Systems for Production Control and Production Planning
- Lecture on manufacturing and its IT-systems -

Fraunhofer Institut Informations- und Datenverarbeitung

Shenyang, November 22, 2007
"Chart of the week" (source: Automobilwoche 2006)

Planned manufacturing sites of German suppliers in the next 10 years

- China: 75%
- Eastern-Europe (EU): 58%
- Eastern-Europe (non-EU): 44%
- South-east Asia: 21%
- Southamerica: 14%
- India: 13%
- Northamerica: 5%
- Japan: 1%
- Western Europe: 0%
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3. Strategies for modern production: control and logistic approaches

4. Trends in manufacturing; current developments in manufacturing companies

5. Systems supporting production planning, monitoring & control: Manufacturing execution systems (MES)
1. Short introduction to the lecturer’s organization:

Fraunhofer IITB and its business unit production monitoring & control
1. Short introduction to Fraunhofer IITB

- Applied research
- 56 institutes
- 40 locations in Germany
- 12 800 employees
- 1 Billion € budget
1. Short introduction to Fraunhofer IITB (2)

- **Fraunhofer society:**
  - 12,700 ‘applied scientists’ focused on R&D-services
  - 1 bio € revenue
  - 58 institutes including overseas offices

- **Core competencies of IITB business unit:**
  - Real time applications for production monitoring, control and maintenance support
  - Consulting for Manufacturing Execution Systems
  - Optimization algorithms for manufacturing scheduling and sequencing
  - Detailed know-how of manufacturing and assembly processes in discrete manufacturing

- **Customers:**
  - DaimlerChrysler, plants Bremen, Wörth, Sindelfingen
  - Siemens A&D ("PCS7 Batch")
  - ThyssenKrupp Steel
  - ‘MES-software’ suppliers (Manuf. Execution Systems)
1. Services and products of IITB’s business unit PMC

Production monitoring
- Shared realtime applications for facility monitoring
- Business intelligence tools for KPI calculation
- Assisting functions for control rooms
- Visualization and SCADA-functions
- Software agents in realtime systems

Innovative MES-components
- Optimization algorithms for manufacturing
- Concepts for lean manufacturing control
- Planning and scheduling
- Ambient Intelligence in manufacturing
- Applications for digital production
1. Examples for current projects

- Production monitoring system ProVis.Agent, DaimlerChrysler AG, plants Bremen und Woerth, in body, paint, assembly incl. hotline and service
- Development of IO-Module ("Primary Data Manager - PDM") incl. PLC-connection via ‘Integra-channel’ for Siemens, business unit A&D
- Production monitoring & control system for 20 annealing furnaces, ThyssenKrupp Stahl AG, Duisburg plant incl. hotline and service
- Cooperation with Siemens A&D for production monitoring systems (PCS7) and OPC-tools applied to process industries (food, beverage, etc.)
- Concept for plug-and-work engineering, PLC-programming and process pictures for Hottinger Maschinenbau GmbH, Mannheim (Germany)
- Evaluation of strategies for manufacturing control and their impacts on manufacturing execution functionalities, MPDV GmbH, Mosbach (Germany)
2. Production: what is it all about?

A framework for factory planning and operations
2. Factory types for production of goods (source: Spur, G.: Fabrikbetrieb)

- Types of factories
  - Simple products
    - Geometrically non-defined products
      - Continuous manufacturing
  - Complex products
    - Geometrically defined products
      - Discrete manufacturing
        - One piece production
        - Serial production
        - Mass production
2. How the sectors of the German economy develop

![Diagram showing the development of primary, secondary, and tertiary sectors from 1882 to 2004.]

