Production Planning Material Requirements Planning (MRP)

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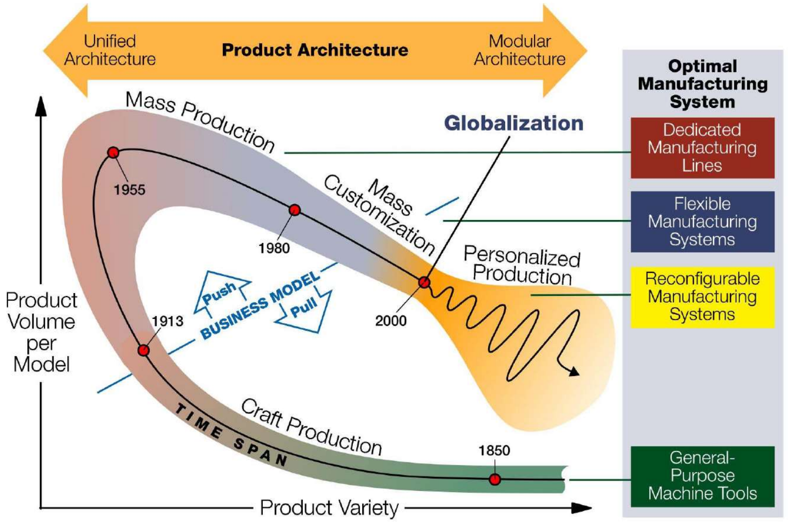
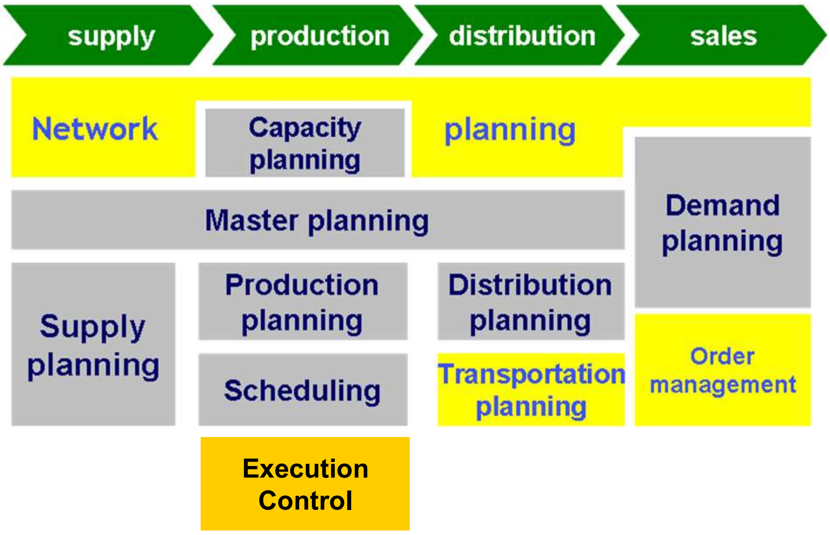
Production paradigms



[Koren, 2009]

Overview: The planning matrix



Principles

- Abundance and uncertainty of information → aggregation
  - In several dimensions
    - Production goals
    - Products
    - Time
    - Resources
  - The closer to real production
    - The more details,
    - The shorter horizons,
- Complexity → decomposition and relaxation
  - Capacity and material flow oriented subproblems
  - Focusing on
    - Resource constraints
    - Temporal constraints
  - Solution of simplified (sub)problems
  - Examples
    - MRP with infinite capacity
    - Capacity planning without temporal relations

The dilemma of planning

Goal: meeting market demand

Basic problem

- Produce only what is needed
  - not more, not less,
  - not later, not earlier,
  - just in the required quality
- At minimum cost
  - Production,
  - Logistics,
  - Environmental, ...

•Control over the uncertain future

- Based on information what is
  - Certain (products, technology, resource capability)
  - Uncertain (market demand, resource and material availability)
  - Asymmetric (supply chain, production network)

•Results: plans of future courses of actions over time

- Production
- Inventory holding
- Capacity investment
- Subcontracting
- Material supply, ….

