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Materials planning

Material requirement planning (MRP)

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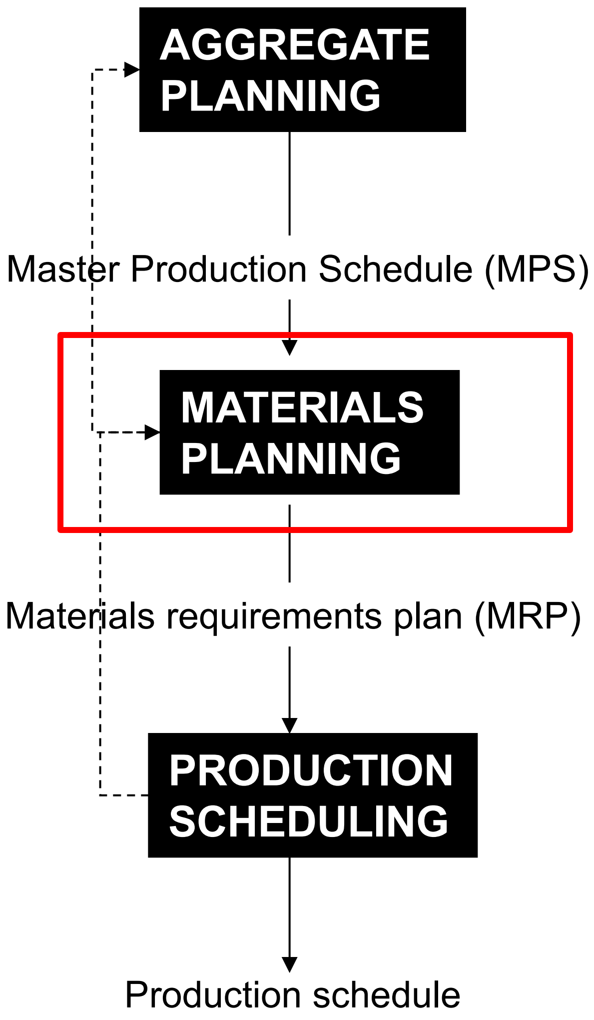
Materials planning


AGGREGATE PLANNING

Master Production Schedule (MPS)

MATERIALS PLANNING

Materials requirements plan (MRP)

PRODUCTION SCHEDULING

Production schedule

•The planning of materials requirements consists of the determination of:

- What
- How much and
- When

to order at every stage of the production process

Materials planning approaches

Materials planning approaches

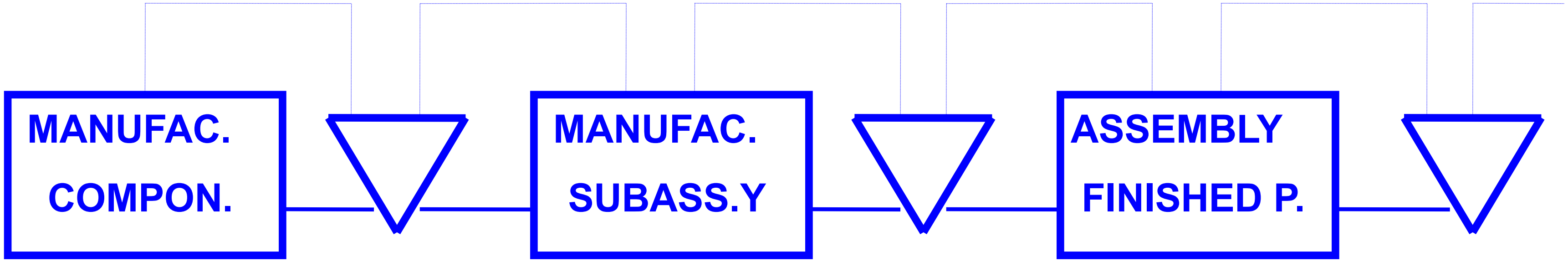
Stock based
“**PULL**”
also called
“**INVENTORY MANAGEMENT**”