- **Primary sector**, e.g. agriculture
- **Secondary sector**, e.g. manufacturing
- **Tertiary sector**, e.g. services
2. Reference model for factory planning

- **Factory idea**
  - From market demands to an operating factory

- **Industrial engineering**
  - From a product idea to the work plan

- **Factory concept**
  - From a spec. to machines

- **Factory planning**

- **Realization**

- **Ramp up**
  - From a control philosophy to IT-supported operations

- **Machines/equipment**

- **Building**
  - Utilities
  - Outside facilities

- **Project management**

- **Manufacturing execution systems**

- **Operations**
2. Reference model for factory planning: connection of planning and operations

**Project management**

- Design
- Engineering
- Idea

- Planning
- Concept

- Facilities
- Building
- Realization
- Ramp up

- Operations
- Supplier parts
- Manufacturing execution systems for
  - Detailed scheduling
  - Tool management
  - Material management
  - Staff management
  - Data acquisition
  - Key performance indicators
  - Quality management
  - Information management

*DF= Digital Factory systems, e.g. DELMIA, Siemens UGS, etc.*
3. Strategies for modern production:
control and logistic approaches
3. Current situation of manufacturing companies (1)

Flexibility

Traditional markets, e.g. machines, automotive, shipbuilding, etc., are saturated
⇒ over capacities, buyer-markets, flexibly acting markets, high requirements concerning flexibility

Variants

Markets are increasingly segmented, products are to a maximum degree customized
⇒ High degree of variants and therefore complexity in production and assembly, lot size 1 also in serial production

Supply Chain

Global competition and international work share also in small and medium sized companies
⇒ Product quality and know-how about processes are common xxx, international supply networks, high competitive pressure
3. Current situation of manufacturing companies (2)

- **Time**
  - Short life cycles, caused e.g. by permanent innovation in microelectronics
  - Lead time and delivery times become strategic performance indicators

- **Organization**
  - Qualified staff is entitled to self-determination, entrepreneurial spirit concerning their work
  - Small, self-organizing units in manufacturing, no hierarchies, KAIZEN (continuous improvement)

- **Information techn.**
  - Realtime-IT in manufacturing from machine controllers up to the ERP-system, new software technologies
  - Approaches of shared, decentralized intelligence will become accepted
3. Manufacturing and control strategies (1)

Job shop manufacturing
(turning shop, milling shop, grinding shop, paint shop...)

Characteristics:

- Equivalent equipment is concentrated in manufacturing shops, e.g. all turning machines in the turning shop. With multi-level products the material flow gets very complex (spaghetti!)

- Work flow is bound to manufacturing of lots; when the last part of a lot is finished the entire lot is transported to the next production step.

Example: factory layout of a job shop manufacturing (source: Röhrig, M.)

IITB traffic light

<table>
<thead>
<tr>
<th>Flexibility</th>
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<tbody>
<tr>
<td>Variants</td>
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<td>Supply Chain</td>
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<td>Time</td>
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<td>Organization</td>
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<td>Information tech.</td>
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3. Manufacturing and control strategies (2)

Cell manufacturing – decentralized units in production

Characteristics:
- Workers produce parts, sub-assemblies or finished goods completely, if possible in group technology. Workers are in charge of control and quality management.

- Applying cells means manufacturing part families, that means parts that are similar to each other.

Benefits from a combination of job shop and cell manufacturing (source: Hauertmann, W., et.al.)

IITB traffic light

<table>
<thead>
<tr>
<th>Flexibility</th>
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<tbody>
<tr>
<td>Variants</td>
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Legend:
- D: Turning machine
- B: Drilling machine
- F: Milling machine
- S: Grinding machine

Usage of resources
- Smooth material flow

Usage of productivity
- Flexible work system
3. Manufacturing and control strategies (3)

Line manufacturing (automated / manual)

Characteristics:

- Machines and production steps are arranged according to the production flow
- Used for large order numbers, specialized equipment, mostly machines with fixed cycle times

Examples for line manufacturing (source: IFA, Hanover)

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| Flexibility |  |
| Variants |  |
| Supply Chain |  |
| Time |  |
| Organization |  |
| Information techn. |  |

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NEW: variant enabling manufacturing

Characteristics:

- Manufacturing process is divided in variant neutral and variant building production steps.