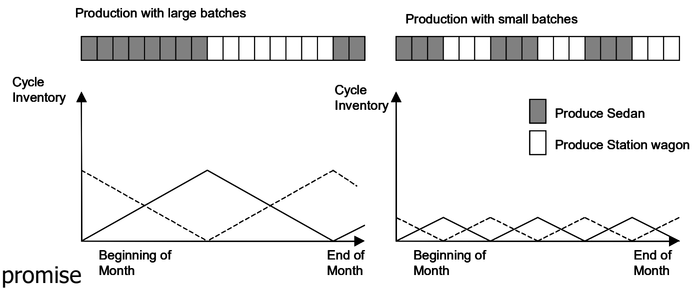
Why not to produce just the quantity needed?

•Producing in lots: cheaper, due to economies of scale in

- Material supply
- Production
- Distribution and transportation …

•Producing in lots (batches) is more expensive

- Reserves extra capacity
- Increases inventories
- Increases risk of obsolete inventories



•Solution is a compromise

Demand

Independent demand
- For end items
- Forecasts + orders + safety stocks

Dependent demand
- For subassemblies and components

In reality uncertain, now – and in most models - fixed

Transformation of demand

MRP history

- '60s: MRP
  - IBM, Joseph Orlicky
  - MRP: *Material Requirements Planning*
  - Application of computers in production planning
- '70s: proliferation in the USA
  - MRP Crusade
- '80s: MRP II
  - *Manufacturing Resource Planning*
  - Planning with infinite capacities
  - System integration
- '90: ERP
  - *Enterprise Resource Planning*
  - Software revenue: 1 billion USD/year
- '00: SCM
  - *Supply Chain Management*

Simplifying assumptions of MRP

Capacities (machine, human, …) are infinite
- No need to deal with capacities

Fixed lead times
- Consequence of the previous assumption
- No dependence from the actual load
- Though may be different for each product

Material and components are available
- No need to deal with supply

Basic concepts

- Time
  - Discrete periods, so called time buckets
    - One week, one day, …
  - Finite horizon
- Orders (demand)
  - Product, quantity, due date
  - External independent demand
    - For end items (or spare parts)
    - *Master Production Schedule*
    - Generates *Gross Requirements*
  - Internal demand
    - What, when and how much to produce so as to meet external demand?
    - *Planned Order* (*Job*)
      - Start: *Planned Order Release*
      - Finish: *Planned Order Receipt*
  - Running jobs
    - Under processing according to earlier plans
    - *Scheduled Receipts*

Basic concepts (2)

Inventories

- *On-hand inventories*
  - Quantities actually on the shelves
- Projected inventories
  - Availability projected for future periods

Product structure

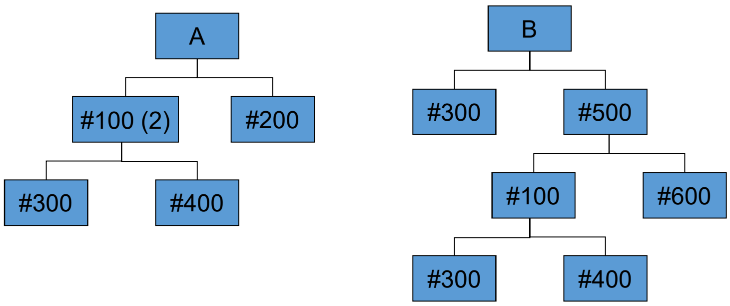
- *Bill of Materials* (BOM)
  - Assembly tree, gozinto graph
- Certain information

Bill of Materials (BOM)

Structure of the product

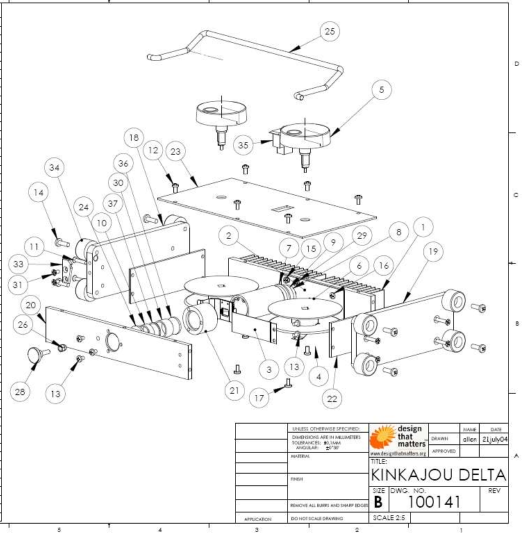
- End item
- Lower-level items (subassemblies)
- Composition
- Quantities