Materials’ production/purchase orders are issued in order to replenish a stock

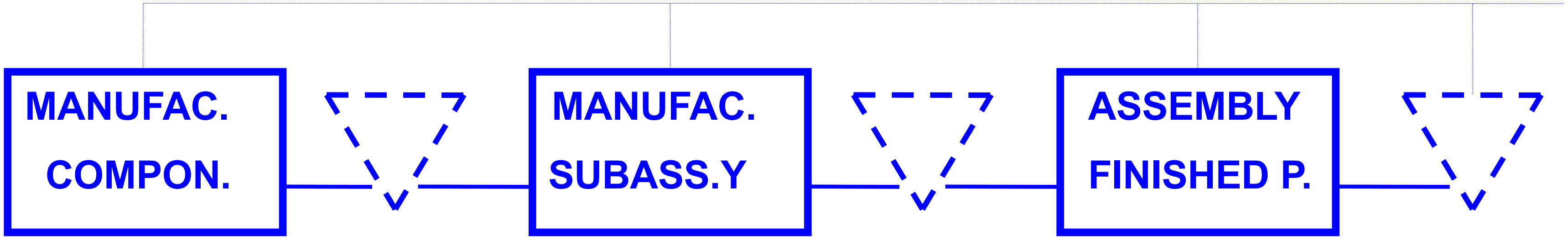
Requirements based
“**PUSH**”
also called
“**ON DEMAND MANAGEMENT**”

Materials’ production/purchase orders are issued in order to satisfy a finished product requirement

Materials planning approaches

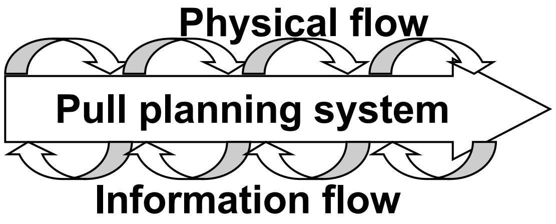


PULL SYSTEM



PUSH SYSTEM

Pull systems - Issues



- **Pull** (stock based) systems
  - Objective:
    having "always" the required product stored in the warehouse
    - according to the service level
  - Required information:
    order issuing criteria (re-order policy): the triggering mechanism
    - e.g. Economic Order Quantity – Re-Order Point
  - Implicit hypotheses:
    - Demand stationary
    - Demand as sum of "small" and independent demands
    - Smoothed and even stock consumption
    - Errors distributed normally
  - Distinctive feature:
    to manage the inventory level of components, each phase of the production process only "sees" the warehouse immediately downstream
    - while it is completely blind with reference to the remainder of the production / inventory system

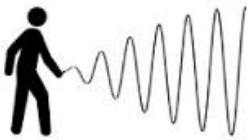
- **Saw tooth consumption profile over time**
- **Safety stocks based on variance**
- **Service level taken from the Gauss function**

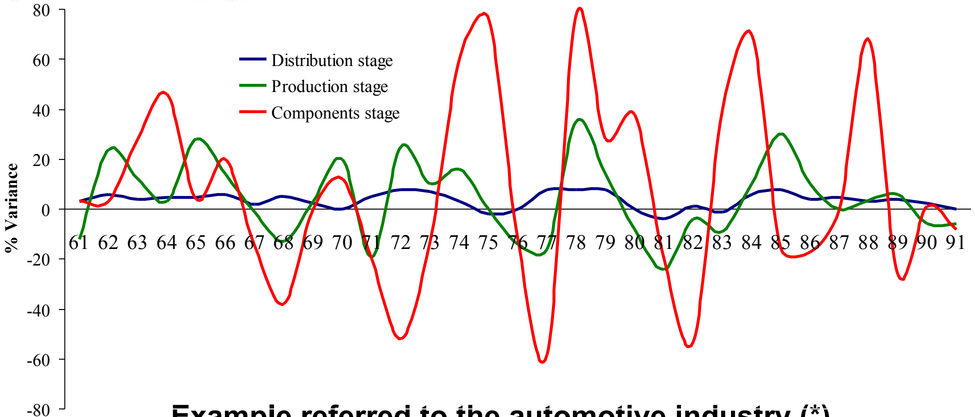
This does not protect the inventory system against the so-called bullwhip effect

