Beyond ERP: Towards Intelligent Manufacturing Planning and Control

Beyond ERP: Towards Intelligent Manufacturing Planning and Control

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

- Hardware automation (Computer Numerically Controlled machines, Flexible Manufacturing and Assembly Systems, Automatic transport Systems, Automated Storage and Retrieval Systems)

- Design and Process Planning (Computer Aided Design, Computer Aided Process Planning, Rapid Prototyping techniques)

- 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

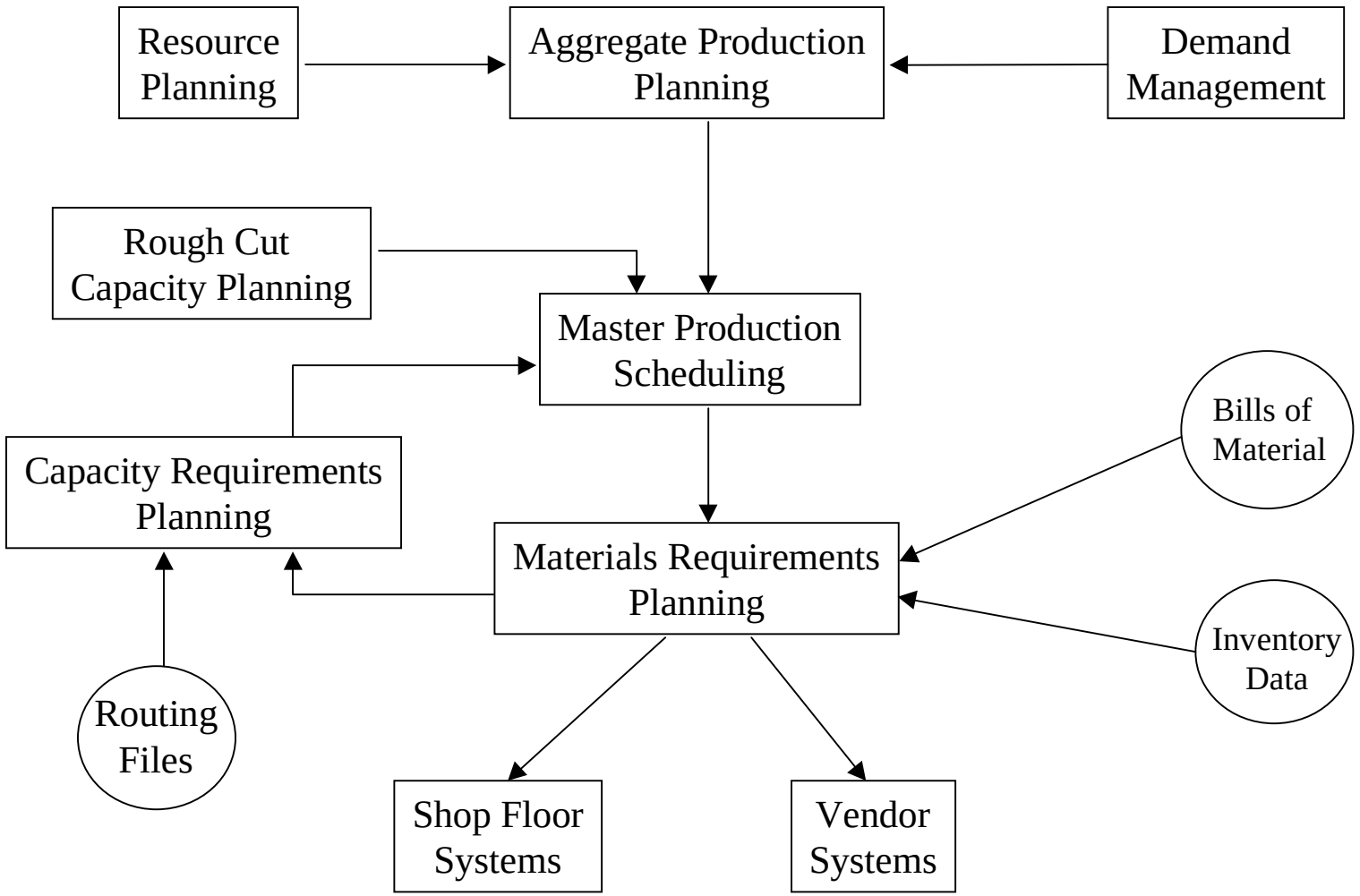
- Production Planning ***(Holt et al., Hadley and Whitin, Hax, Whybark, Bertrand et al.)***
- Inventory Management ***(Scarf, Silver, Axsäter, Inderfurth, Federgruen, Zipkin, De Kok, Van Houtum, Zijm)***
- Distribution planning ***(Christofides et al., Fleischmann)***
- Queueing models ***(Jackson, Buzacott,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

Models had limited impact, as opposed to

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

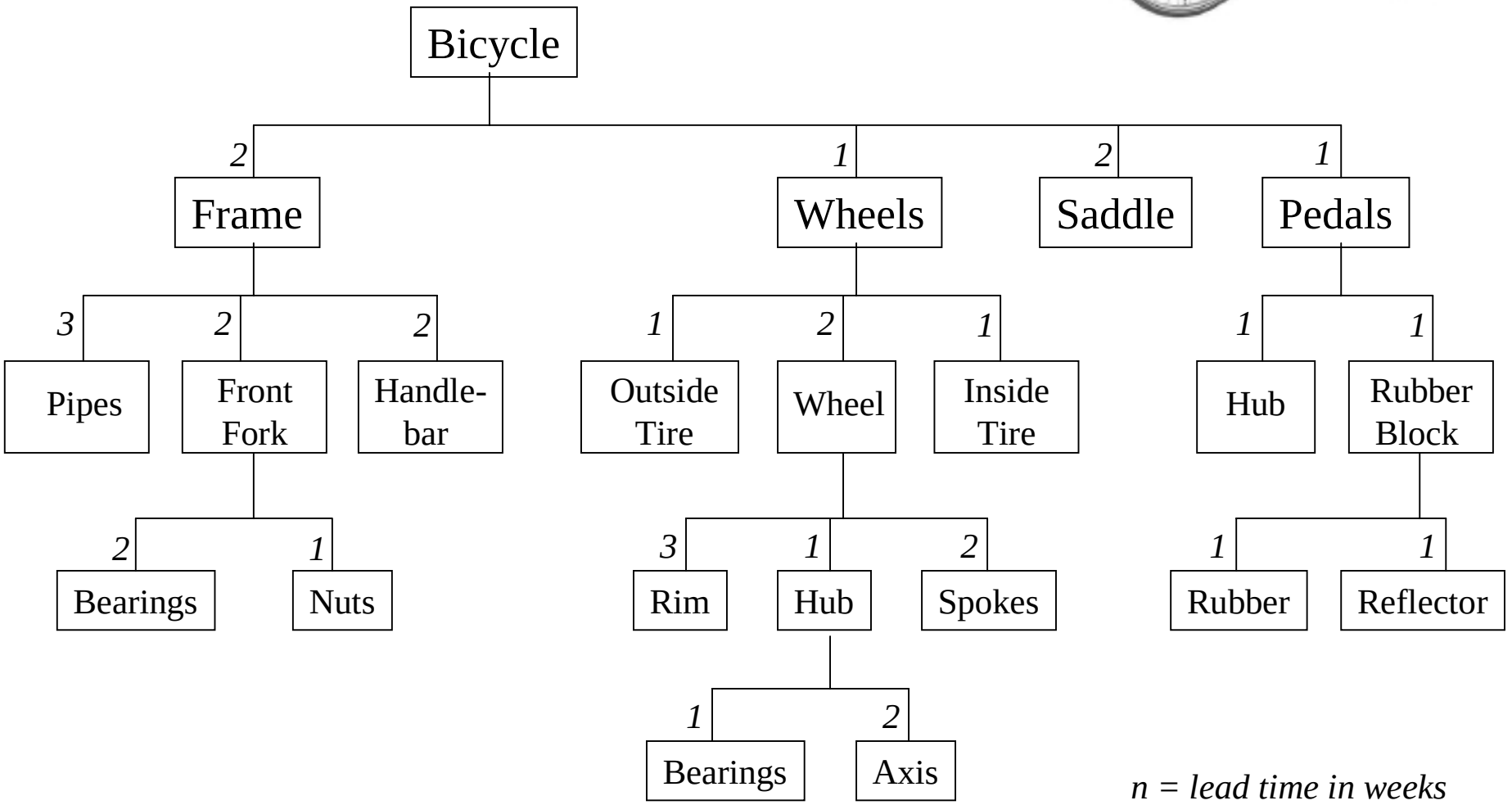
Why?

PUSH SYSTEM:
Manufacturing Resources Planning (MRP II)



Vollmann et al., 1997

Bill of Material and lead time off-set's in MRP



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)