- A special cell manufactures only parts without customer specific options; in the final cell customer specific options and variants are assembled including some machines, that produce customer specific options.
3. Manufacturing and control strategies (5)

Push-control: MRP, MRP II, load dependant order control, cumulative quantity, etc.

Characteristics:
- Central and batch oriented production planning and control; difficulties to short term reactions to unexpected changes on the shopfloor
- Central release of manufacturing orders according to methodology of termination

IITB traffic light

- **F**lexibility
- **V**ariants
- **S**upply Chain
- **T**ime
- **O**rganization
- **I**nformation techn.

Draft MRP II process (source: Betriebshütte)

- Sales planning
- Planning of primary demand
  - Calculation of manufacturing numbers regarding amount and period
  - Adaptation of capacities is possible, e.g. extra shifts
  - Capacity requirement and existing capacities match
    - Not o.k.
    - o.k.
- Calculate Master Production Schedule (MPS)
- Material requirements planning
  - Turnover, sales numbers, investments, financial plans from enterprise level
  - no, change dates or lot size
  - Material demand realistic?
    - no
    - yes
- Calculate manufacturing orders
3. Manufacturing and **control strategies** (6)

**Pull control: KANBAN, CONWIP**

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<td>Information techn.</td>
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* Not applicable in case of unsteady part consumption
** Originally without use of IT-systems

**Characteristics:**

- Only a real customer demand triggers manufacturing (like in the supermarket). Lot sizes are broken down to daily demands.
- The manufacturing process gets a signal, which parts are to be produced in a certain number at a certain point of time; the signal is triggered by a KANBAN.

**Material flow and information flow of a KANBAN controlled production (source: METROPLAN)**

- Rolling forecast
- Production KANBAN
- Withdrawal KANBAN
- Daily sequence
- Machining of complex aluminum parts
- Lot size pallet
- Buffer
- Assembly, lot size 1
3. Manufacturing and control strategies (7)

Pull control: 'lean production'

Manufacturing strategy to eliminate waste;
Characteristics:

- Produce in the customer’s cycle time: the ideal manufacturing line produces according to its customer’s cycle or according to the customer’s call-off

- One-piece flow: single process steps must be as close as possible in a process flow and should be synchronized

- PULL-system: if it’s not possible to shape a continuous flow, the most efficient material flow is a PULL-System, connecting process steps throughout the value adding chain

- Control of only one process step: this pacemaker-process is directly ‘controlled’ by the customer demand

- Constant PULL of small units: use small load carriers instead of large wire metal boxes; reduce range of coverage and provide the line continuously by milk runs
3. Practical use of strategies

<table>
<thead>
<tr>
<th>Sophisticated terms made simple</th>
<th>Current use</th>
<th>Use in future</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Job shop manufacturing</strong></td>
<td>Traditional structures, „small and medium sized production“</td>
<td>Manufacturing and technology experts</td>
</tr>
<tr>
<td><strong>Cell manufacturing</strong></td>
<td>Part manufacturing, wide range of parts; physical</td>
<td>Part manufacturing and assembly, logical</td>
</tr>
<tr>
<td><strong>Line manufacturing</strong></td>
<td>Serial production; today use of automated equipment</td>
<td>Small range and serial production; automated and manual steps mixed</td>
</tr>
<tr>
<td><strong>Variant enabling manufacturing</strong></td>
<td>First applications in industry</td>
<td>Small range and serial production; driven by number of variants</td>
</tr>
<tr>
<td><strong>Push control: MRP, MRP II, etc.</strong></td>
<td>Traditional structures, often using SAP</td>
<td>Central control giving an objective for smaller units</td>
</tr>
<tr>
<td><strong>PULL control: KANBAN, CONWIP</strong></td>
<td>Assembly, provision of low value parts</td>
<td>Used between parts manuf. and assembly; also between companies</td>
</tr>
<tr>
<td><strong>PULL control: lean production</strong></td>
<td>Mostly serial production e.g. from automotive</td>
<td>Small range and serial production; commonly used</td>
</tr>
<tr>
<td><strong>Local intelligence; agent control</strong></td>
<td>First applications in industry</td>
<td>Shared production, PLC-/ CNC-controlled machines</td>
</tr>
</tbody>
</table>
3. Link between manufacturing and control strategies