Pull systems - Issues

- **Pull** (stock based) systems
  - The bullwhip effect

    Also called Forrester (1961) effect

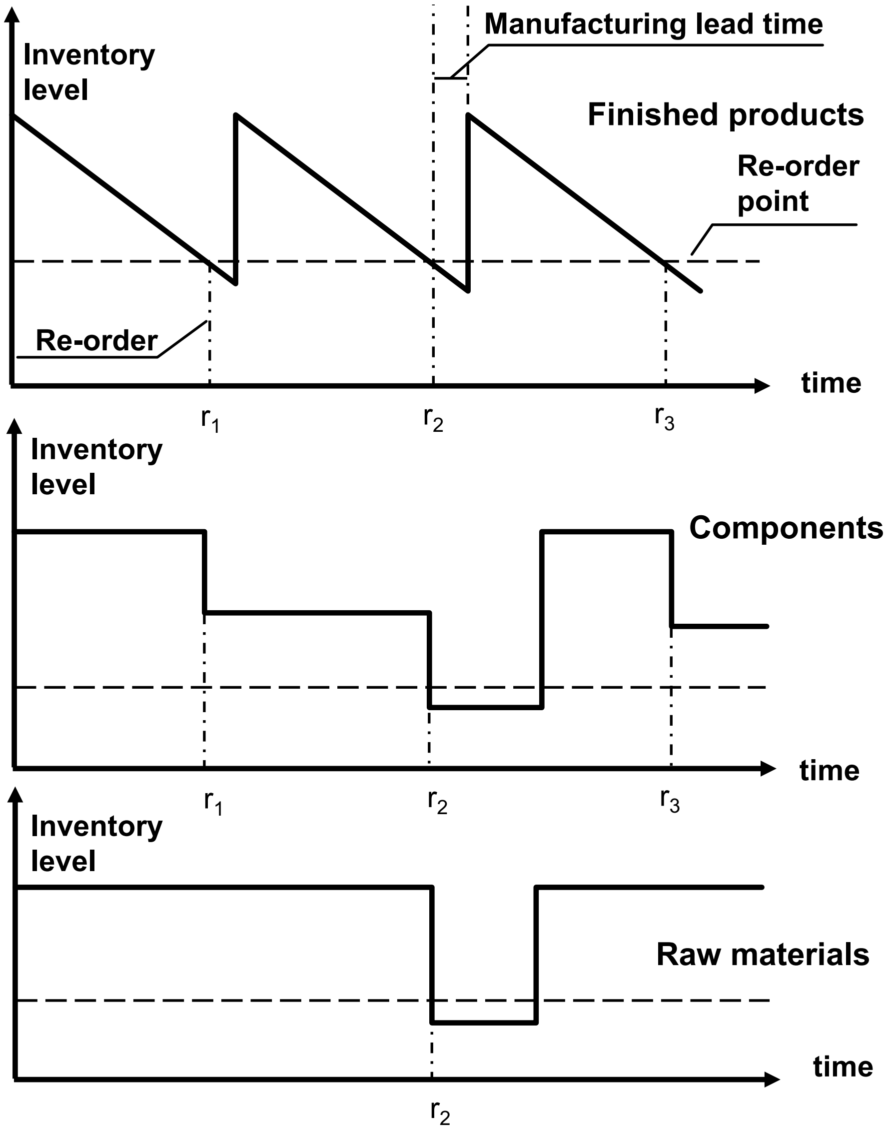




Example referred to the automotive industry (*)

Even a very small change at the finished product level may represent a remarkable source of variance when going upstream along the bill of materials (and also along the supply chain)

(*) Source: Anderson, E. Fine, C., Parker, G. (2000) "Upstream volatility in the supply chain: the machine tool industry as a case study“, Production & Operations Management, 9, (3), 239-261.