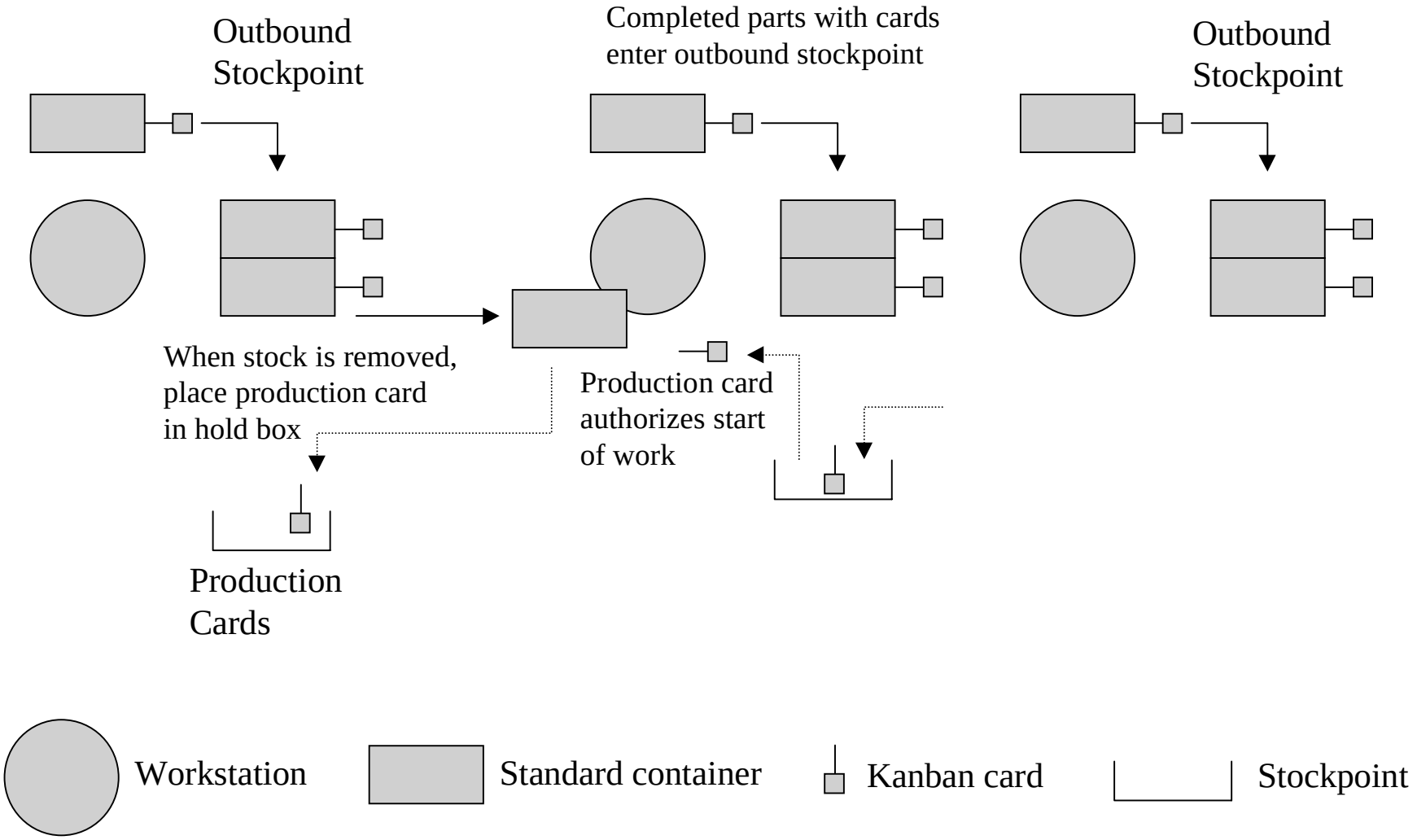
Advantages of MRP systems

- 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



Schonberger, 1982

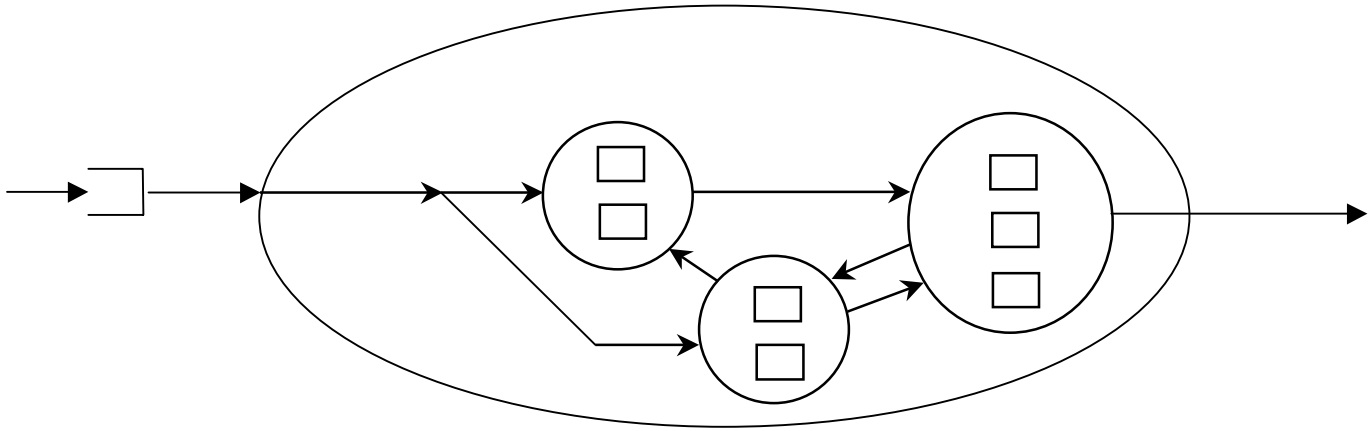
Advantages of JIT/Kanban systems

- 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

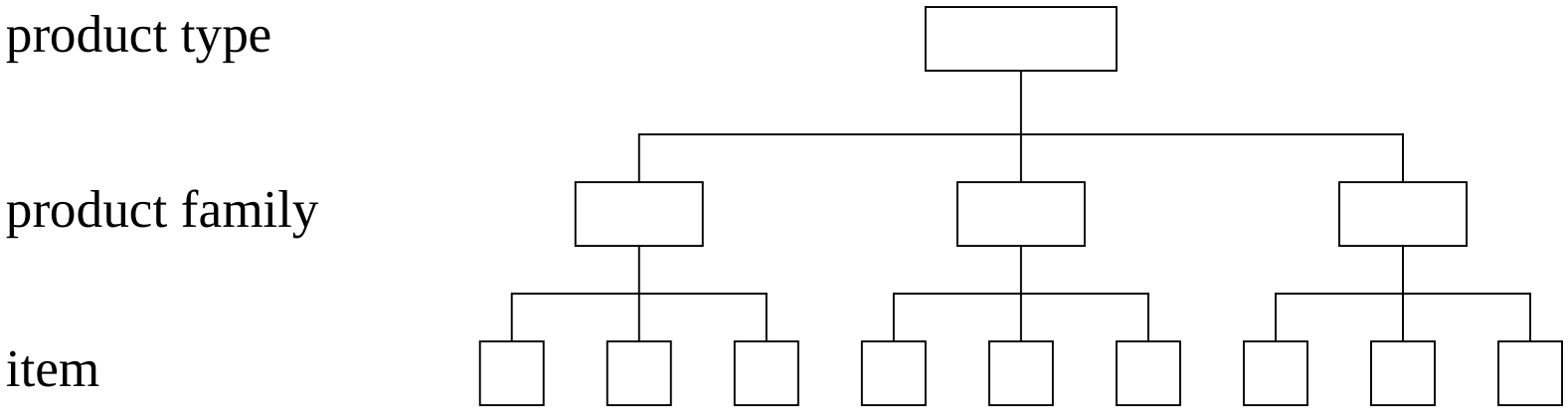


Operates primarily as shop floor release mechanism

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

Bertrand and Wortmann, 1981, Bechte, 1987,
Wiendahl, 1993, Spearman et al., 1989, Van Ooijen, 1996

Hierarchical Production Planning (HPP)



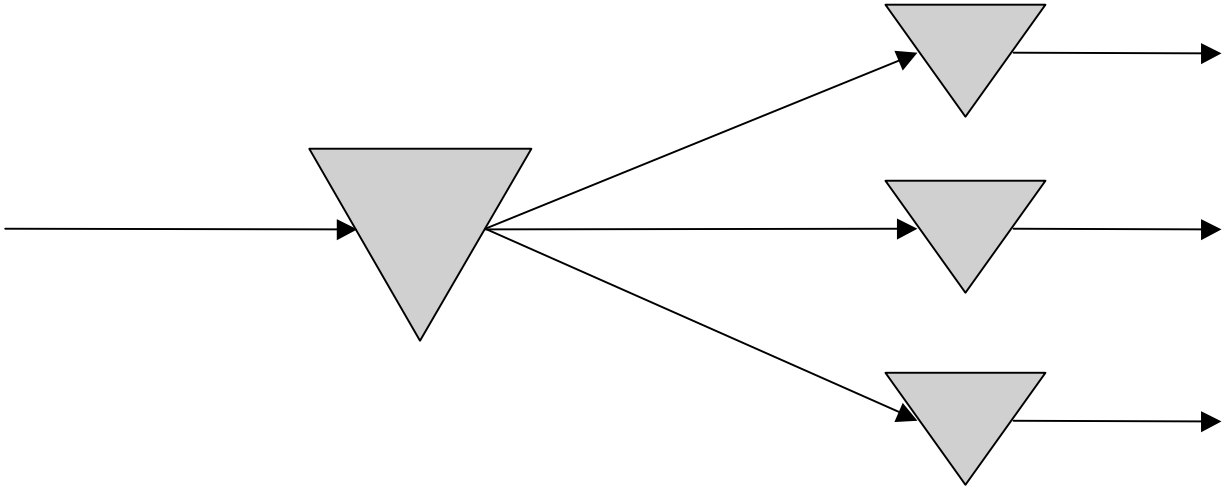
Capacity oriented planning system

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



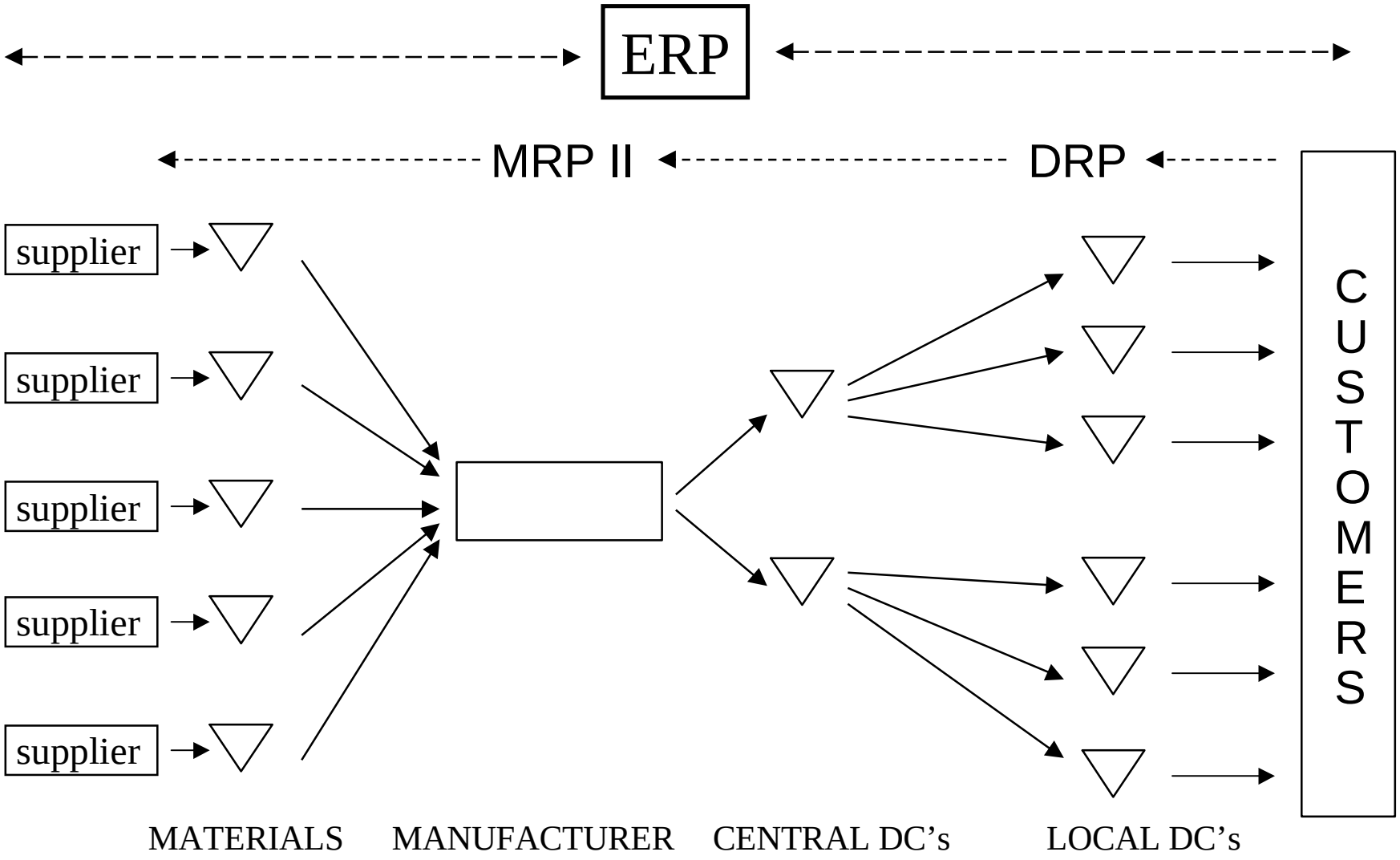
• Determine order quantities at a central warehouse. At some later point in time, allocate these quantities to local warehouses

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)

Federgruen and Zipkin, 1984, Federgruen, 1993
Axsäter, 1993, Zipkin, 1999, De Kok, 1990, 1999
Zijm, 1992, Van Houtum et al., 1996

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

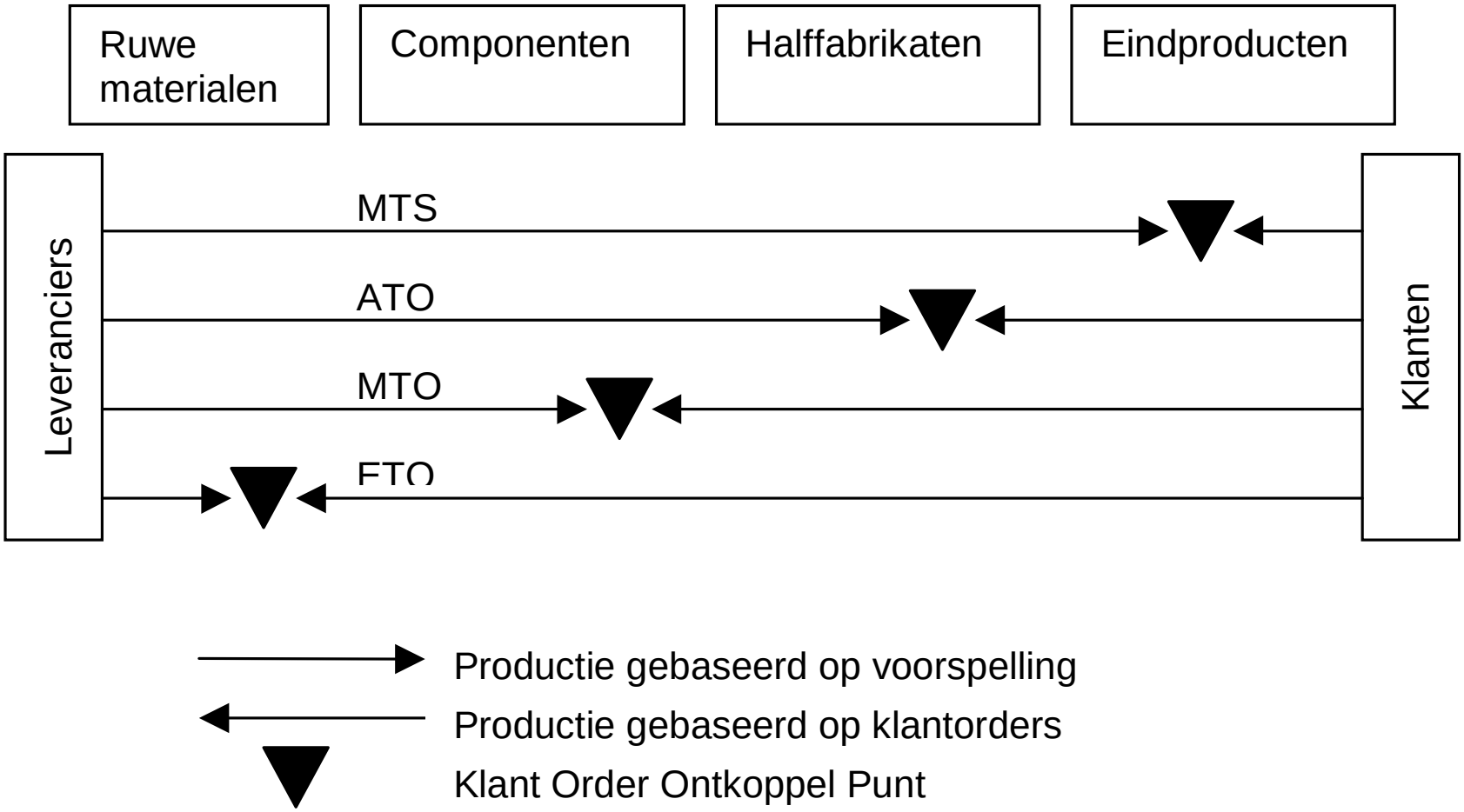
?