Control strategies fitting manufacturing strategies; combinations found in practical use

<table>
<thead>
<tr>
<th></th>
<th>Push control: MRP, MRP II, etc.</th>
<th>PULL control: KANBAN, CONWIP</th>
<th>PULL control: lean manufacturing</th>
<th>Local intelligence: agent control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job shop manufacturing</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
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<tr>
<td>Cell manufacturing</td>
<td>![Symbol]</td>
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</tr>
<tr>
<td>Line manufacturing</td>
<td>![Symbol]</td>
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</tr>
<tr>
<td>Variants enabling</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
</tr>
</tbody>
</table>

- Not applicable
- Partly applicable
- Well applicable

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4. Trends in manufacturing;

current developments in manufacturing companies
4. Globalization

Europe’s most important suppliers come from...
(source: A.T.Kearney/Produktion 06092007)
4. Increasing product variants

Development of product variants (source: requirements to tomorrow's manufacturing technology, Fraunhofer ISI, September 2005; n= 613)
4. Short time to market

Currently: 52 month

Vision: 20 month + x

Reduce "time-to-market"
Extension 1:

To cope with product variants
4.1 To cope with product variants (1)

Dilemma of mass customization (source: Roehrig, M.)

- **Unsecure sales forecasts**
- **Increasing variety**
- **Reduced delivery times**

Cost drivers

Resulting requirements to manufacturing

- **High flexibility concerning volume**
- **High variety**
- **Short delivery times**
- **Cost effectiveness**

Increasing competition

Cost drivers

Mobile phone sales in Germany
- Forecast from 1998
- Forecast from 1999

Handy-Absatz in Deutschland

Mio. Stück

1998 1999 2000 2001

Unsecure sales forecasts

Rationalization driver

Increasing competition

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4.1 To cope with product variants (2)

Dilemma of mass customization (source: Roehrig, M.)

- Unsecure sales forecasts
- Increasing variety
- Reduced delivery times

Cost drivers

High flexibility concerning volume
High variety
Short delivery times
Cost effectiveness

Resulting requirements to manufacturing

Volkswagen will double the number of models in the years to come

Increasing competition

Number of models offered

BMW 1971 2010
VW 1971 2010
Opel 1971 2010
Ford 1971 2010
Audi 1971 2010

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4.1 To cope with product variants (3)

Possible solutions

<table>
<thead>
<tr>
<th>Product</th>
<th>Clearly defined variant features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building blocks</td>
<td>Modular structures</td>
</tr>
<tr>
<td>Product configurator</td>
<td>Flexible production technology</td>
</tr>
<tr>
<td>Lot size 1</td>
<td>Minimum lot sizes</td>
</tr>
<tr>
<td>Set-up flexible processes</td>
<td></td>
</tr>
</tbody>
</table>

Ability for mass customization

- Logistics/controlling: Demand-oriented production
- Cost transparency concerning A and C products
- Allocations of costs acc. to cause of costs
- Production with minimum work in process
- Fast moving items/exotic items
- Latest point of configuration
- Reduction of internal variance
- Flexible production technology
- Set-up flexible processes
- Minimum lot sizes
- Production structure
- Flexible Fertigungstechnik
- Rüstflexible Prozesse
- Modular structures
- Cell manufacturing
- Fast moving items/exotic items
- Flexible production technology
- Minimum lot sizes
- Production structure
4.1 To cope with product variants (4)

Examples from industry: production of blank cans of soups

Basic product  

<table>
<thead>
<tr>
<th>Palletizing</th>
<th>Fast moving items</th>
<th>Store</th>
<th>Depalletizing</th>
<th>Exotic items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filling lines</td>
<td>3 lines</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Customer related product

<table>
<thead>
<tr>
<th>Labelling/packaging</th>
<th>2 lines</th>
<th>Customer</th>
</tr>
</thead>
</table>

1 type of can  

Up to 6 different „private-labels”

Production volume: app. 100 mio. units p.y.
Line output: app. 500 cans/min.