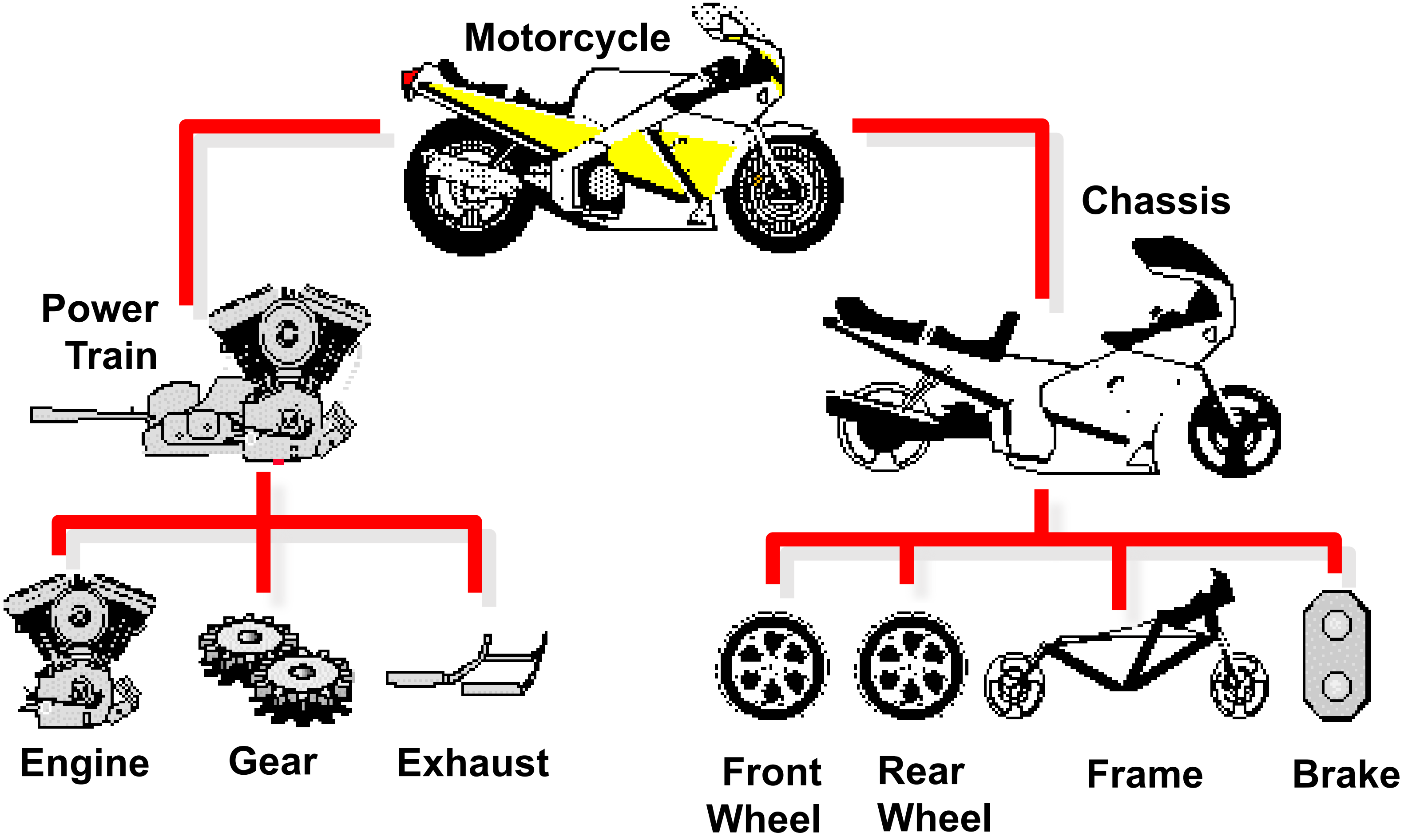
Pull systems - Issues

- In the industrial reality often ......
  1) «limited» number of clients (impact on: stationary demand, normality, etc.)
  2) Several production stages with lot policies, even with stationary demand of the finished products (bullwhip effect, …)
  3) Bill of Materials (BOM) "large" and "deep" (e.g., complex product): to ensure a high service level at finished product level, "unrealistic" high stocks of components are needed to be held (e.g., probability composition)
  4) Dependent demand (e.g., projects) and no need to have "always" the required product stored in the warehouse

So push system is to be considered also when the product/part is expensive, with long LT, from the same supplier …

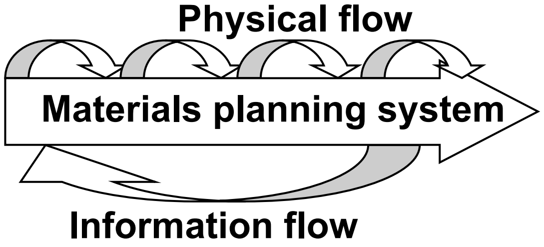
Pull systems - Issues

- To clarify the concept of Bill Of Materials (BOM)



Materials planning – requirements based (PUSH systems)

•**Objective**:
Calculating what, how many and when components, sub-assemblies, parts, raw materials etc. are required to put a plan into operation, i.e. to ensure that the customers' orders due dates (deadlines) are respected

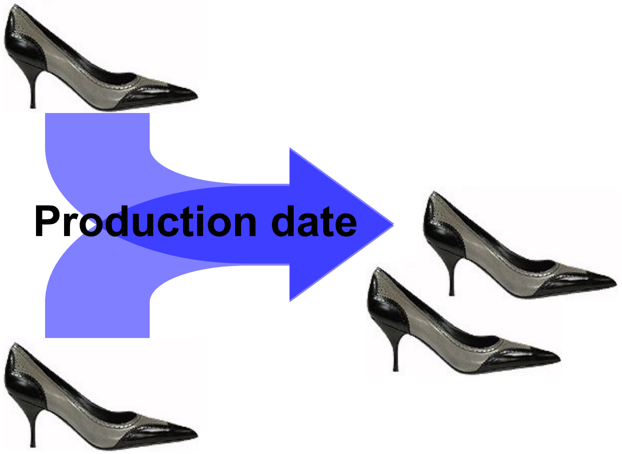


Physical flow

Materials planning system

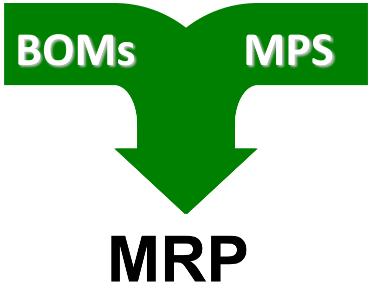
Information flow

- Requirements of components directly depend on a **plan** (e.g. the master production schedule)
- Requirements of components are therefore **calculated**
- In the end, the objective lies in **coordinating the production dates** (rendezvous) of components to manufacture finished products (or higher level components in the bill of materials)



Production date

- Required information:
  It is much huge, as it is needed
  to know the **master production schedule**, the **bills of materials** and to consider **at the same time** all the data referred to all the products and departments involved.
- To process all the information MRP is needed.