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

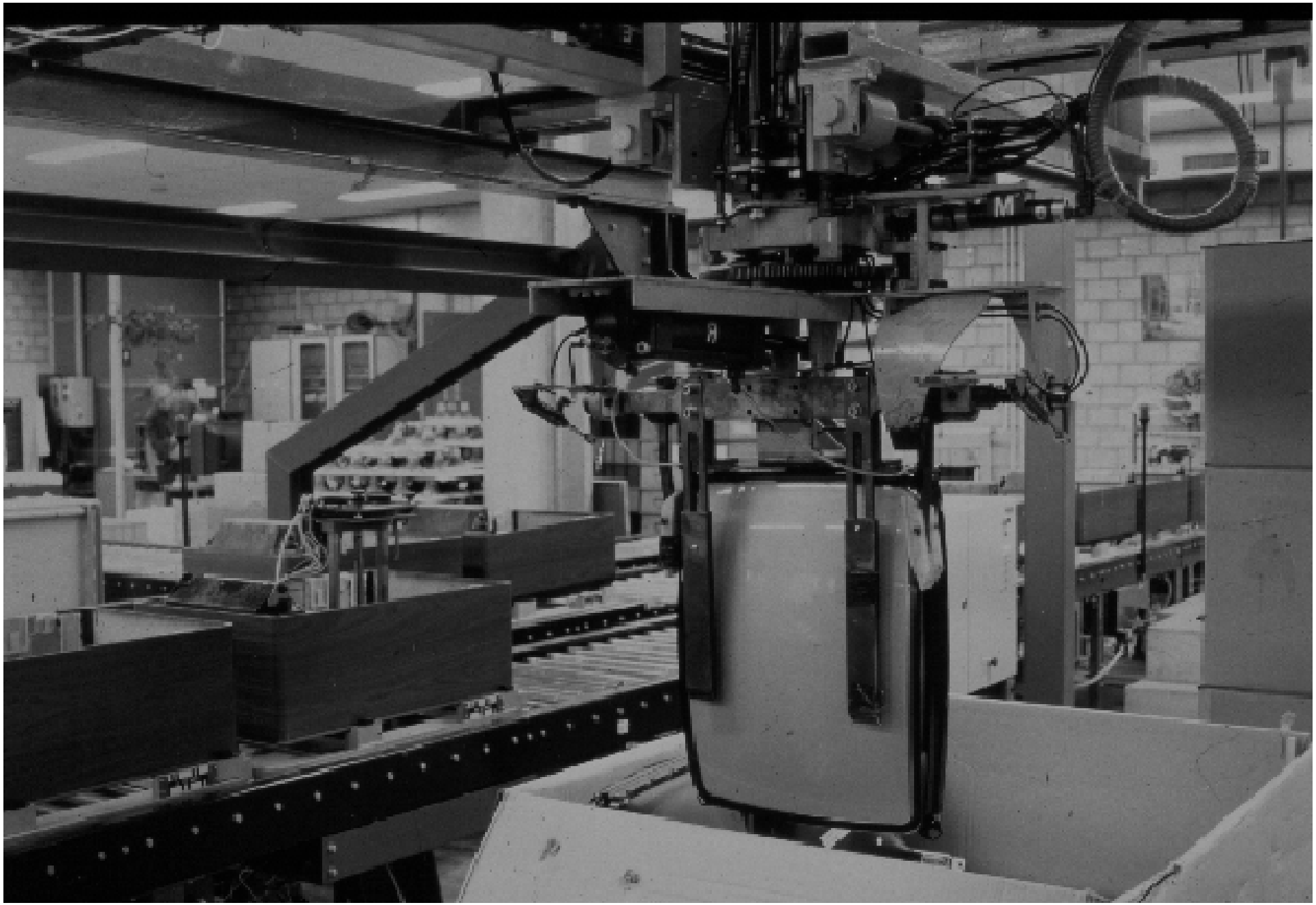
Klantorder ontkoppelpunt (KOOP)



Product/market relations and production typology

Make and assemble to stock	Flow production (large batches)
Make to stock, assemble to order	Job shop (small batches)
Make to order	
Engineer to order	Project-based (unique)

Materials oriented / Capacity oriented



Television Set Assembly: MATS/flow production

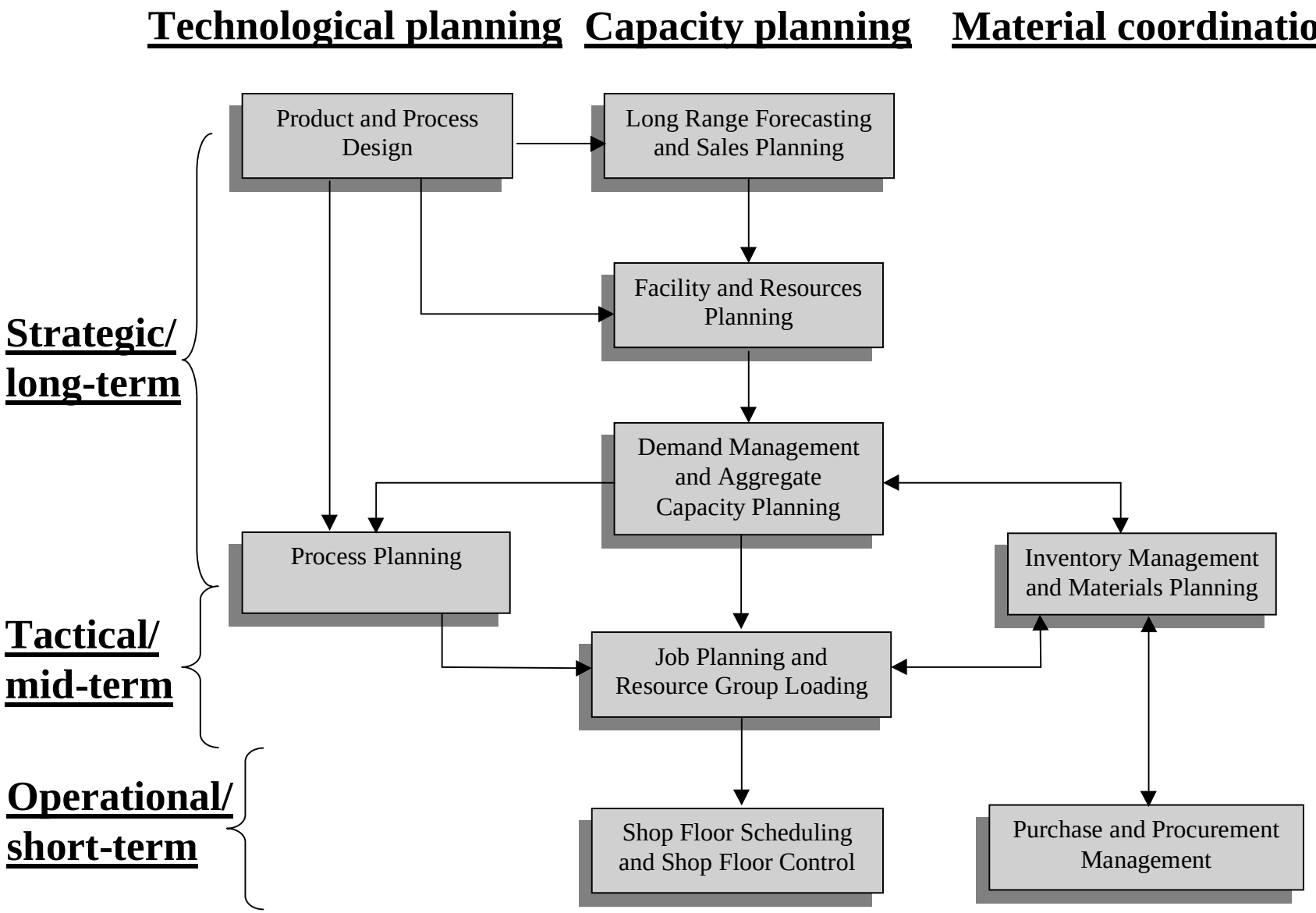
Truck Manufacturing and Assembly: MTS/ATO production

Precision machining of actuators, MTO/job shop production

Engineering/construction of military frigates:

ETO/project production

An MPC reference architecture



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	*Boothroyd et al., 1994*
Rapid Prototyping	*Kalpakjian, 1992*
	Kusiak, 1990
Graph-theoretical methods	*Ulrich and Eppinger, 1995*

Long Range Forecasting and Sales Planning

Causal Forecasting methods (regression analysis)	
Qualitative Judgement (e.g. Delphi methods)	*Makridakis et al., 1998*

Facility and Resources Planning

Facility Layout Planning	*Francis et al., 1992*
Queueing Network Analysis	*Suri et al., 1993, Wemmerlov, 1989*
Production Flow Analysis	*Burbidge, 1975*

Demand Management and Aggregate Capacity Planning

Time Series Forecasting Models	*Box and Jenkins, 1970*
	Makridakis et al., 1998
Linear and Integer Programming Models	*Hopp and Spearman, 1996*
	Buzacott, 1989

Process Planning

Macro Process Planning: queueing analysis	*Kusiak, 1990*
Micro Process Planning: feature-based techniques	*Zijm, 1995*

Production Order Planning and Resource Group Loading

Multi-echelon queueing models	*Buzacott and Shanthikumar, 1993*
Dynamic Project Scheduling models	*Kolisch and Drexl, 1996*
Lot size / lead time trade-off models	*Karmarkar, 1987, Suri et al., 1993*
Capacitated Lot sizing models	*Salomon, 1991*
Resource group loading models & methods	*Hans, 2001*