Examples



BOM example

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	100132	Heatsink, Aavid 60520	1
2	PCB		1
	100104	Circuit board blank	1
	100015	LED, Luxeon LXHL-LW6C	1
3	GATE		1
	100110	Film Gate	1
	100011	Backgate	1
	100024	Film Spacer	1
4	Bottom		1
	100144	Bottom Plate	1
	100029	Leaf Spring	2
5	Knobreel		2
	100106	Cover Bush	1
	100151	Dowel .125 dia 2.000 long	1
	100009	Driver	1
	100153	Gripring .125 dia	1
	100149	Knob bush	1
	100007	Clutch, one-way, Torrington RC-02	1
	100152	Washer, ss .125 id, McMaster 98019A310	1
	100017	Knob, plastic McMaster 7354K15	1
	100045	Felt washer	1
6	Reel		2
7	condentube		1
	100031	Condenser lens, small Fisher Price	1
	100105	Condenser Tube	1
	100154	O-ring Buna -120	1
	100035	Retaining ring, internal 1.062 dia	1
	100031b	Condenser lens, large, Fisher-Price	2
8	100162	Spacer, condenser lens, short	1
9	100136	Spacer, condenser lens, long	1
10	100163	Spacer, projector, short	1
11	FHMS Phillips M4x20		8
12	PHMS Phillips M4x8		6
13	PHMS Phillips M4x6		5
14	PHMS Phillips M5x16		8
15	FHMS Phillips M4x12		6
16	PHMS Phillips M4x12		1
17	PHMS M4x8		6
18	100150	Endplate, Right	1
19	100160	Endplate, Left	1
20	100100	Front Plate	1
21	100138	Projector Lens Housing	1
22	100148	End Spacer	2
23	100145	Top Plate	1
24	100158	Window Edmund R39-773	1
25	100146	Handle	1
26	100161	M5 Acorn Nut	1
27	100147	Half Bridge	1
28	100012	Focus Screw McMaster 92558A170	1
29	100143	Spacer, .25 dia, .19 long	4
30	100156	Spacer, projector, long	1
31	FHMS Phillips M4x8		2
32	100150	Washer, Nylon, MSC 05401757	1
33	100159	Detent	1
34	100101	Bumper, rubber McMaster 9540K35	8
35	100039	Switch, SPST rocker Carlingswitch	1
36	100155	Projector lens, concave	1
37	100157	Projector lens, plano	1

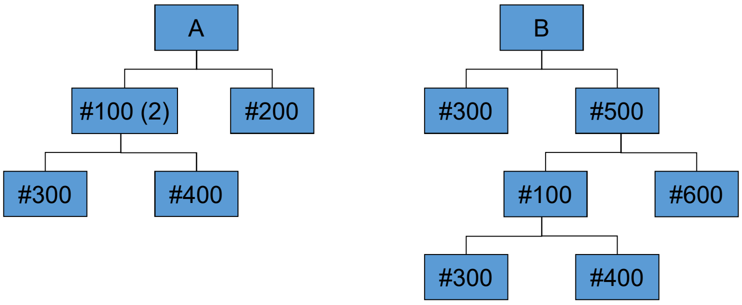


BOM (3)

- Properties
  - Tree structure
    - Nodes, edges, parent – child relations
    - Root: end item
    - Children: component to be included
  - Inclusion of several instances
  - At several levels
  - Into several end items
- Low-level code (LLC)
  - End item: LLC = 0
  - Child: LLC(parent) + 1
  - When at several levels: LLC = max(LLC_i)
- Examples
  - LLC(B) = 0
  - LLC(#100) = max(1,2) = 2
  - LLC(#300) = max(2,1,3) = 3

Bill of Materials (BOM)