BOMs

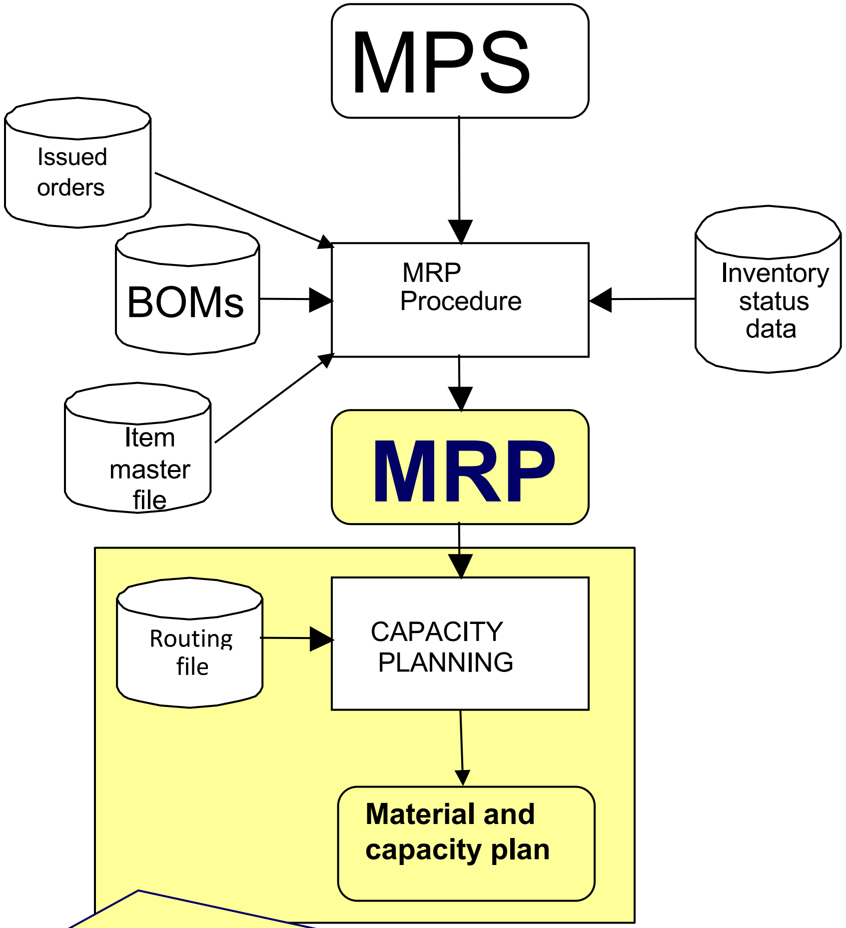
MPS

MRP

MRP - Materials Requirements Planning

- MRP means Materials Requirements Planning and it represents **the procedure** that implements the data processing needed to manage inventories, **so as the output** of that procedure

- MRP procedure consists of planning, on a time horizon made up of several time buckets (i.e. periods of a predetermined length over time) in the future, the inventory level (i.e. the availability) of each item of the bill of materials
  - finished products, components, raw materials etc.

