Beyond ERP: Towards Intelligent Manufacturing Planning and Control
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Contents:

• History: Advances in IT in Manufacturing Planning and Control (MPC)
• The role of OR in MPC
• An evaluation of current MPC systems
• A manufacturing system typology
• A hierarchical MPC reference architecture
• An algorithmic framework for parameter setting
• Algorithms for Manufacturing Planning and Control

• Case Study: the Netherlands Navy Dockyard
Practice:

I(C)T in Manufacturing and Logistics


- Manufacturing Planning and Control Systems (MRP I, MRP II, OPT, Workload Control, Just in Time control)

- Decreasing system complexity (Production Flow Analysis, Cellular and Team-based manufacturing, Business Process Re-engineering)

- Impact of Electronic Commerce, Mass Customization
Science:

Operations Research in manufacturing/logistics

- Production Planning (*Holt et al.*, *Hadley and Whitin*, *Hax*, *Whybark*, *Bertrand et al.*)
- Inventory Management (*Scarf*, *Silver*, *Axsäter*, *Inderfurth*, *Federgruen*, *Zipkin*, *De Kok*, *Van Houtum*, *Zijm*)
- Distribution planning (*Christofides et al.*, *Fleischmann*)
- Queueing models (*Jackson*, *Buzacott*, *Suri*, *Tempelmeier*)

Models had limited impact, as opposed to

- Manufacturing Resources Planning (MRP II)
- Just in Time production (JIT)
- Lean Manufacturing, etc.

Why?
PUSH SYSTEM:
Manufacturing Resources Planning (MRP II)

Resource Planning → Aggregate Production Planning → Demand Management

Rough Cut Capacity Planning

Capacity Requirements Planning

Routing Files

Master Production Scheduling

Materials Requirements Planning

Bills of Material

Inventory Data

Shop Floor Systems

Vendor Systems

Vollmann et al., 1997
Bill of Material and lead time off-set’s in MRP

Bicycle

2

Frame

2

Pipes

3

Front Fork

2

Handle-bar

2

Wheels

1

Outside Tire

1

Inside Tire

2

Saddle

1

Pedals

1

Hub

1

Rubber Block

1

Rubber

1

Reflector

1

Rim

3

Spokes

2

Bearings

1

Nuts

1

Bearings

2

Axis

1

n = lead time in weeks
John Kanet (formerly Black & Decker Materials Manager)

Many reasons were mentioned why MRP did not work appropriately, including:

- inaccurate computer records  
  (but MRP didn’t work after fixing)
- unrealistic Master Production Schedule  
  (but after realistic MPS, still no improvement)
- Lack of top management involvement  
  (they got involved, no result)
- insufficient training of employees  
  (spawning the golden age of MRP-based consulting)
Advantages of MRP systems

• Emphasis on Bill of Materials and dependent demand
• Emphasis on information structuring

Drawbacks of MRP systems

• No finite capacity planning
• Fixed, instead of state-dependent lead times
• Product characteristics must be known in advance
• No capabilities to deal with uncertainty
• Materials oriented, not process oriented
PULL SYSTEMS:
JIT/Kanban systems

Outbound Stockpoint

Completed parts with cards enter outbound stockpoint

Outbound Stockpoint

Production Cards

When stock is removed, place production card in hold box

Production card authorizes start of work

Workstation

Standard container

Kanban card

Stockpoint

Schonberger, 1982
Advantages of JIT/Kanban systems

- Simple logic, no computerization needed
- Reduction of in-process inventories
- Stable lead times

Drawbacks of JIT/Kanban systems

- Limited number of products allowed
- Stable demand required (repetitive manufacturing) and/or high technical flexibility
- High line-reliability requested
- Set-up times should be minor, or eliminated
Workload Control

Operates primarily as shop floor release mechanism

Advantage: stable internal lead times (limited WIP, quality)
Drawback: ignores external delay times (due date reliability)

Hierarchical Production Planning (HPP)

Capacity oriented planning system

Planning decisions determined by
- Linear Programming (product type level)
- Knapsack-type allocation models (product family level)
- Run-out time based heuristics (item level)

Hax and Candea, 1984
Multi-echelon systems

- Determine order quantities at a central warehouse. At some later point in time, allocate these quantities to local warehouses.

