description
- Required production volume
- Product variants

### Examples
- Company guideline
- Existing equipment
- Skills, experience and knowledge

### Examples
- Component packing
- Quality assurance
- Regulations
- Employment laws

### Examples
- Time to customer
- A specific type of cost
- A specific type of flexibility
- A specific type of productivity

Wiktorsson, 2000
### Spec´s framework for the three cases

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<th>Functional req’s</th>
<th>QUALIFYING LEVELS</th>
<th>External design constr’s</th>
<th>WINNING ABILITIES</th>
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</thead>
<tbody>
<tr>
<td><strong>Case A</strong></td>
<td><strong>Nominal values</strong></td>
<td><strong>Internal design constraints</strong></td>
<td><strong>Component suppliers and packing</strong></td>
<td><strong>Availability, ease of operations</strong></td>
</tr>
<tr>
<td></td>
<td>* 2 product progr. for 1,5 year</td>
<td>* Production according to a company-specific philosophy</td>
<td>* Assembly-kitting</td>
<td>* Complexity and size of material handling</td>
</tr>
<tr>
<td></td>
<td>* Verified quality in product start</td>
<td>* Work in one shift</td>
<td>* Product quality-assurance</td>
<td>* Ease of installation &amp; resetting</td>
</tr>
<tr>
<td></td>
<td>* No constraints in product mix</td>
<td>* Existing building &amp; line for today’s product</td>
<td>* Regulations</td>
<td>* Flexibility for new and existing variants</td>
</tr>
<tr>
<td></td>
<td><strong>Threshold values</strong></td>
<td>* Balancing on group level</td>
<td>* Employment laws</td>
<td>* Working environment, controllability</td>
</tr>
<tr>
<td></td>
<td>* X products/day and Y kits/day</td>
<td>* New assembly sequence</td>
<td></td>
<td>* Economy: costs for investments and operations</td>
</tr>
<tr>
<td></td>
<td>* Decrease assembly cost … by 20%, due to production improvements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>… by 10%, due to product imprvm.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Case B</strong></td>
<td><strong>Nominal values</strong></td>
<td><strong>Internal design constraints</strong></td>
<td><strong>Component suppliers and packing</strong></td>
<td><strong>Simplicity and visuality of the process</strong></td>
</tr>
<tr>
<td></td>
<td>* Today’s product</td>
<td>* Two shifts</td>
<td>* Assembly-kitting</td>
<td><strong>Minimised material handling</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Threshold values</strong></td>
<td>* Today’s building</td>
<td>* Product quality-assurance</td>
<td><strong>Investments and operational costs</strong></td>
</tr>
<tr>
<td></td>
<td>* X products/day</td>
<td>* Line solution. Possibly some parallel sections</td>
<td>* Regulations</td>
<td></td>
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<tr>
<td></td>
<td>* Y on a productivity measure</td>
<td>* A visual process.</td>
<td>* Employment laws</td>
<td></td>
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<tr>
<td></td>
<td>* Z % decrease in assembly-time</td>
<td>* Pre-assembly by the suppliers, if economically justifiable</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>compared to today’s situation</td>
<td></td>
<td></td>
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<tr>
<td><strong>Case C</strong></td>
<td><strong>Nominal values</strong></td>
<td><strong>Internal design constraints</strong></td>
<td><strong>Component suppliers and packing</strong></td>
<td><strong>Minimise used floor area in the assembly shop</strong></td>
</tr>
<tr>
<td></td>
<td>* Existing product</td>
<td>* X hours per year available</td>
<td>* Assembly-kitting</td>
<td><strong>Minimise used floor area in the assembly shop</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Threshold values</strong></td>
<td>* Existing building</td>
<td>* Product quality-assurance</td>
<td><strong>Maximise productivity by reducing man hours</strong></td>
</tr>
<tr>
<td></td>
<td>* Reduce used floor area by a specific space</td>
<td>* Line flow with a fixed sequence</td>
<td>* Regulations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* Given capacity / variant &amp; year</td>
<td>* Limitations on new equipment</td>
<td>* Employment laws</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* Today’s quality</td>
<td>* Installation during operation</td>
<td></td>
<td></td>
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</tbody>
</table>
Guidelines for deploying the production flow

1. Should the product be in separate processes due to product differences?
2. Should the process be parallelised due to cycle time and capacity?
3. Can the process be modularised based on a modular product structure?