Examples



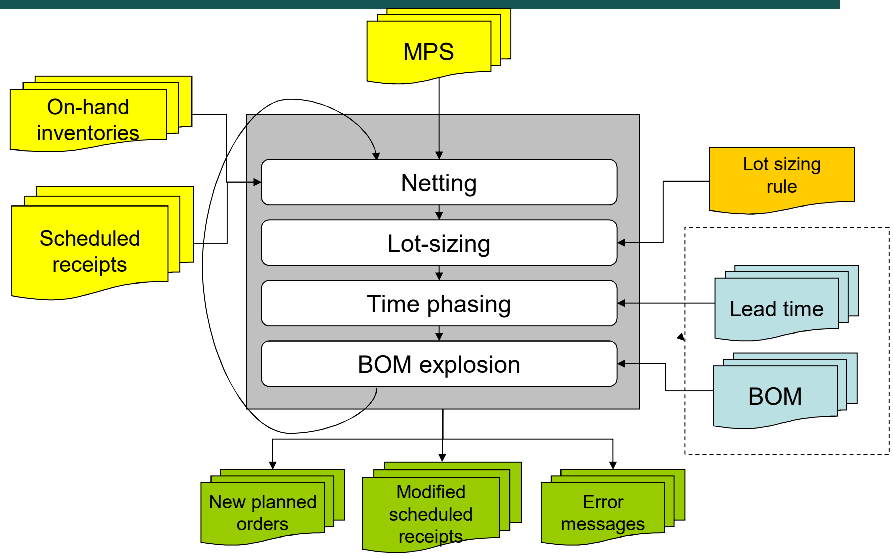
MRP input data

- Independent demand for end items
  - *Master Production Schedule* (MPS)
  - What, when, how much to have ready
- Item master data
  - For each product
  - *BOM*
  - *Planning Lead Time*
- Internal material flow
  - *On-hand Inventory*
    - For end items and subassemblies alike
  - *Scheduled Receipts*
    - Quantities scheduled for given due dates
    - Jobs under processing in the factory
    - Receipt scheduled from external supplier

MRP results

- New planned orders
  - Initiating production
    - Item
    - Quantity
    - Internal release and due dates
  - For end items and subassemblies alike
  - Cannot directly be bound to external orders
    - E.g., one subassembly in several end items
  - *Planned Order Release* (POR)
- Modified scheduled receipts
  - Re-scheduling due dates of running/planned jobs
    - Closer: *expediting*
    - Farther: *deferring*
  - *Change Notice*
- Error messages
  - When there is no feasible solution that meets all requirements
  - *Exception Reports*

The MRP process



The MRP process (2)

1. Netting: Determine net requirements by subtracting on-hand inventory and any scheduled receipts from the gross requirements. The gross requirements for level-zero items come from the MPS, while those for lower-level items are the result of previous MRP operations.
   Calculation of net demand, based on gross requirements, on-hand inventory and scheduled receipts
   - Gross requirements
     - End items: *Master Production Schedule* (MPS)
     - Subassembly: result of previous level's MRP
   - Starting at end items (LLC = 0)
2. Lot sizing: Divide the netted demand into appropriate lot sizes to form jobs.
   - Making lots (batches) out of net demand,
3. Time phasing: Offset the due dates of the jobs with lead times to determine start times
   - From due dates back to release dates.
4. BOM explosion
   Use the start times, the lot sizes, and the BOM to generate gross requirements of any required components at the next level.
   - Generating gross requirements for subassemblies
   - On the next LLC
   - Gross requirements coming from several parents aggregated
5. Iteration
   - Until subassemblies on all LLC levels are processed

1. *Netting:* Determine net requirements by subtracting on-hand inventory and any scheduled receipts from the gross requirements. The gross requirements for level-zero items come from the MPS, while those for lower-level items are the result of previous MRP operations.

2. Lot sizing: Divide the netted demand into appropriate lot sizes to form jobs.

3. Time phasing: Offset the due dates of the jobs with lead times to determine start times.

4. BOM explosion: Use the start times, the lot sizes, and the BOM to generate gross requirements of any required components at the next

5. Iterate: Repeat these steps until all levels are processed.

In addition to the BOM information, MRP requires information concerning independent

demand, which comes from the master production schedule (MPS). The MPS

contains gross requirements, the current inventory status known as on-hand inventory,

and the status of outstanding orders (both purchased and manufacturing) known as

scheduled receipts.

Simple example

Conditions

- *MPS* is given
- No *Scheduled Receipt*
- On-hand inventory: 30 units

Part A	1	2	3	4	5	6	7	8
Gross requirements	15	20	50	10	30	30	30	30

1. Netting

Part A		1	2	3	4	5	6	7	8
Gross requirements		15	20	50	10	30	30	30	30
Projected on-hand	30	15	-5	-	-	-	-	-	-
Net requirements		0	5	50	10	30	30	30	30

Simple example (2)

2. Lot sizing
   - Fixed quantity: 75 unit per lot
   - Starting a lot whenever demand is uncovered, even partially
3. Time phasing
   - When to start production? Example: fixed planning lead time: 1 week

To determine when to release the jobs (if made in-house) or purchase orders (if bought from someone else), we simply subtract the lead time from the time of the planned order receipts to obtain the planned order releases.