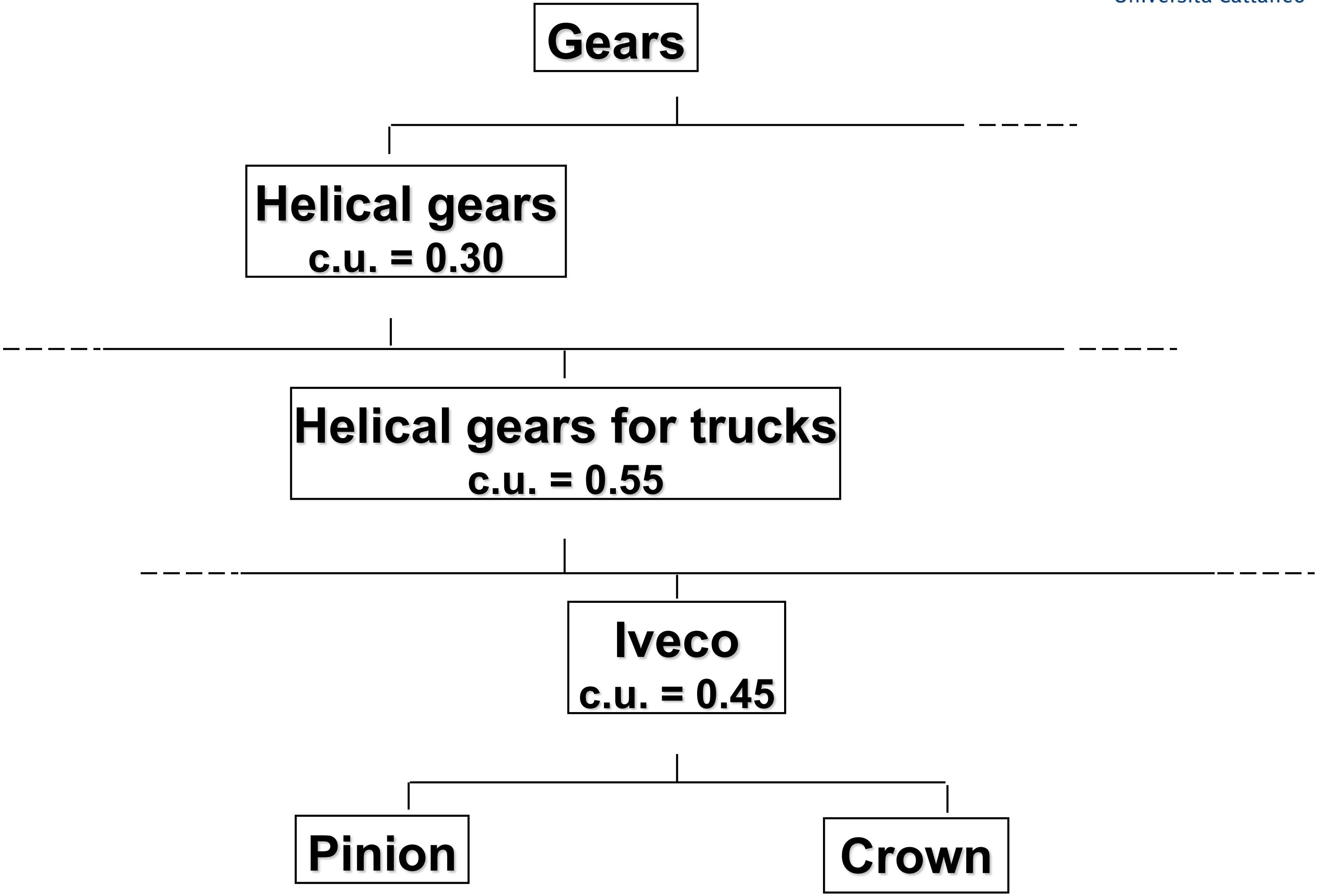


Capacity planning is run after MRP in order to verify production resource availability at a more detailed level than MPS (by considering the resources needed by all the materials, not only by finished products) and at a less detailed level than Scheduling (item sequence is not detailed at this moment, time buckets are more aggregate)

From MPS to MRP: Family bills

- The family bills are used to switch from product families to single items (from MPS to MRP logic)
- In the family bills:
  - at “level 0” there is a “type” (i.e. a group of families),
  - at level 1 there are the real families,
  - at the lower levels, there are the sub-families, the “average products” or, in few cases, the finished products, or the critical module/component items.

From MPS to MRP: Family bills



Gears

Helical gears
c.u. = 0.30

Helical gears for trucks
c.u. = 0.55

Iveco
c.u. = 0.45

Pinion

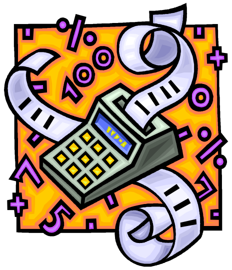
Crown

From MPS to MRP: Family bills

- By means of the coefficients of usage and the family bill structure it is possible to disaggregate the medium-long term forecast data (usually computed only for each type) …

- ... into the corresponding forecast data for the families and the products. Therefore it is possible to compute the MPS on a longer time horizon.