The same analytical methods can be used to:

- Determine production quantities on a family level (and produce already common components). At some later point in time, split these quantities among the various items within each family (and hence allocate common components).

Supply Chain Management

Tayur et al., 1999
Advanced Planning Systems

Resource Constraints:

- Capacity Planning by LP/MIP
- Vehicle Routing in Distribution Planning
- Shop Floor Scheduling / Dispatching

Incorporating uncertainty:

- Multi-echelon inventory theory
- Order uncertainty in MTO systems
- Quality and Reliability issues
MPC deficiencies

MPC’s are mostly:
• Either material oriented or capacity oriented
• Unable to deal with uncertainty (safety stock, long lead times)
  • deterministic solution: generate robust plans
  • stochastic solution: explicitly model the stochastic behavior
• Unable to recognize all available information generated at each level
• Unfit for the underlying production model & conditions
Klantorder ontkoppelpunt (KOOP)

Ruwe materialen → Componenten → Halffabrikaten → Eindproducten

Leveranciers

MTS → ATO → MTO → ETO → Klanten

Productie gebaseerd op voorspelling

Productie gebaseerd op klantorders

Klant Order Ontkoppel Punt
Product/market relations and production typology

Make and assemble to stock
Make to stock, assemble to order
Make to order
Engineer to order

Flow production (large batches)
Job shop (small batches)
Project-based (unique)

Materials oriented / Capacity oriented
Television Set Assembly: MATS/flow production
Truck Manufacturing and Assembly: MTS/ATO production
Precision machining of actuators, MTO/job shop production
Engineering/construction of military frigates:

ETO/project production
An MPC reference architecture

**Technological planning**  
- Product and Process Design

**Capacity planning**  
- Long Range Forecasting and Sales Planning
  - Facility and Resources Planning
  - Demand Management and Aggregate Capacity Planning
  - Job Planning and Resource Group Loading
    - Shop Floor Scheduling and Shop Floor Control

**Material coordination**  
- Inventory Management and Materials Planning
  - Purchase and Procurement Management

Strategic/long-term

Tactical/mid-term

Operational/short-term
Objective of framework:

Bringing together

- Innovations in Information Technology
- Advances in Operations Research modeling and techniques

(as far as related to manufacturing and logistics)

to pave the road for more intelligent Manufacturing Planning and Control Systems
Product and Process Design
Design for Manufacturing and Assembly
Rapid Prototyping
Graph-theoretical methods

Long Range Forecasting and Sales Planning
Causal Forecasting methods (regression analysis)
Qualitative Judgement (e.g. Delphi methods)

Facility and Resources Planning
Facility Layout Planning
Queueing Network Analysis
Production Flow Analysis

Demand Management and Aggregate Capacity Planning
Time Series Forecasting Models
Linear and Integer Programming Models

Boothroyd et al., 1994
Kalpakjian, 1992
Kusiak, 1990
Ulrich and Eppinger, 1995

Makridakis et al., 1998

Francis et al., 1992
Suri et al., 1993, Wemmerlov, 1989
Burbidge, 1975

Box and Jenkins, 1970
Makridakis et al., 1998
Hopp and Spearman, 1996
Buzacott, 1989
Process Planning

Macro Process Planning: queueing analysis  
Micro Process Planning: feature-based techniques  

Kusiak, 1990
Zijm, 1995

Production Order Planning and Resource Group Loading

Multi-echelon queueing models  
Dynamic Project Scheduling models  
Lot size / lead time trade-off models  
Capacitated Lot sizing models  
Resource group loading models & methods  

Buzacott and Shanthikumar, 1993
Kolisch and Drexl, 1996
Karmarkar, 1987, Suri et al., 1993
Salomon, 1991
Hans, 2001

Purchase and Procurement Management

(Multi-echelon) inventory models, EOQ type models  

Federgruen and Zipkin, 1984
Silver et al., 1998
De Kok et al., 1996
Van Houtum et al., 1996

Shop Floor Scheduling and Control

Shifting Bottleneck type models  
Adaptive randomized search models  
Random local search models  

Adams et al., 1988
Pinedo and Chao, 1999
Schutten, 1998
Meester et al, 1999
MPC reference architecture applied to MTO

Technological planning

Company management

Production planning

Strategic

Aggregate capacity planning

Tactical

Order acceptance

Macro process planning

Resource loading

Operational

Micro process planning

Scheduling
Resource Loading

During order acceptance, for any given set of orders, these questions need to be answered:

- When should orders be released for production?
- Can the delivery dates be met?
- How much operator & machine capacity is required per department per week?
- Is irregular capacity (e.g. overtime work, subcontracting) required?