Purchase and Procurement Management

Federgruen and Zipkin, 1984

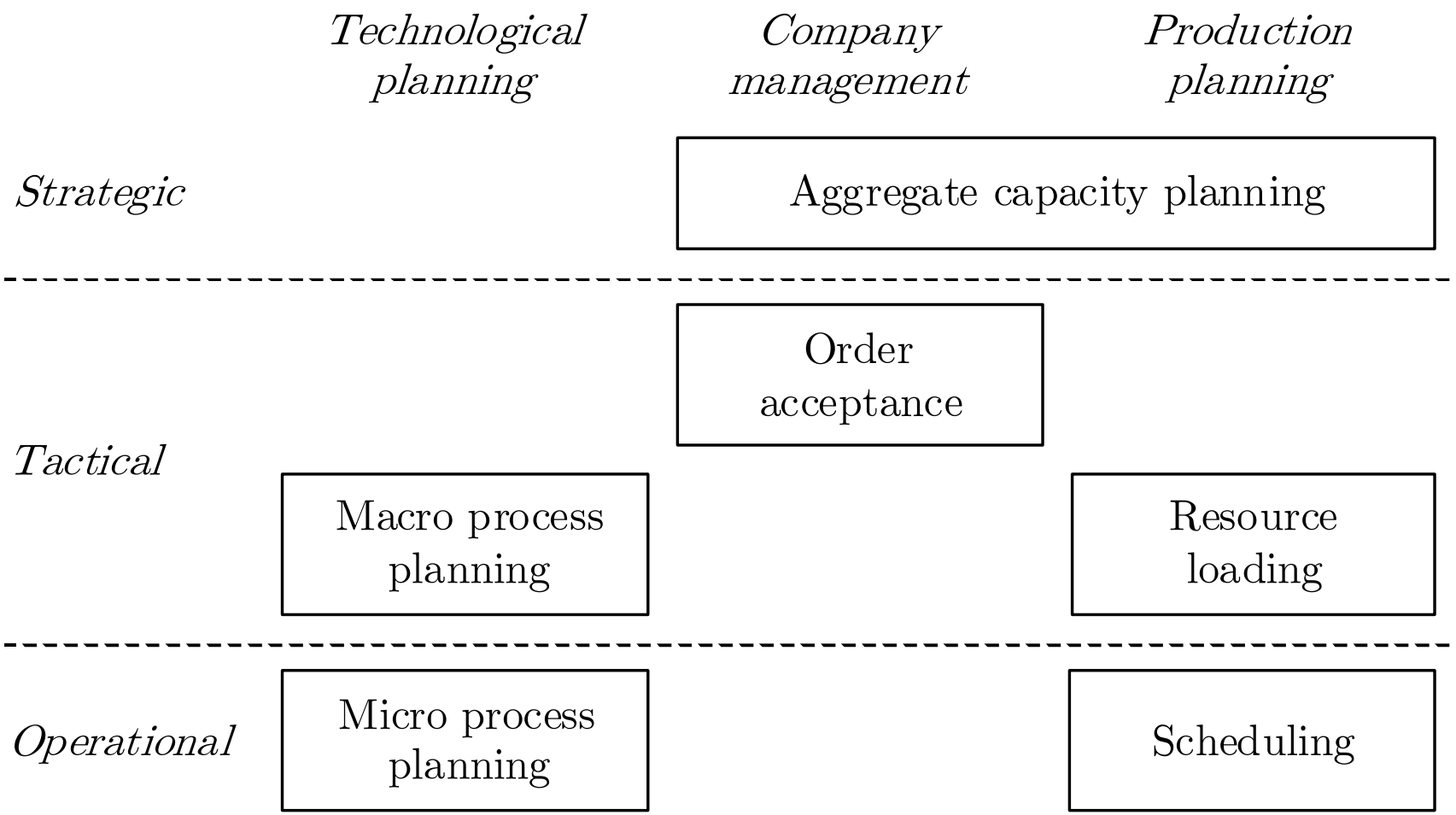
(Multi-echelon) inventory models, EOQ type models

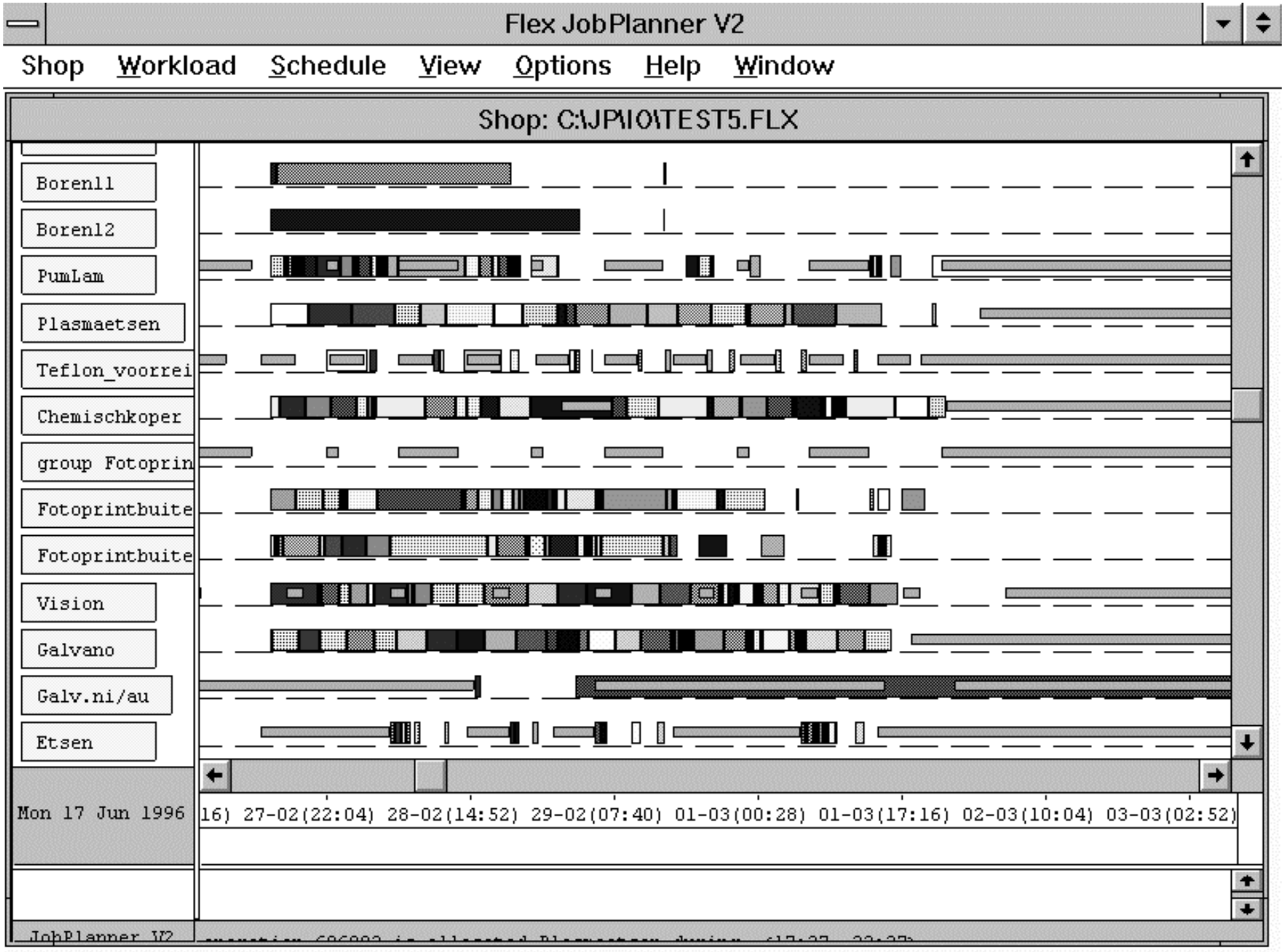
Silver et al., 1998
De Kok et al., 1996
Van Houtum et al., 1996

Shop Floor Scheduling and Control

Shifting Bottleneck type models	*Adams et al., 1988*
Adaptive randomized search models	*Pinedo and Chao, 1999*
Random local search models	*Schutten, 1998*
	Meester et al, 1999

MPC reference architecture applied to MTO




Flex JobPlanner V2
Shop Workload Schedule View Options Help Window
Shop: C:\JP\IO\TEST5.FLX
Borenl1
Borenl2
PumLam
Plasmaetsen
Teflon_voorrei
Chemischkoper
group Fotoprin
Fotoprintbuite
Fotoprintbuite
Vision
Galvano
Galv.ni/au
Etsen
Mon 17 Jun 1996
16) 27-02(22:04) 28-02(14:52) 29-02(07:40) 01-03(00:28) 01-03(17:16) 02-03(10:04) 03-03(02:52)
JobPlanner V2

Resource Loading

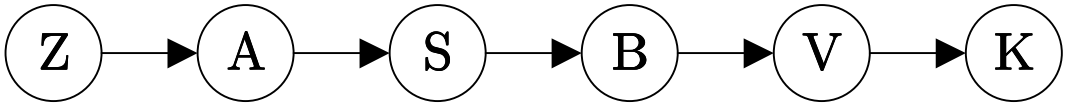
During **order acceptance**, for any given set of orders, these questions need to be answered:

- 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:



Productiestappen / afdelingen:

Z = Verzagen
A = Assembleren
S = Schoonmaken
B = Bekleden / stofferen
V = Verven
K = Kwaliteitscontrole

Planningsvoorbeeld

Klantorder	jobs (bewerkingstijd)						Levertijd
	1	2	3	4	5	6	
1	Z (37)	A (19)	S (14)	B (32)	K (5)		7
2	Z (18)	A (12)	S (15)	V (10)	B (14)	K (10)	8
3	Z (20)	A (21)	S (17)	K (8)			5
4	A (10)	S (25)	B (16)	K (7)			5
5	Z (16)	A (33)	S (14)	V (16)	B (15)	K (10)	9
6	Z (36)	A (16)	S (20)	V (15)	B (15)	K (9)	9
7	Z (15)	A (10)	S (15)	V (15)	B (20)	K (10)	6

Klantorder	Aantal jobs	Levertijd	Starttijd
1	5	7	3
2	6	8	3
3	4	5	2
4	4	5	2
5	6	9	4
6	6	9	4
7	6	6	1

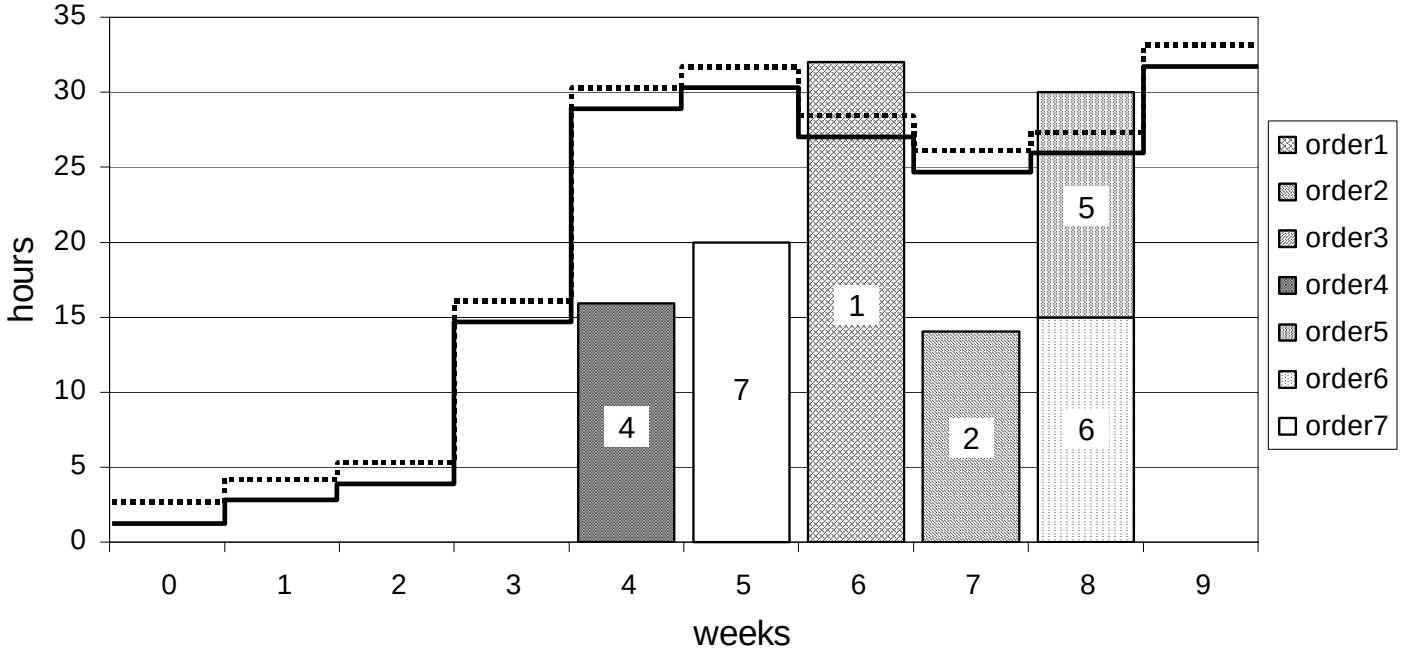
Loading methode van planner

- Klantorder bestaat uit x jobs. Reken voor iedere job een doorlooptijd (**lead time**) van 1 week