MRP - Materials Requirements Planning



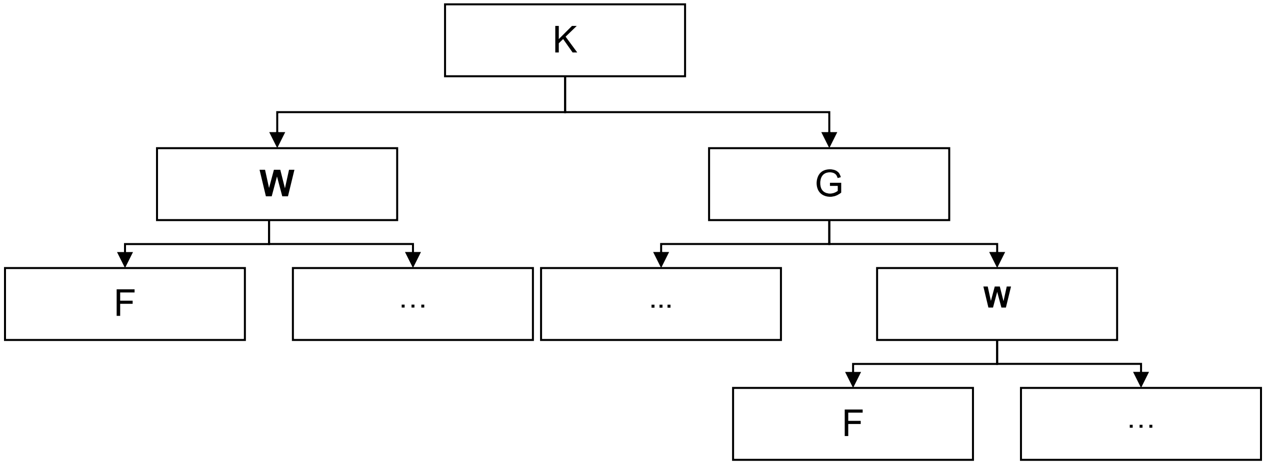
- MRP procedure operates according to the so-called “3S” approach:
  - **Sum** the requirements of the same component coming from different orders and referred to the same period
  - **Split** the overall requirements per period of each component according to the lot-sizing policy
  - **Shift** (backward) the lot-sized requirements along the time-related dimension (i.e. over time) according to the lead times reported in the bills of materials (to take into account the production routings)
- This leads to a plan of purchasing and manufacturing order proposals
- Which in turn generates
  - falling to the lower level of the BoM

  gross requirements of lower-level components
- The interactive procedure is finished with the analysis of raw materials
  - also called “leaves” of the bill of materials

Explosion of the bills of materials

Low level code

- The "Low level code" rule refers to the lowest level code used in the Bill Of Materials (BOM) to identify a specific item.
- It is necessary to identify the lowest level of the BOM at which a code is found (e.g. code W can be found at level 1 of BOM and at level 2 of BOM), and then re-classify it at the lowest level (e.g. code W is then re-classified at level 2 only of the BOM).
- This is needed in order to be able to calculate the (gross total) requirements of the code - only once and at the lowest level possible - as the sum of all the requirements related to its parent codes.