This problem is the so-called resource loading problem
Voorbeeld: meubelfabriek

Voorbeeld van klantorder met 6 productiestappen:

\[ Z \rightarrow A \rightarrow S \rightarrow B \rightarrow V \rightarrow K \]

Productiestappen / afdelingen:
Z = Verzagen
A = Assembleren
S = Schoonmaken
B = Bekleden / stofferen
V = Verven
K = Kwaliteitscontrole
# Planningsvoorbeeld

<table>
<thead>
<tr>
<th>Klantorder</th>
<th>jobs (bewerkingsstijd)</th>
<th>Levertijd</th>
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<td>A (19)</td>
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<td>A (21)</td>
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<td>A (10)</td>
<td>S (25)</td>
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<td>A (16)</td>
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<tr>
<td>7</td>
<td>Z (15)</td>
<td>A (10)</td>
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<table>
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<th>Aantal jobs</th>
<th>Levertijd</th>
<th>Starttijd</th>
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Loading methode van planner

- Klantorder bestaat uit x jobs. Reken voor iedere job een doorlooptijd (*lead time*) van 1 week
- operator & machine capacity check per afdeling
- repareer plan, indien nodig
- iedere afdeling is verantwoordelijk voor hun eigen schedulingsprobleem

<table>
<thead>
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<th>due date (week)</th>
<th>number of jobs</th>
<th>start time (week)</th>
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</table>
Machinecapaciteit check voor D-afdeling:

Machinecapaciteit check voor Q-afdeling:
Machinecapaciteit check voor D-afdeling:

Optimale loading van D-afdeling:
Machinecapaciteit 
check voor 
Q-afdeling:

Optimale loading 
van Q-afdeling:
Aggregate (long-term) planning

concerns:

- Staffing / workforce planning
- (Single-/multi-) product planning
- Procurement (contracts with suppliers of components)
- Subcontracting (arrange contracts with subcontractors)
- Marketing (which products to produce)

planning period: usually 1-2 years
MPC reference architecture applied to ETO/project environment

Strategic
- Strategic resource planning

Tactical
- Rough-cut capacity planning
  - Rough-cut process planning

Tactical/operational
- Resource-constrained project scheduling
  - Engineering & process planning

Operational
- Detailed scheduling
Royal Netherlands Navy Dockyard
Tasks:
• Overhaul, repair, modification;
• Maintenance Engineering;
• Provisioning
Order Types

Legenda:
1. major overhaul/modification
2. large maintenance
3. ‘quick’ repairs
4. maintenance ‘small objects’
5. maintenance repairable items
6. supply of goods and services
7. engineering
Why a DSS?

To support management in:

Order acceptance;
Capacity management;
Lead time management;
Crisis management.
Aggregate project plan

Detailed project plan
Solution methods included:

**Aggregate Capacity Planning**: Integer Linear Programming models. Solution by: column generation techniques (LP relaxation), followed by branch and bound (using Lagrange relaxation) to determine integer solutions

*Hans et al., 1999*

**Process Planning**: Database models and construction

**Detailed Project Scheduling**: adaptive randomized search techniques

**Organizational issues**: Integration of Production and Engineering, implementation of self-directed, multi-functional teams

*De Boer, 1998, De Waard, 1999*
Summary and Conclusions

Current Manufacturing Planning and Control systems suffer from various important drawbacks, including:

- addressing various production typologies (in particular MTO and ETO)
- integration with design and process planning decisions
- integration of materials and capacity planning/loading
- reflecting hierarchical decision making
- integration of uncertainty issues

Opportunities exist to build more advanced, intelligent MPC systems, including:

- Hierarchical planning frameworks
- Integration of models for design and process planning
- Integration of stochastic network models for joint materials/capacity planning
- Integration of advanced scheduling systems

while using advancements in Information Systems development.