Decision concerning blank can production due to higher flexibility and less investment
4.1 To cope with product variants (5)

Examples from industry: to cope with product variants by modular products (basic product + different connection adapters) and cellular manufacturing at a producer of filters

Example:
by combination of 10”- basic filter cartridges with
- different connection adapters,
- multiple cartridges,
- various packings
the entire variety of customer specific products are derived.

The range of final products is < 10,000 and shows a typical ABC-characteristics. The number of individual products is between <50 p.y. up to more than 10,000.

The production structure is organized as cellular manufacturing (cartridge-/connection adapter cells) and a manufacturing cell for exotic items.
4.1 To cope with product variants (6)

Examples from industry: coping with variants by latest point of configuration – example screw compressors (source: GEA Grasso GmbH, Berlin)

The entire manufacturing process is customer neutral. The specific parts, that make a customer related solution are produced together with the compressor’s case.

For a specific customer order the related parts are milled right before the final assembly.

Benefits:
- Customer neutral manufacturing. The throughput time has no impact on the delivery time.
- Possibility to assemble a customer related compressor from a very limited number of parts.
Examles from industry: building blocks for a family of rail vehicles

Goal of the project:
80% of all customer orders should be fulfilled with standard components, such as air condition, doors, brake systems, etc.

Steps:
- Define a generic product: what is equal with all sold vehicles?
- Define components that can be assembled to this generic product
- Define customer related features that may be added to the generic product, such as width of window, width of seats, number of doors, entrance height, engine concept, etc.
- Define components that fit to the customer related features.

One train - x variants
4.1 To cope with product variants (8)

Examples from industry: machine configurator and support of PLC-programming and machine visualization
Extension 2:

Lean manufacturing: simplify your factory
4.2 Lean manufacturing: simplify your factory (1)

Definition

To react flexibly to customers needs

1. Internal flexibility
   = to be able to produce customer related products ➔ to cope with products variants (see 3.1)
   = to quickly adapt facilities to new products/new orders ➔ facility planning
   = to flexibly react to changes concerning the product’s configuration ➔ manufacturing control
   = to react to unleveled customer demands ➔ manufacturing control
   = to adapt the factory to new processes and organizational changes

2. External flexibility
   = to efficiently shape value creating networks
4.2 Lean manufacturing: simplify your factory (2)

Features of a continuous process flow:

- Produce in the customer’s cycle time: the ideal manufacturing line produces according to its customer’s cycle or according to the customer’s call-off

- One-piece flow: single process steps must be as close as possible in a process flow and should be synchronized

- PULL-system: if it’s not possible to shape a continuous flow, the most efficient material flow is a PULL-System, connecting process steps throughout the value adding chain

- Control of only one process step: this pacemaker-process is directly ‘controlled’ by the customer demand

- Constant PULL of small units: use small load carriers instead of large wire metal boxes; reduce range of coverage and provide the line continuously by milk runs (example see next page)
4.2 Lean manufacturing: simplify your factory (3)

Features of a continuous process flow:

- Constant PULL of small units: use small load carriers instead of large wire metal boxes

- Space for material provision reduced by app. 60 %
- Range of coverage reduced from 3 shift to 2 hours!
4.2 Lean manufacturing: simplify your factory (4)

Examples from industry: set-up flexible processes in an engine plant

Number of engines: 250,000 engines p.y.
Cycle time: app. 60 sec.
Lot size final assembly: 1
Lot size machining: 1 or capacity of one pallet
Number of engine variants: app. 20

The requirements of the engine manufacturer have been set up in a way that it now is possible to produce any kind of engine variant according to the customer demands without extra setup time for machines.