Part A		1	2	3	4	5	6	7	8
Gross requirements		15	20	50	10	30	30	30	30
Projected on-hand	30	15	-5	–	–	–	–	–	–
Net requirements		0	5	50	10	30	30	30	30
Planned order receipts			75			75		75	
Planned order releases		75			75		75		

Simple example (3)

4. BOM explosion
   - Gross requirements are generated for each direct subassembly of
     - Part A
     - Part B
   - These are dependent demands already
   - Aggregation of dependent demand for each subassembly
   - Planning in increasing LLC order (0,1,2,…)

MRP process: details

Notation

- For each end item and subassembly
- Time period: t
- Demand D_t
  - *gross requirement*
- Scheduled receipt S_t
- Projected on-hand inventory I_t
- Net requirements N_t

1. Netting

- Task
  - Cover each amount of gross requirement
  - Without loosing quantities
  - Without delay
- Strategy
  - First, cover from on-hand inventory
  - Next, re-schedule scheduled receipts
    - Forward/backward
  - Finally, launch new planned orders

1. Netting (2)

- Procedure
  1. ***Initialize***: $t = 0, I_0$
  2. ***Calculate covered demand***

     Repeat until $I_t < 0$

     $t = t + 1$

     $I_t = I_{t-1} - D_t$
  3. ***Re-schedule scheduled receipts***

     Repeat until $I_t < 0$ and there is no more SR to be moved

     3.1 Repeat until $I_t \geq 0$ and there is SR to be moved

     move first SR to period t

     $I_t = I_t + S_t$

     3.2. $t = t + 1$

     $I_t = I_{t-1} - D_t$
  4. ***Calculate new net requirements***

     from the first period t^*

     where $I_{t^*} < 0$

$$N_t = \begin{cases} 0, t < t^* \\ -I_t, t = t^* \\ D_t, t > t^* \end{cases}$$

Example: initial data – from master productionschedule

Part A		1	2	3	4	5	6	7	8
Gross requirements		15	20	50	10	30	30	30	30
Scheduled receipts		10	10		100				
Adjusted SRs									
Projected on-hand	20								
Net requirements									
Planned order receipts									
Planned order releases									

Starting with 20 units in stock, we subtract 15 for the gross requirements in period 1, leaving five remaining on-hand.
Notice we do not consider the SR of 10 in period 1 since we always use on-hand inventory before using scheduled receipts.

Example: netting

Part A		1	2	3	4	5	6	7	8
Gross requirements		15	20	50	10	30	30	30	30
Scheduled receipts		10	10		100				
Adjusted SRs			20	100					
Projected on-hand	20	5	5	55	45	15	-15	-	-
Net requirements							15	30	30
Planned order receipts									
Planned order releases									

Second period: the gross requirement of 20 exceeds the five in stock, and so we issue a change notice to defer the SR with 10 from period 1 to period 2. This still provides only a total of 15 units, five less than what is needed. **Add** the second SR to period 2, bringing the total to 25 units. Since this SR is already scheduled for period 2, we do not need to generate a change notice. An so on…..

This more than covers the 10 units in period 4, leaving 45, as well as the 30 in period 5, leaving 15 units. **The demand in period 6 exceeds the projected on-hand inventory, and there are no more SRs to be adjusted. Thus, the first uncovered demand occurs in period 6 and is equal to 15.**

Netting cont.

The net requirements are now easily computed.

For periods 1 through 5they are zero because projected on-hand inventory is greater than zero.

For period 6 they are 15, simply the negative of projected on-hand inventory.

For periods 7 and 8 the net requirements are equal to the gross requirements, both of which are 30.

- **Moving SRs**
  - Only if necessary
  - Towards the future: *defer*
  - Towards the present: *expedite*
  - Quantities not split

2. Lot sizing

- Task
  - Decreasing the cost of set-ups
  - Though, lots increase inventories of end items and WIPs
    - WIP: *Work in Process*
  - Various compromises
- Assumptions
  - Deterministic demand
  - Maybe different from time period to time period
- Simple rules
  - Lot for lot (LFL)
    - In each period, same as the net requirement
    - Does nor combine the demand of several periods
  - Fixed order period (FOP)
    - Combines the demand of P periods
    - If P = 1, then LFL
    - In our running example let P = 2