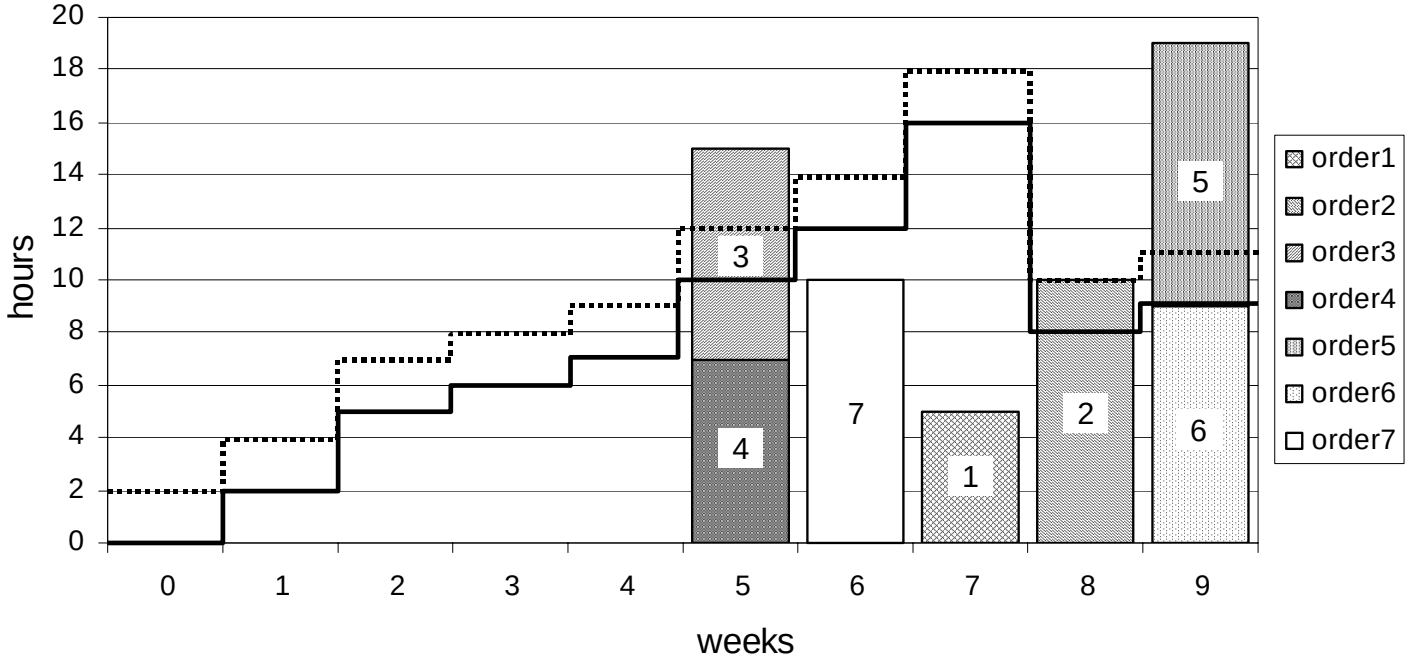
- operator & machine capacity check per afdeling
- repareer plan, indien nodig
- iedere afdeling is verantwoordelijk voor hun eigen schedulingsprobleem

due date (week)	number of jobs	**start time (week)**
7	5	**3**
8	6	**3**
5	4	**2**
5	4	**2**
9	6	**4**
9	6	**4**
6	6	**1**

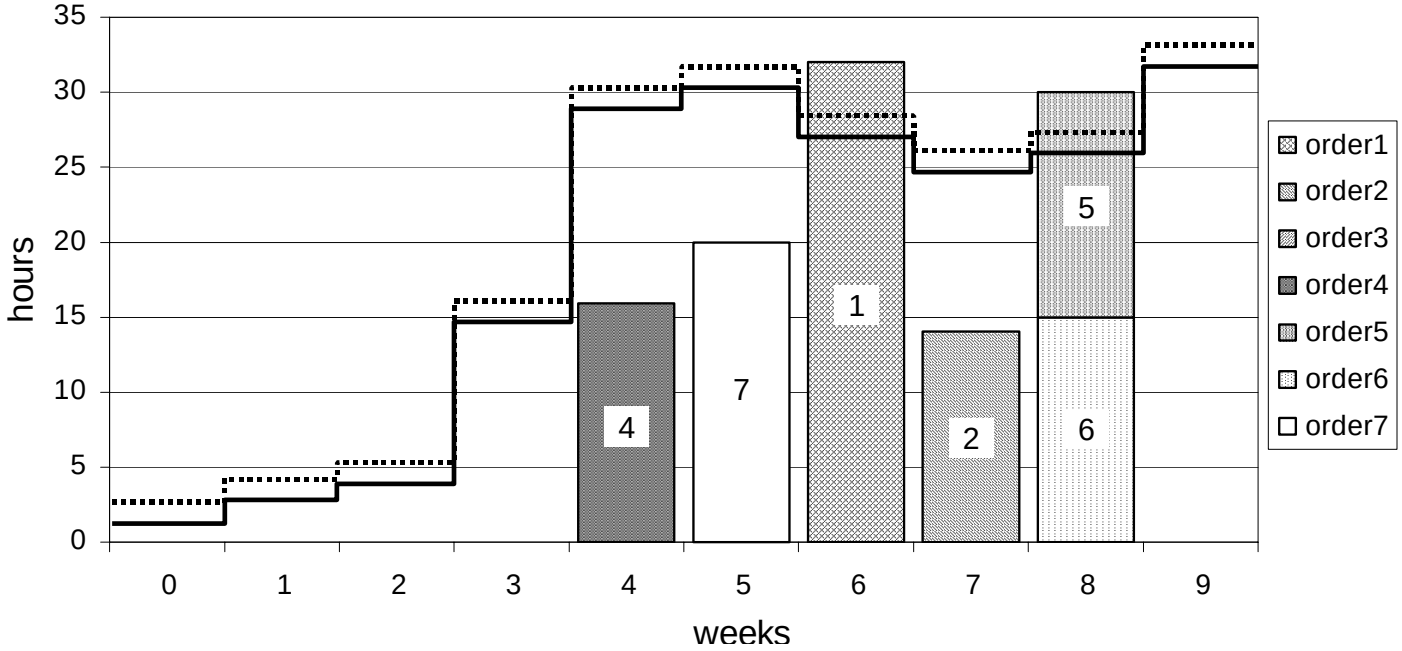
Machinecapaciteit check voor D-afdeling :



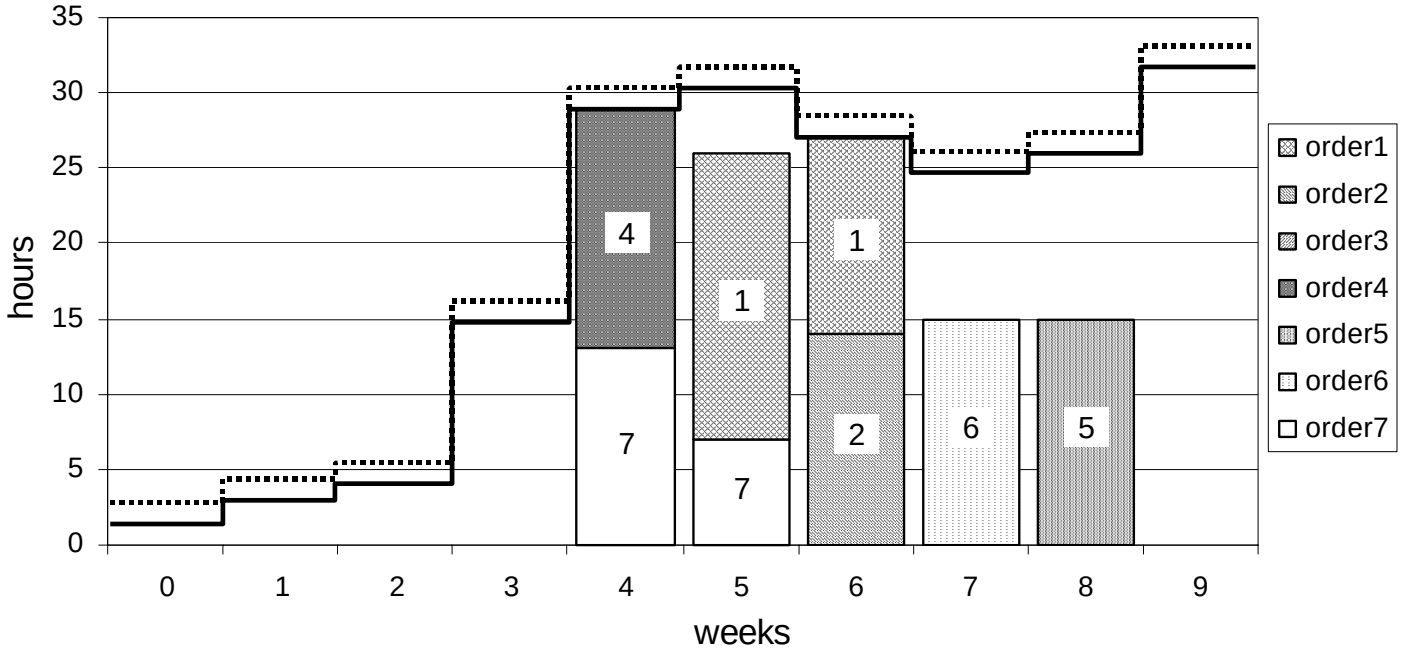
Machinecapaciteit check voor Q-afdeling:



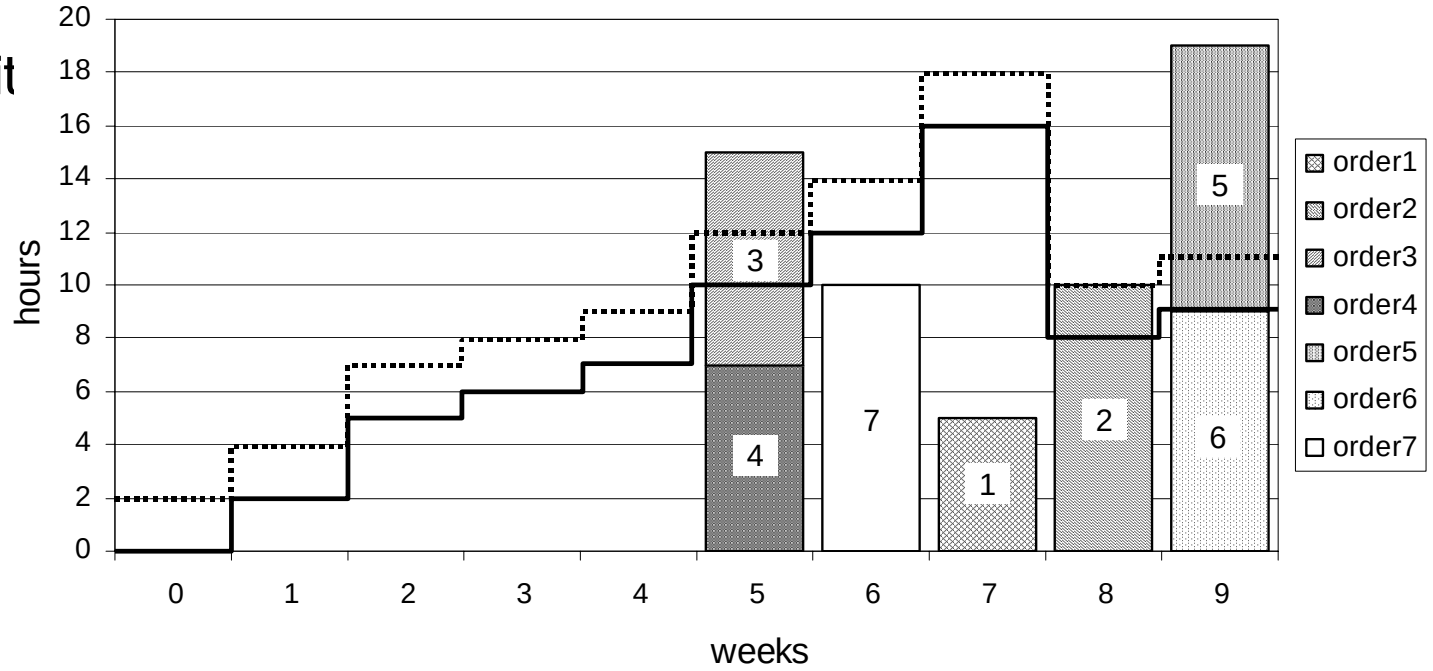
Machinecapaciteit check voor D-afdeling:



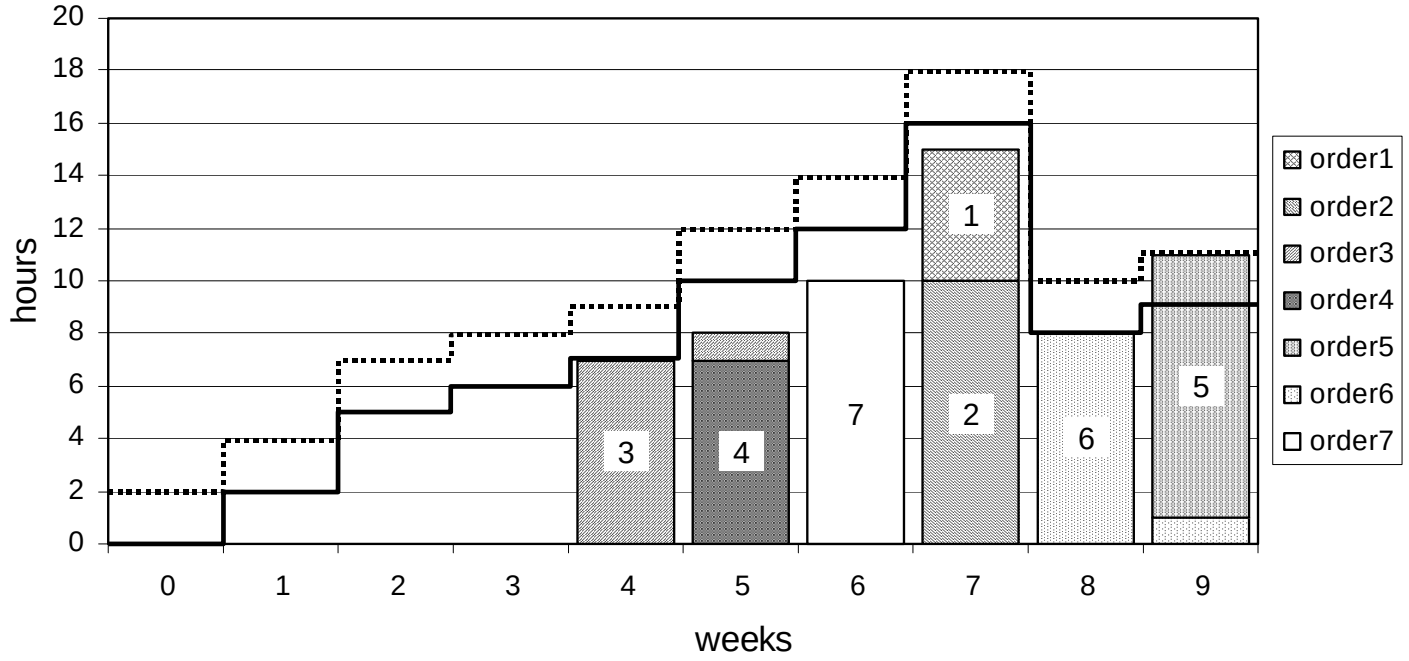
Optimale loading van D-afdeling:



Machinecapaciteit check voor Q-afdeling:



Optimale loading van Q-afdeling:



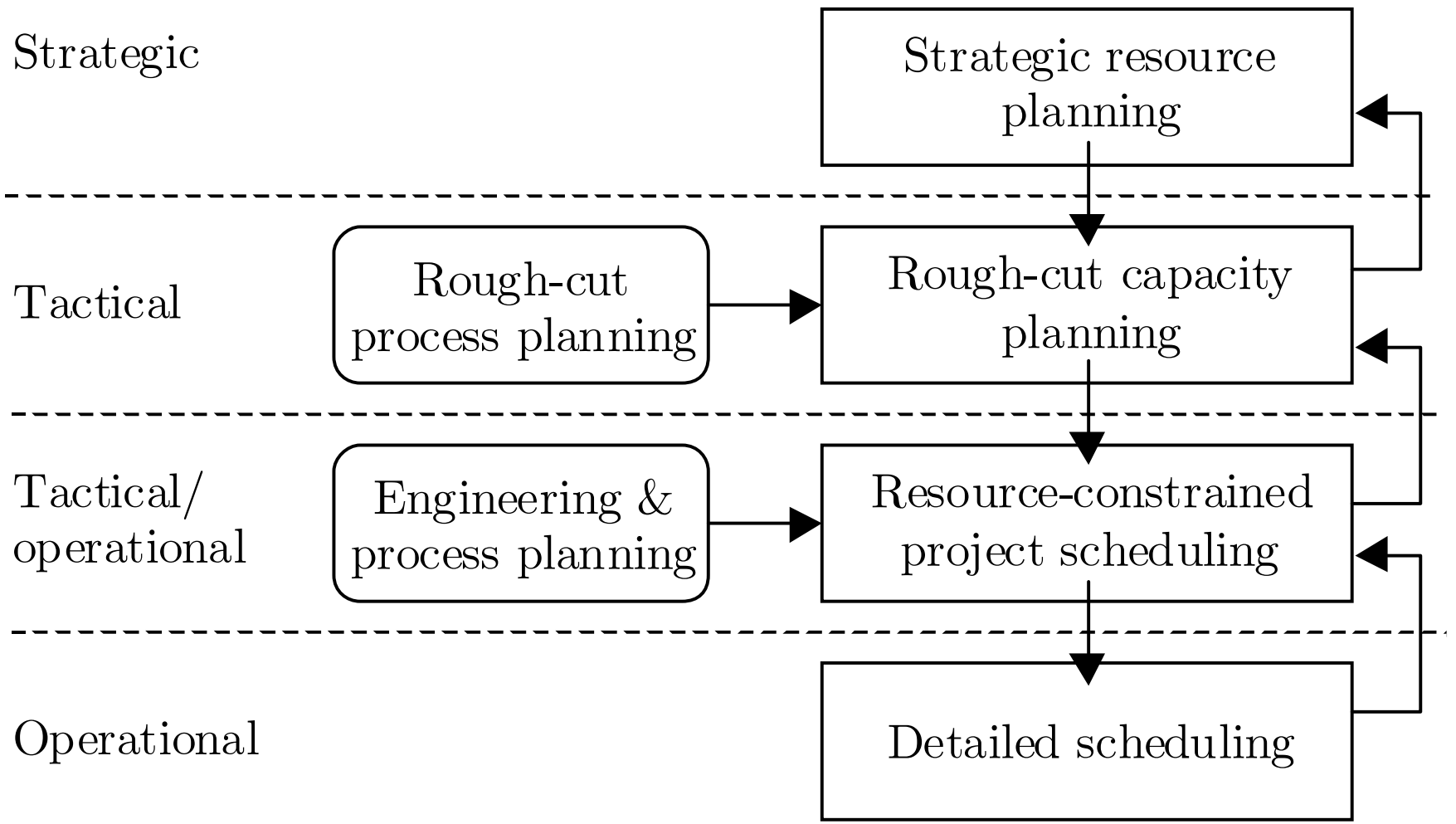
Aggregate (long-term) planning

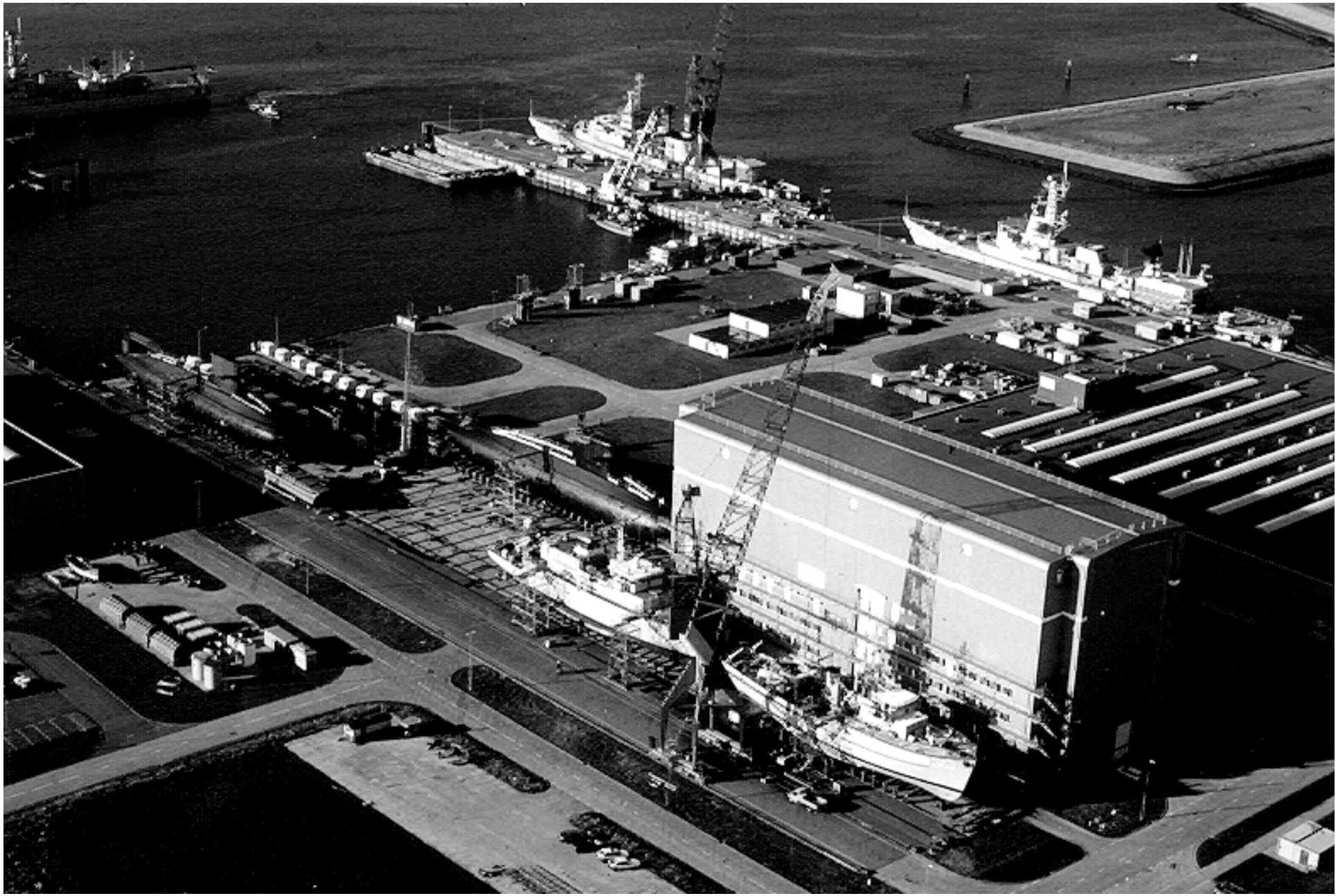
concerns:

- **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



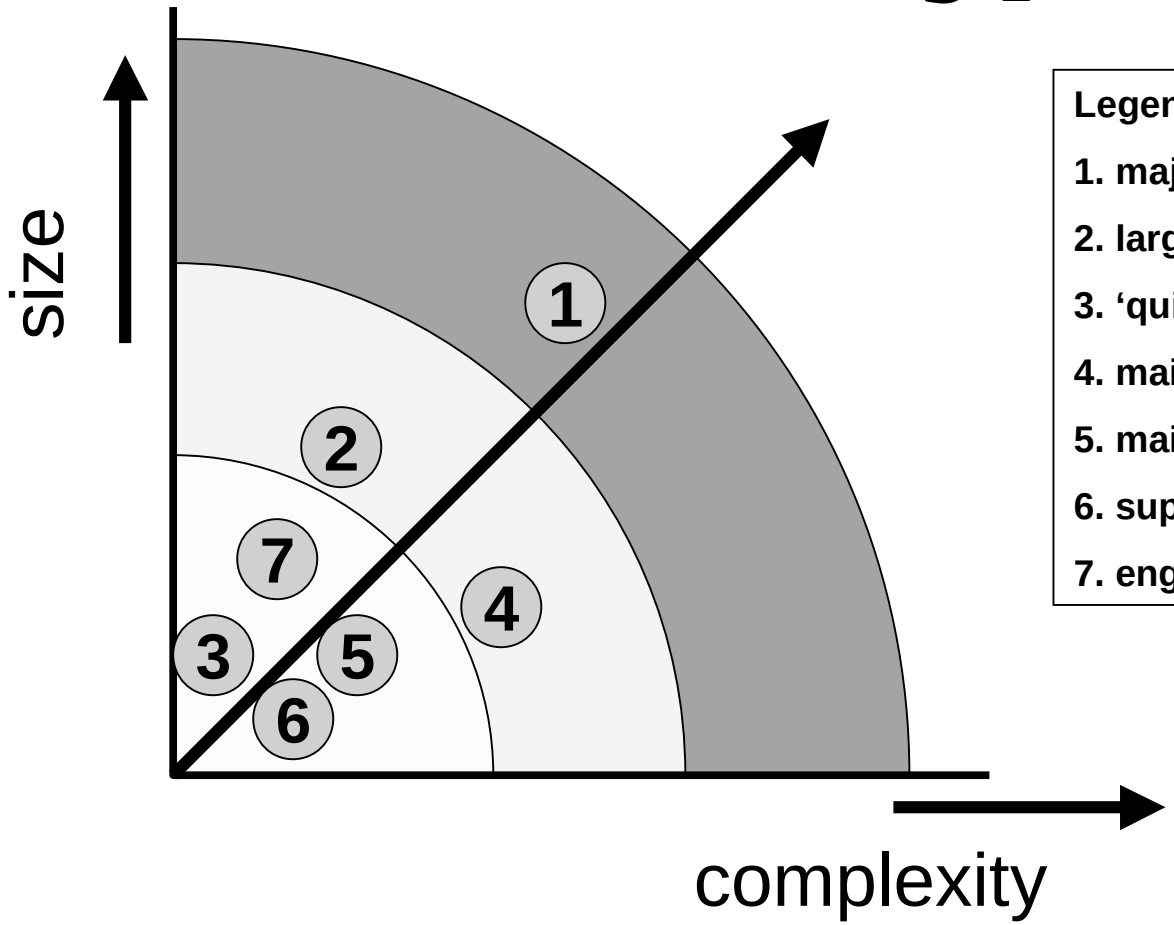


Royal Netherlands Navy Dockyard

Tasks:

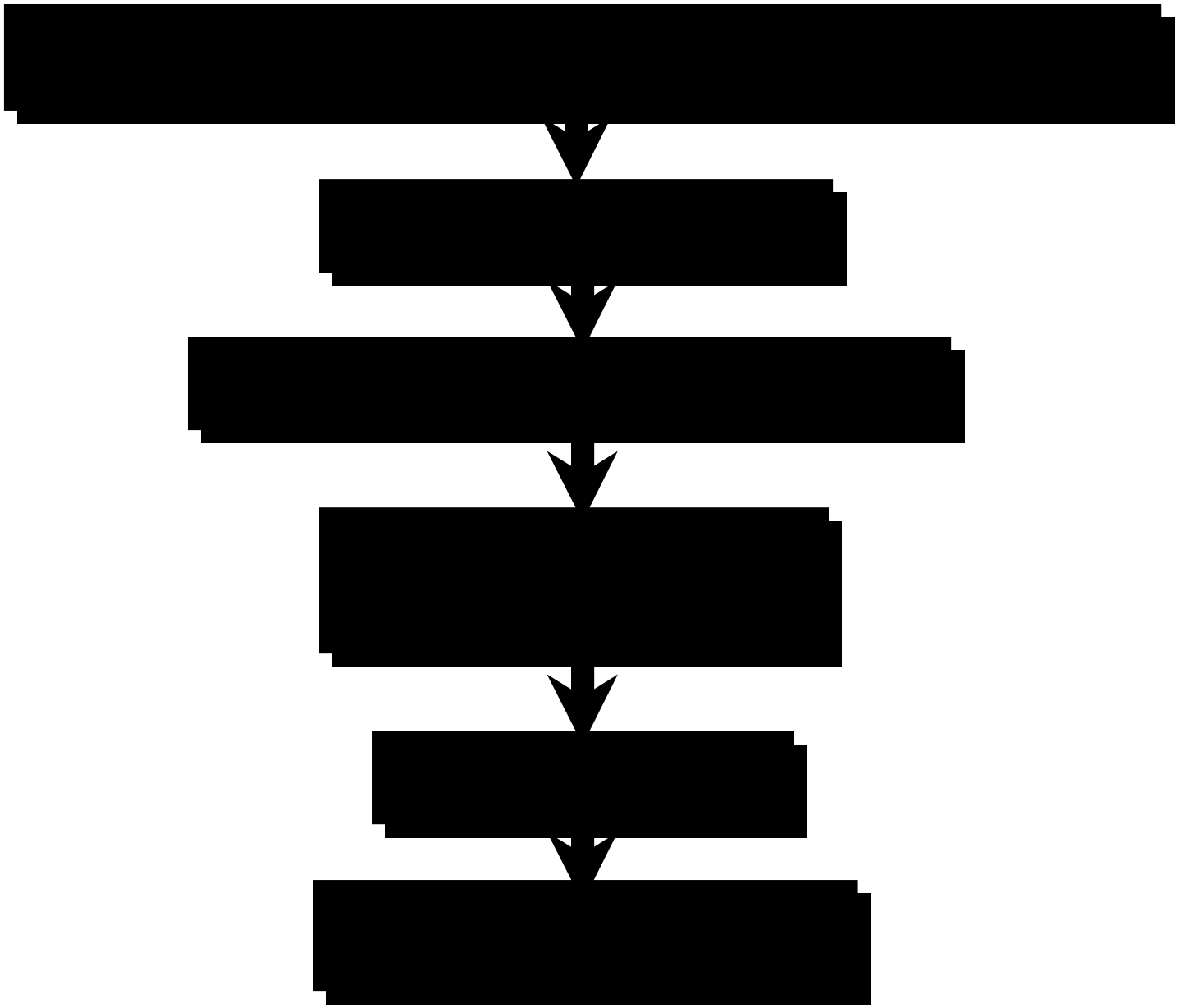
- Overhaul, repair, modification;
- Maintenance Engineering;
- Provisioning

Order Types

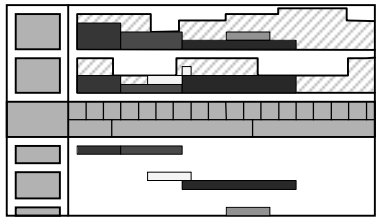


Legenda:

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

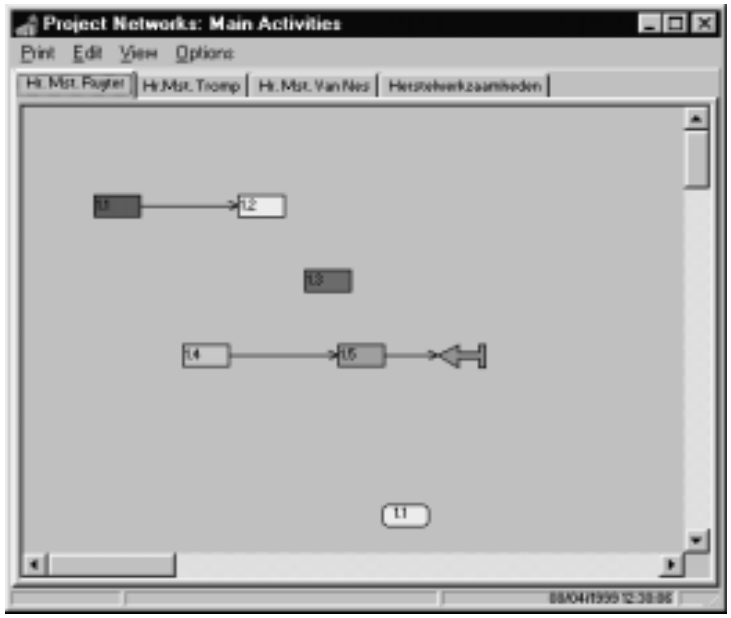


Why a DSS?



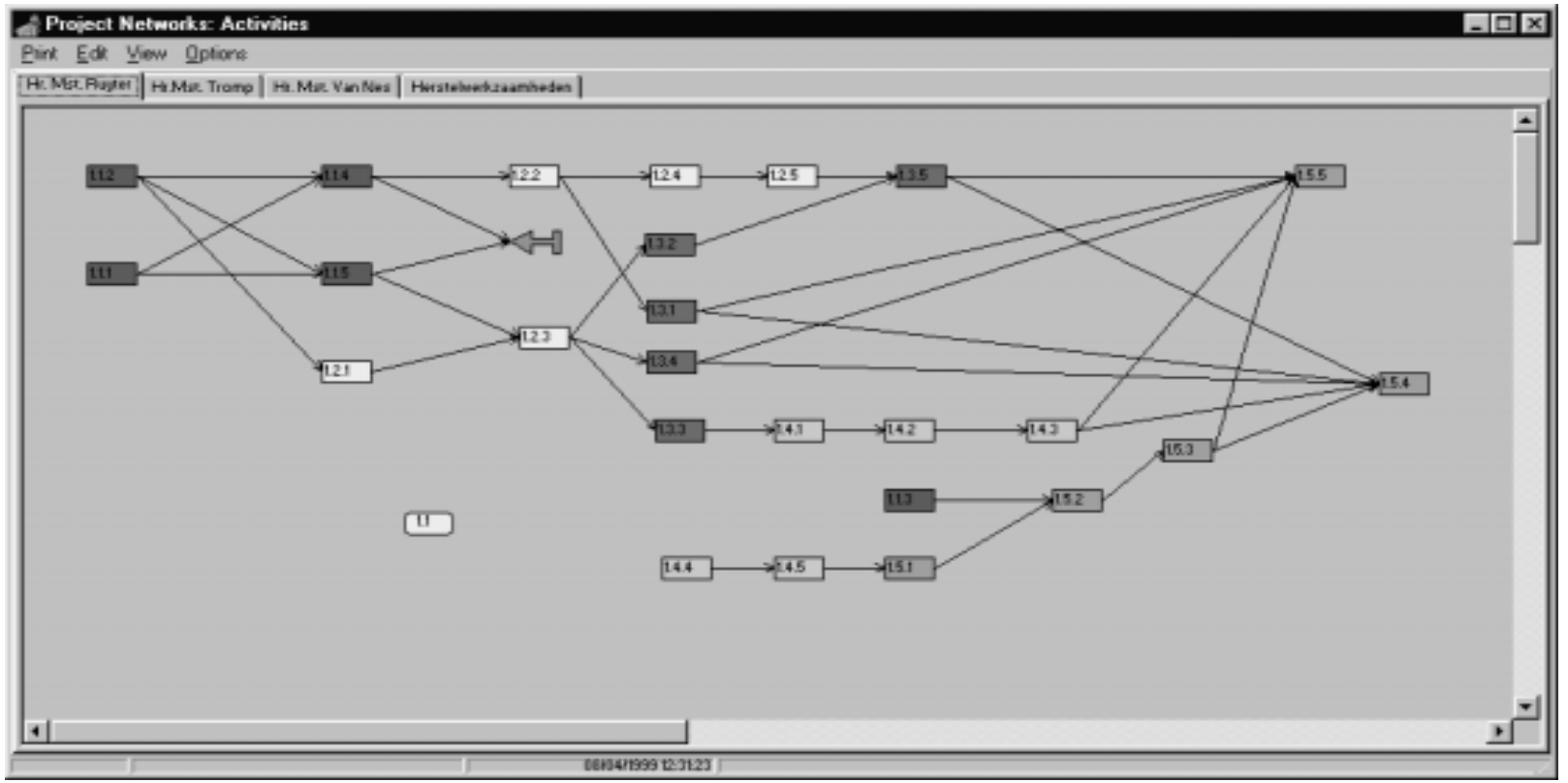
To support management in:

- 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

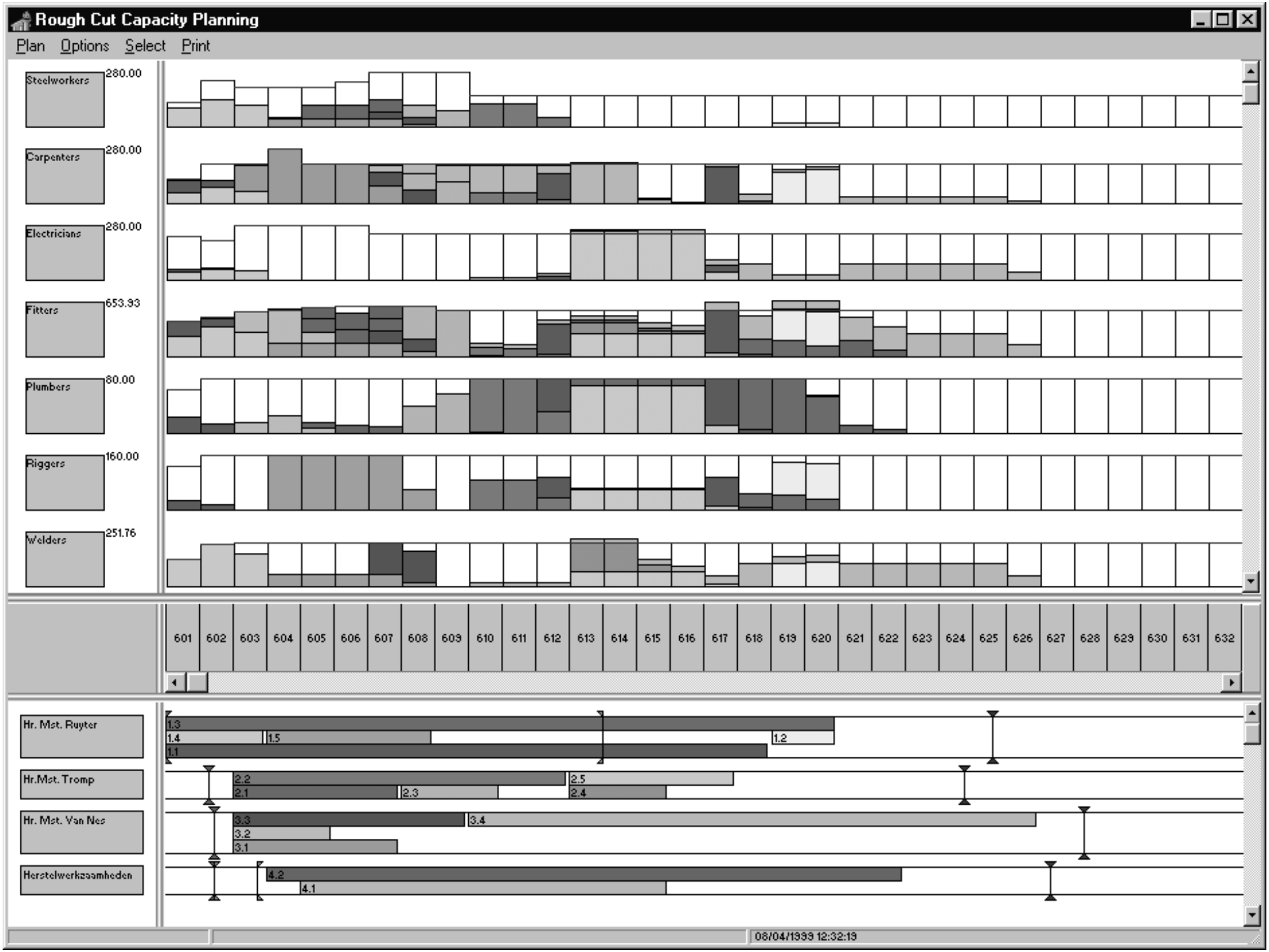
Hans et al., 1999

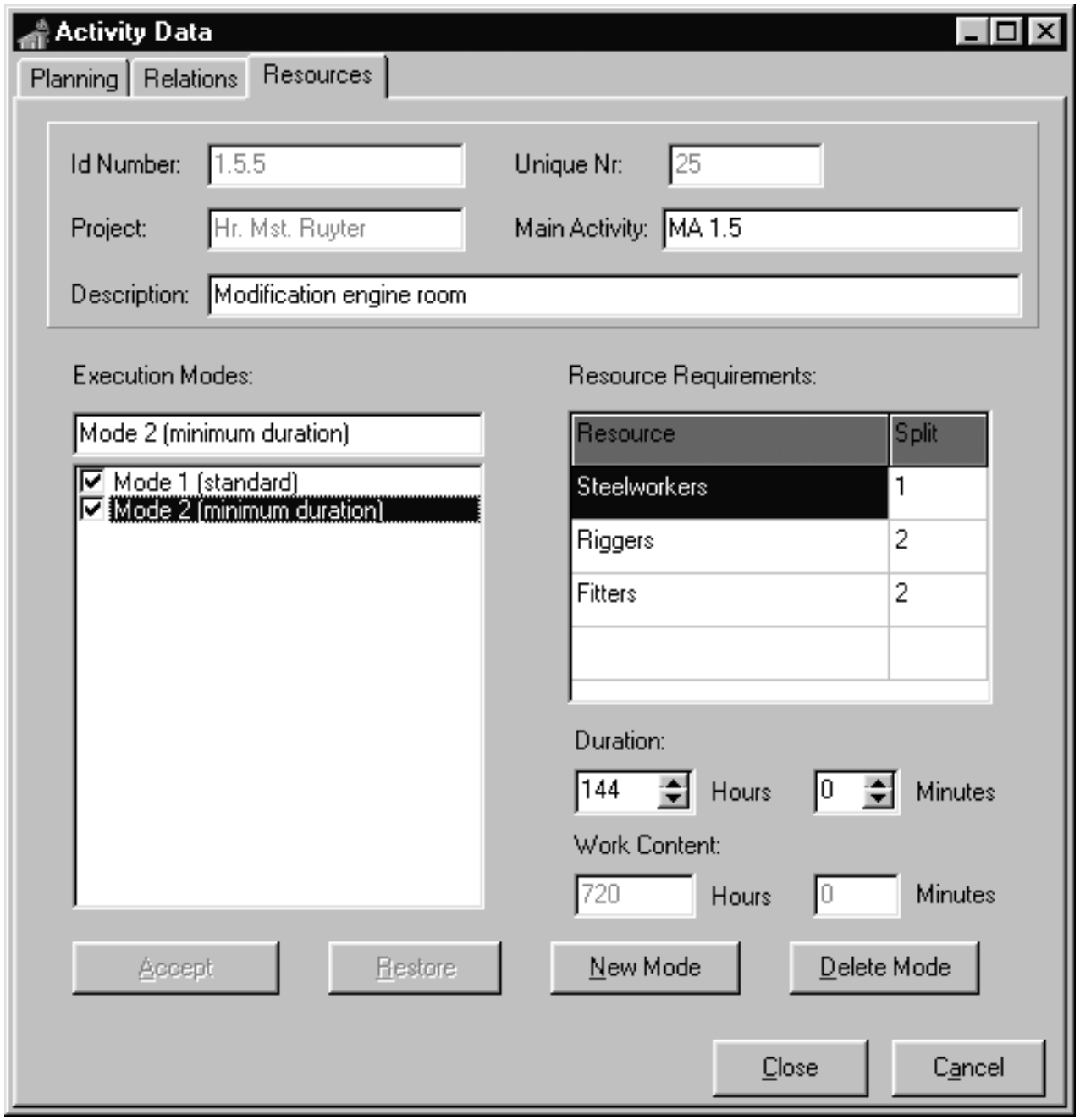
Process Planning: Database models and construction

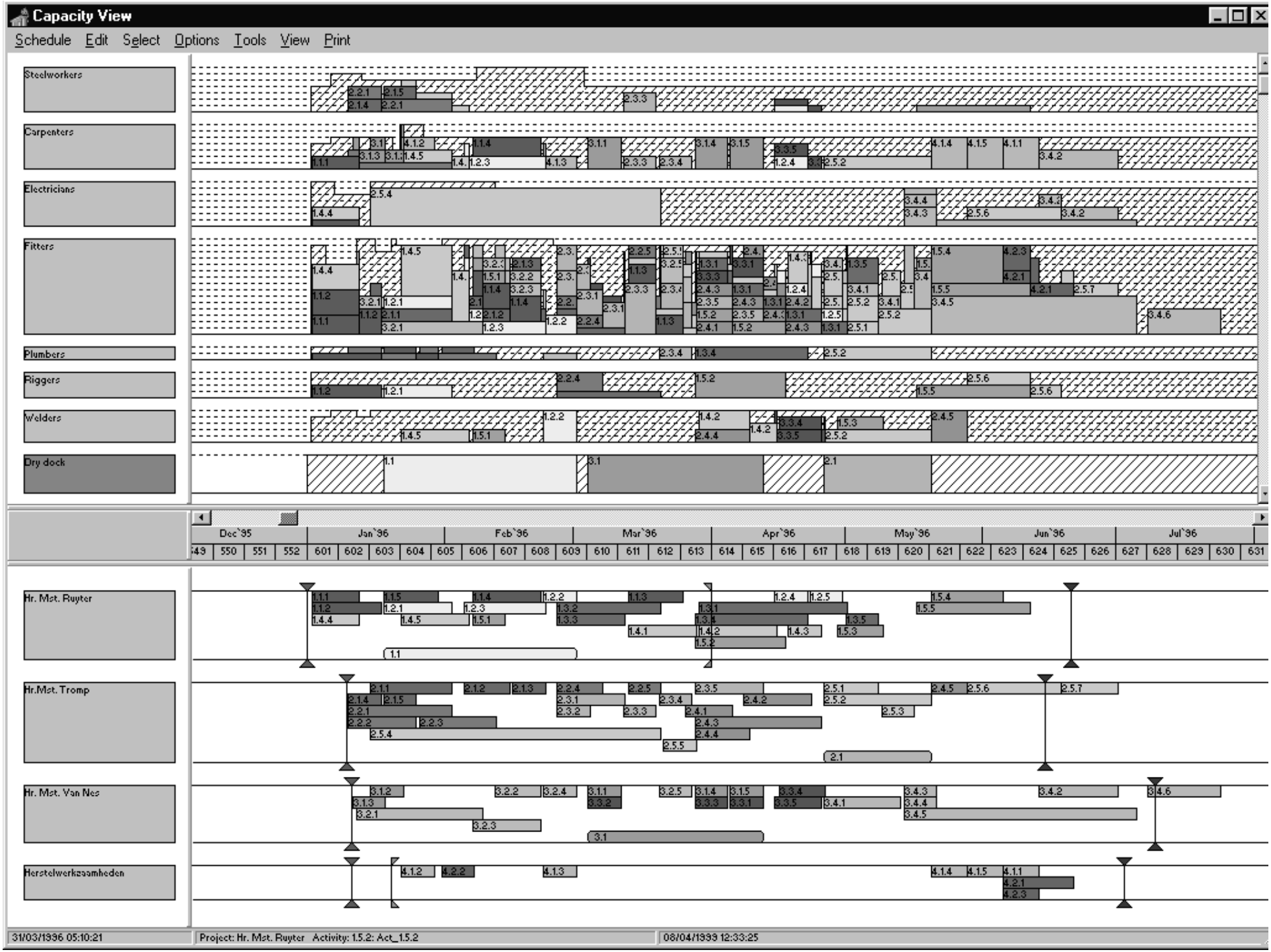
Detailed Project Scheduling: adaptive randomized search techniques

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

De Boer, 1998, De Waard, 1999


Rough Cut Capacity Planning
Plan
Options
Select
Print
Steelworkers
280.00
Carpenters
280.00
Electricians
280.00
Fitters
653.33
Plumbers
80.00
Riggers
160.00
Welders
251.76
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
Hr. Mst. Ruyter
Hr.Mst. Tromp
Hr. Mst. Van Nes
Herstelwerkzaamheden
1.3
1.4
1.5
1.2
1.1
2.2
2.5
2.1
2.3
2.4
3.3
3.4
3.2
3.1
4.2
4.1
08/04/1999 12:32:19


Activity Data
Planning
Relations
Resources
Id Number:
1.5.5
Unique Nr:
25
Project:
Hr. Mst. Ruyter
Main Activity:
MA 1.5
Description:
Modification engine room
Execution Modes:
Mode 2 (minimum duration)
Mode 1 (standard)
Mode 2 (minimum duration)
Resource Requirements:
Resource
Split
Steelworkers
1
Riggers
2
Fitters
2
Duration:
144
Hours
0
Minutes
Work Content:
720
Hours
0
Minutes
Accept
Restore
New Mode
Delete Mode
Close
Cancel


Capacity View
Schedule Edit Select Options Tools View Print
Steelworkers
Carpenters
Electricians
Fitters
Plumbers
Riggers
Welders
Dry dock
Dec`95
Jan`96
Feb`96
Mar`96
Apr`96
May`96
Jun`96
Jul`96
549 550 551 552 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631
Hr. Mst. Ruyter
Hr.Mst. Tromp
Hr. Mst. Van Nes
Herstelwerkzaamheden
31/03/1996 05:10:21
Project: Hr. Mst. Ruyter Activity: 1.5.2: Act_1.5.2
08/04/1999 12:33:25

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.