1. The level of mechanisation and automation
2. Production rate = time available / number to be assembled
3. Number of stages in a line solution = total work content / cycle time
4. Minimise losses by balancing
5. The layout of the flow depends on the building and philosophy
Example on Modelling techniques

GRAI (Graphe à Résultats et Activités Interliés) (Doumeingts et al., 1987)
Structured Analysis and Design Technique (SADT) (Ross and Brackett, 1976)
IDEF₀ (Integrated computer-aided manufacturing DEFINition) / Astrakan
CIM-OSA (1989) for Computer Integrated Manufacturing
The Structured Systems Analysis and Design Method (SSADM) presented by for instance Downs et al. (1992)
Case: Example on first rough modelling of assembly plant
Justification approaches for analysis of production systems

Justification Methodologies

Strategic Approaches
- Technical benefits
- Business Advantage
- Competitive factors
- Future Expansion

Analytic Approaches
- Value Analysis
  - Scorecards
  - Linear additive models
  - AHP Models
- Mathematical Analysis
  - "Back-of-the-envelope" calculations
  - Spreadsheets
  - Queuing networks
  - Optimisation techniques
- Experimental Analysis
  - Trace-driven simulations
  - Monte Carlo simulations

Economic Approaches
- Payback
- Net Present Value
- Internal Rate of Return
- Other Discounted Cash Flow methods
- Non DCF methods
- Sensitivity Analysis

Wiktorsson, 2000
Value analysis models

Profile charts, checklists and symbolic scorecards

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Weight</th>
<th>Alt. 1</th>
<th>...</th>
<th>Alt. M</th>
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<tbody>
<tr>
<td>Criterion A</td>
<td>4</td>
<td>3</td>
<td>...</td>
<td>1</td>
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<tr>
<td>Criterion B</td>
<td>2</td>
<td>7</td>
<td>...</td>
<td>5</td>
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<tr>
<td>Criterion C</td>
<td>1</td>
<td>4</td>
<td>...</td>
<td>7</td>
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<td>...</td>
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<tr>
<td>Criterion X</td>
<td>2</td>
<td>1</td>
<td>...</td>
<td>3</td>
</tr>
</tbody>
</table>

Σ Weighted scores: 105 ... 77

Linear additive models

Analytical hierarchy process (AHP)

Strategic attributes

Level 1 Categories

Level 2 Attributes

Level 3 Alternatives

Req´s - Alt´s - Eval.
**10 years ago: DE and geom. simulation and their vendors**

<table>
<thead>
<tr>
<th>Software</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arena</td>
<td>Systems Modeling Company</td>
</tr>
<tr>
<td>AutoMod</td>
<td>AutoSimulations</td>
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<tr>
<td>DE3</td>
<td>BYG Systems Ltd.</td>
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<tr>
<td>Extend</td>
<td>Imagine That, Inc.</td>
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<tr>
<td>Factor/Aim</td>
<td>Pritsker Corporation</td>
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<td>Micro Saint</td>
<td>Micro Analysis and Design, Inc.</td>
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<tr>
<td>ProModel</td>
<td>Production Modeling Corp. of Utah</td>
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<tr>
<td>Quest</td>
<td>Deneb Robotics</td>
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<tr>
<td>Simple++</td>
<td>Aesop</td>
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<tr>
<td>Taylor</td>
<td>F&amp;H Simulations Inc.</td>
</tr>
<tr>
<td>Witness</td>
<td>Lanner Group</td>
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</table>

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<thead>
<tr>
<th>Software</th>
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</tr>
</thead>
<tbody>
<tr>
<td>CimStation</td>
<td>SILMA</td>
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<tr>
<td>GRASP</td>
<td>BYG Systems Ltd.</td>
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<tr>
<td>IGrip</td>
<td>Deneb Robotics</td>
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<tr>
<td>Robcad</td>
<td>Tecnomatics Technologies Inc.</td>
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<tr>
<td>Workspace 4</td>
<td>Robot Simulations Ltd.</td>
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</tbody>
</table>

Klingstam and Gullander, 1997
The tools and methods used in the previous Case

<table>
<thead>
<tr>
<th>Description</th>
<th>Usage in this case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catia</td>
<td>Engineering design</td>
</tr>
<tr>
<td>IGRIP</td>
<td>Geometric simulation</td>
</tr>
<tr>
<td>RobCAD</td>
<td>Geometric simulation</td>
</tr>
<tr>
<td>4D-Navigator</td>
<td>Geometric packing</td>
</tr>
<tr>
<td>Ergoplan</td>
<td>Work place design</td>
</tr>
<tr>
<td>Visualising assembly and material facades.</td>
<td></td>
</tr>
<tr>
<td>Visualising product and tools</td>
<td></td>
</tr>
<tr>
<td>CC-Plant</td>
<td>Process description</td>
</tr>
<tr>
<td>Witness</td>
<td>Flow simulation</td>
</tr>
<tr>
<td>FMEA</td>
<td>Checklist for failure/consequence analysis</td>
</tr>
<tr>
<td>VCCQ</td>
<td>Checklist for quality assurance</td>
</tr>
<tr>
<td>SAM</td>
<td>Time analysis of assembly activities</td>
</tr>
<tr>
<td>DFA/DFM</td>
<td>Analysis of assemblyability and manufactureability</td>
</tr>
</tbody>
</table>

Wiktorsson, 2000
Case: tool usage

- 4D-Navigator
- CC-Plant
- Witness
- IGRIP/RobCAD
- Ergoplan
- Flow Process
- Product

Static model: Geometric/Descriptive
Dynamic model: Kinematic/Flow simulation

Wiktorsson, 2000