Example: lot sizing

Part A		1	2	3	4	5	6	7	8
Gross requirements		15	20	50	10	30	30	30	30
Scheduled receipts		10	10		100				
Adjusted SRs			20	100					
Projected on-hand	20	5	5	55	45	15	-15	–	–
Net requirements							15	30	30
Planned order receipts							45		30

3. Time phasing

Task
- Determine the release (start) time of new planned orders

Assumptions
- Infinite capacities
- Fixed, a priori known (estimated) lead times
  - Independent of
    - Actual load
    - State of the factory
    - Lot size
- Component/material availability

Process
- Simple backward calculation from the due dates

Example: time phasing

Part A		1	2	3	4	5	6	7	8
Gross requirements		15	20	50	10	30	30	30	30
Scheduled receipts		10	10		100				
Adjusted SRs			20	100					
Projected on-hand	20	5	5	55	45	15	-15	–	–
Net requirements							15	30	30
Planned order receipts							45		30
Planned order releases					45		30		

4. BOM explosion

Task
- Determine dependent demand
- For the subassemblies
- That are included (potentially) in several items

Procedure
- Net requirement of parent generates gross requirement for its children
- Gross requirements from various sources are aggregated in each period
- Netting
  - MRP calculation
- Order of processing
  - Start at end items, LLC = 0
  - Continue with increasing LLC

Example: BOM explosion

Part B data
- Gross requirement (MPS)

t	1	2	3	4	5	6	7	8
MPS	10	15	10	20	20	15	15	15

Master production schedule - demand

- Master data and earlier plan

part	on-hand	scheduled receipt		lot-sizing rule	lead time (week)
		due	qty		
B	40	0		FOP, 2 weeks	2
#100	40	0		LFL	2
#300	50	2	100	LFL	1
#500	40	0		LFL	4

MRP: Part B

Since there are no scheduled receipts for part B, the MRP calculations for this part are simple:

Part B		1	2	3	4	5	6	7	8
Gross requirements		10	15	10	20	20	15	15	15
Scheduled receipts									
Adjusted SRs									
Projected on-hand	40	30	15	5	-15	-	-	-	-
Net requirements					15	20	15	15	15
Planned order receipts					35		30		15
Planned order releases			35		30		15		

MRP: Part #500

- **Demand only from Part B** (The only source of demand for part 500 is from part B)
- **LLC = 1**
- **Exception report** (Because the lead time for part 500 is four weeks, there is not enough time to finish the first 25 units before week four. Therefore, a planned order release is scheduled for week one (as soon as possible) with an indication on an exception report that it is expected to be late.)
  - Work should have started in period 0 (present)
  - No solution of the MRP problem

Part #500		1	2	3	4	5	6	7	8
Requirements from B			35		30		15		
Gross requirements			35		30		15		
Scheduled receipts									
Adjusted SRs									
Projected on-hand	40	40	5	5	-25	-	-	-	-
Net requirements					25		15		
Planned order receipts					25		15		
Planned order releases		25*	15						

MRP: Part #100

- **Demand from Part A and subassembly #500**
- **LCC = 2** (no schedueled receipts).

Part #100		1	2	3	4	5	6
Required from A					90		60
Required from #500		25	15				
Gross requirements		25	15		90		60
Scheduled receipts							
Adjusted SRs							
Projected on-hand	40	15	0	0	-90	-	-
Net requirements					90		60
Planned order receipts					90		60
Planned order releases			90		60		

MRP: Part #300

Part #300		1	2	3	4	5	6	7	8
Required from B			35		30		15		
Required from #100			90		60				
Gross requirements			125		90		15		
Scheduled receipts			100						
Adjusted SRs			100						
Projected on-hand	50	50	25	25	-65	-	-	-	-
Net requirements					65		15		
Planned order receipts					65		15		
Planned order releases				65		15			

MRP: output

Transaction	Part #	Old Due	Rel. Date	New Due	Qty	Notice
Change notice	A	1		2	10	defer
Change notice	A	4		3	100	expedite
Planned order release	A		4	6	45	OK
Planned order release	A		6	8	30	OK
Planned order release	B		2	4	35	OK
Planned order release	B		4	6	30	OK
Planned order release	B		6	8	15	OK
Planned order release	100		2	4	90	OK
Planned order release	100		4	6	60	OK
Planned order release	300		3	4	65	OK
Planned order release	300		5	6	15	OK
Planned order release	500		1	4	25	Late
Planned order release	500		2	6	15	OK