Benefits:
- maximum flexibility concerning variants
- minimum stock of finished engines
- low work-in-process
- high adaptivity to unexpected changes
4.2 Lean manufacturing: simplify your factory (5)

Customer call off → Daily forecast for all calls → Breakdown of B.O.M. → Forecast

Sequence planning, model mix → Forecast

Production KANBAN Crank case → Control impulse crank case

Machining Crank case Cylinder blocks

Manufacturing of other parts

Withdrawal KANBAN

Vendor managed inventory → Call of acc. to production KANBAN

Legend:
- Buffer
- Functions of central planning
- Control function

Fraunhofer Institut für Integrierte Schaltkreise (IITB), 2007
4.2 Lean manufacturing: simplify your factory (6)

Examples from industry: demand oriented control at a producer of brake systems for commercial vehicles

Autonomous assembly cell:
- complete assembly and testing
- rework
- simple maintenance work
- all material is available in the RIP-buffer

Legend:
- assembly station
- assembly buffer
- assembly worker
- flow storage rack
- material flow

RIP-buffer
4.2 Lean manufacturing: simplify your factory (7)

Examples from industry: demand oriented control at a producer of brake systems for commercial vehicles

Source: Wabco, braking systems for commercial vehicles
5. Systems supporting production planning, monitoring & control:

Manufacturing Execution Systems (MES)
5. Manufacturing Execution Systems in a factory’s IT hierarchy (Source: Betriebshütte, VDI 5600)

Enterprise level
- Rich client
- Terminal
- Server

Manufacturing level
- Coupling
- PC
- Control server
- PC

Cell level
- Coupling
- Cell server
- Supervisory PLC
- Control server

Shop floor
- Coupling
- PLC
- PLC
- PLC
- Data acquisition
5. Tasks covered by today’s manufacturing execution systems (Source: VDI 5600)

Hierarchy levels

Enterprise level
- Production order control
- Staff management
- Performance analysis

Manufacturing level
- Information management
- Tool management
- Data acquisition

Shop floor level
- Quality management
- Material management
- Performance analysis
- Data acquisition
- Material management

IT-systems

ERP systems

MES systems

PLCs, CNCs, robot controllers
5. Typical time horizons and items within the various control levels of an enterprise (Source: VDI 5600)

<table>
<thead>
<tr>
<th>Control Level</th>
<th>Time Horizon</th>
<th>Time Pattern</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise level</td>
<td>One or more days / shifts</td>
<td>Some weeks / months</td>
<td>Entire pool of orders</td>
</tr>
<tr>
<td>Manufacturing level</td>
<td>Some seconds up to one shift</td>
<td>One or more shifts</td>
<td>One or more orders</td>
</tr>
<tr>
<td>Shop floor level</td>
<td>Milliseconds up to seconds</td>
<td>Seconds up to some minutes</td>
<td>Single process steps</td>
</tr>
</tbody>
</table>
5. Architecture of today’s and tomorrow’s MES-systems

- **Mainframe (Monolithic Application)**: 1980
- **Client/Server (Client Application)**: 1990
- **Web based**: 2000
  - **Presentation**: Business Logic
  - **Data, Legacy**: Process, Services
- **Service Oriented**: 2010
  - **Presentation**
  - **Data, Legacy**
5. Requirements for production systems

► Facilities survive products, e.g. commercial vehicles 20 years (spare parts)

► PLCs and other controls have to run in changing environment

► Number of products variants increases in many branches

► High variety of controls, software versions and super-ordinate IT-systems

Flexible configuration of production lines during running operations; when facilities are changed, software must be adapted as well
Scope for tomorrow morning

1. Some general remarks on automation

2. Automotive manufacturing

3. Manufacturing execution systems for automotive production
   - example for a successful production monitoring system
   - general aspects of sequencing
   - integration of MES-components
   - central visualization and control room concept
   - integration of MES with digital factory
Thank you for your attention!
Systems for Production Control and Production Planning
- Lecture on manufacturing and its IT-systems –
Shenyang, November 22, 2007

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