Determining the lot size

Lot size as a compromise

Lot sizing methods within MRP

- Lot for lot (LFL)
- Economic order quantity (EOQ)
- Fixed order quantity (FOQ)
- Fixed order period (FOP)

Lot for lot

Produce in each period exactly the net demand

Properties

- No inventory in the end of the periods → minimal inventories
- Each period starts with a setup → maximal setup costs
- Merits
  - Does not combine several periods' work → levelling
  - „Just in time"
  - Worth using in case of small setup costs

Economic Order Quantity (EOQ)

- Assumptions
  - Production is instantaneous
    - Thanks to the infinite capacity
  - Delivery is immediate
  - Demand is deterministic and its rate is constant
    - E.g. if annual demand is 365 units, then daily demand is 1
  - A production run incurs a constant setup cost
  - Products can be analysed singly
- Notation

D = Demand rate, [unit/year]
c = Unit production cost (without setup and holding costs) [$/unit]
A = Constant setup / ordering cost for a lot [$/lot]
h = Holding cost [$/unit/year]

If holding cost consists entirely of interest of money tied up in inventory, then $h = i*c$, where i is the annual interest rate

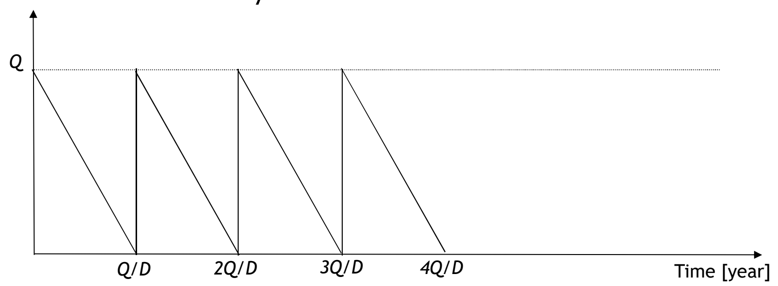
Q = Lot size [unit]: decision variable

EOQ (2)

Modelling convenience

- Lot size and time are continuous

The evolution of inventory levels in time



Objective: minimal total cost per unit

- Setup + production+ inventory holding

EOQ (3)

- **Inventory holding cost:**

  Average inventory level: $\frac{Q}{2}$

  Average holding cost: $\frac{hQ}{2}$

  Per one unit: $\frac{hQ}{2D}$

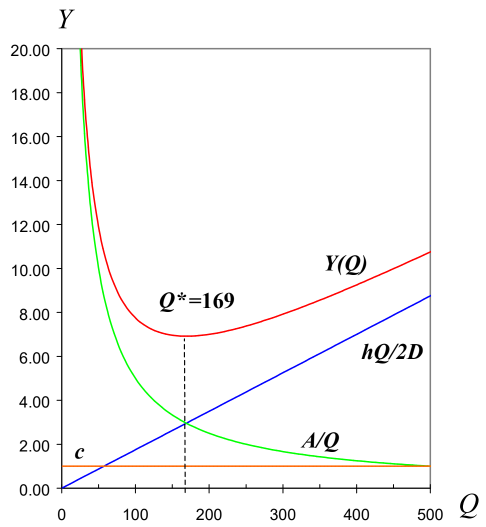
- **Setup cost for each lot is** A, hence for one unit: $\frac{A}{Q}$
- **Production cost per unit:** c
- **Cost function:** $Y(Q) = \frac{hQ}{2D} + \frac{A}{Q} + c$
- **Optimum** $\frac{dY(Q)}{dQ} = \frac{h}{2D} - \frac{A}{Q^2} = 0$ $\boxed{Q^* = \sqrt{\frac{2AD}{h}}}$

EOQ (4)

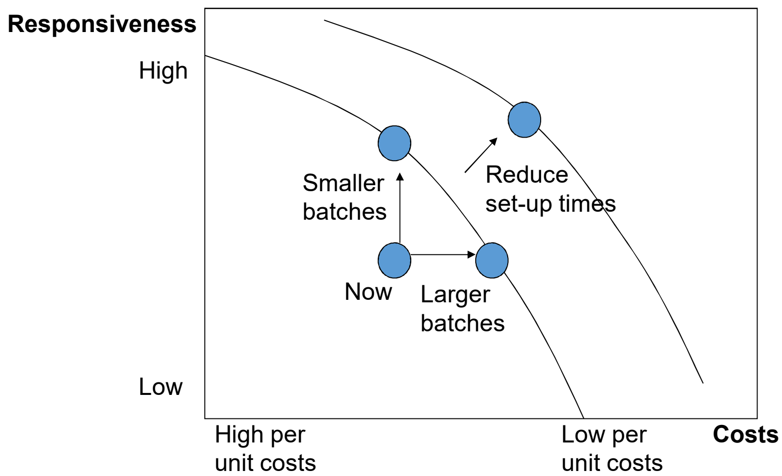
Example

D = 1000
c = \$250
A = \$500
h = (0.1)(\$250) + \$10 = \$35
per year and unit
i = 10%

$$Q^* = \sqrt{\frac{2(500)(1000)}{35}} = 169$$



Lot sizing: try reduce setup times



Lot sizing FOQ/EOQ

- Fixed Order Quantity/Economic Order Quantity
- Internal orders for fixed quantities
  - Due to properties of resources
    - Palette, cart, container, ….
    - According to power law: 1,2,4,8,…
  - So as to reduce average setup costs
- Using the EOQ model
  - Demand rate $\bar{D}$
  - Setup cost A
  - Inventory holding h
  - Lot size Q

$$Q = \sqrt{\frac{2A\bar{D}}{h}}$$

  - Approach EOQ by merging net demands
  - Example: Q = 50

Period	1	2	3	4	5	6	7	8
Net requirements	15	15	60	65	55	15	20	10
Planned order receipts	30		60	65	55	45		

Lot sizing: FOP

- Fixed Order Period
- If production is started in period t, then produce the demand of the subsequent P periods, too.
  - If P = 1, LFL

Period	1	2	3	4	5	6	7	8	9
Net requirements		15	45			25	15	20	15
Planned order rec.		60				60			15

- Determining P on the basis of EOQ

$$\bar{D} = 135/9 = 15, A = 150, h = 2$$

$$Q = \sqrt{\frac{2A\bar{D}}{h}} = \sqrt{\frac{2\times150\times15}{2}} = 47.4 \qquad P = Q/\bar{D} = 47.4/15 = 3.16 \approx 3$$

Safety buffers

Handling uncertainty
- MRP is deterministic, reality is not
- Sources of uncertainty
  - Demand change (quantity, timing)
  - Changing production times
  - Changing yield (scrap production)

Safety stocks (SS)
- Against demand uncertainty
- Calculation
  - *Projected on-hand* is decreased by SS

Safety lead time (SLT)
- Handing uncertainties in timing
- Pushing due dates earlier
  - As of the lead time would be longer

Example: safety stock

Safety stock should be used to protect against uncertainties in production and demand *quantities,* while *safety lead time* should be used to protect against uncertainties in production and demand *timing.*

SS = 10

FOP, P = 2

This time we compute the first net requirement as we did before, but we subtract an additional 10 units for the desired safety stock. The projected on-hand *minus safety stock* first becomes negative in period 3 (as opposed to period 4 before).

Part B		1	2	3	4	5	6	7	8
Gross requirements		10	15	10	20	20	15	15	15
Scheduled receipts									
Adjusted SRs									
Projected on-hand	40	30	15	5	–	–	–	–	–
Projected on-hand – SS	30	20	5	-5					
Net requirements				5	20	20	15	15	15
Planned order receipts				25		35		30	
Planned order releases		25		35		30			

Example: safety lead time

- **Planned lead time = 2**
- **Safety lead time = 1**

Part B		1	2	3	4	5	6	7	8
Gross requirements		10	15	10	20	20	15	15	15
Scheduled receipts									
Adjusted SRs									
Projected on-hand	40	30	15	5	-15	-	-	-	-
Net requirements					15	20	15	15	15
Planned order receipts					35		30		15
Adjusted POR				35		30		15	
Planned order releases		35		30		15			

- **Danger: self-fulfilling prophecy**
  - Because of increased WIP, lead times will really grow!

Problems of MRP

Capacities neglected
- Infinite capacity assumption
- Result: infeasible plans
  - Especially if the system is working close to congestion
  - It is enough to overload a single resource

Longer lead time than necessary
- For safety's sake
  - Larger inventories
- Meeting due dates has usually higher priority

System nervousness
- Small changes in input may lead to drastically different internal planned orders
- Sometime even a small *decrease* of demand may cause infeasibility

Sources, contact

Textbook

- Hopp, W.J.; Spearman, M.L, *Factory physics, Foundations of manufacturing management*, Irwin, (second edition, 2000, third edition 2008).

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Thank You for your attention!

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