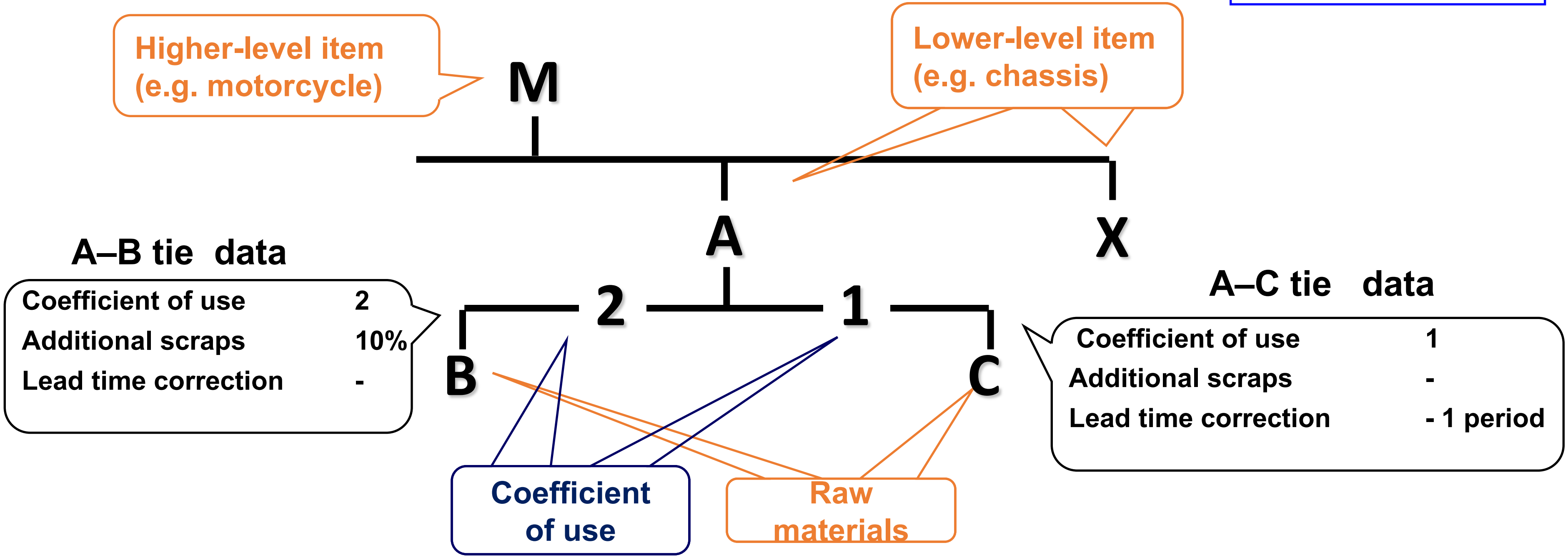


Example of MRP running

Product A data

Lead time	3 periods
Re-order policy	Fixed lot size, 150 pieces
Initial inventory	200 pieces
Reserved stock	30 pieces (1st period)
Orders in progress	48 pieces (3rd period)
Safety stock (*)	50 pieces
Scrap rate	10 %

Other re-order policies are e.g. Lot-for-Lot (L4L) policy and Dynamic EOQ (Wagner & Whitin Model)



A–B tie data

Coefficient of use	2
Additional scraps	10%
Lead time correction	-

A–C tie data

Coefficient of use	1
Additional scraps	-
Lead time correction	- 1 period

(*) Safety stocks are used to face the forecasting error

Example of MRP running

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Product A data

Lead time	3 periods
Re-order policy	Fixed lot size, 150 pieces
Initial inventory	200 pieces
Reserved stock	30 pieces (1st period)
Orders in progress	48 pieces (3rd period)
Safety stock (*)	50 pieces
Scrap rate	10 %

Period	1	2	3	4	5	6	7	8	9	10
Gross internal requirements (of A)	*50*	*30*	*20*	*10*	*40*	*60*	*50*	*10*	*10*	*50*
Gross external requirements (of A)	*10*	*10*	*10*	*10*	*10*	*20*	*20*	*20*	*20*	*20*

Example of MRP running

120 = 200 – 30 – 50 = Initial inventory – Reserved stocks – Safety stocks

Period	1	2	3	4	5	6	7	8	9	10
Gross internal requirements (of A)	*50*	*30*	*20*	*10*	*40*	*60*	*50*	*10*	*10*	*50*
Gross external requirements (of A)	*10*	*10*	*10*	*10*	*10*	*20*	*20*	*20*	*20*	*20*
Gross total requirements (of A)	60	40	30	20	50	80	70	30	30	70
Initial availability (of A)	120	60	20	0	0	0	0			0
Scraps-adjusted requirements (of A)	0	0	11	22	55	88	77	33	33	77
Orders in progress (of A)			48	0	0	0	0	0	0	0
Net requirements (of A)					40	88	77	33	33	77
Lot-sized requirements (of A)					150		150			150
Orders to issue (of A)		150		150			150			
Gross requirements of B coming from A		330		330			330			
Gross requirements of C coming from A			150		150			150		

\-

=

(30 – 20) x 1.1 = 11

55 – (48 – 11 – 22) = 40

\+

=

x 1.1

LT = 3 periods

LT correction = 1 period

x 2.2

"2.2" factor comes from a twofold effect:
"x 2" comes from the coefficient of use and additional "x 1.1" comes from the 10% additional scraps

Example of MRP running

Period	1	2	3	4	5	6	7	8	9	10
Gross internal requirements (of A)	*50*	*30*	*20*	*10*	*40*	*60*	*50*	*10*	*10*	*50*
Gross external requirements (of A)	*10*	*10*	*10*	*10*	*10*	*20*	*20*	*20*	*20*	*20*
Gross total requirements (of A)	60	40	30	20	50	80	70	30	30	70
Initial availability (of A)	120	60	20							
Scraps-adjusted requirements (of A)			11	22	55	88	77	33	33	77
Orders in progress (of A)			*48*							
Net requirements (of A)					40	88	77	33	33	77
Lot-sized requirements (of A)					150		150			150
Orders to issue (of A)		**150**		**150**			**150**			
Gross requirements of B coming from A		330		330			330			
Gross requirements of C coming from A			150		150			150		

Example of MRP running

- Now, on the basis of the data referred to product B and C you can apply the MRP procedure and find the orders to be issued for B and C

B

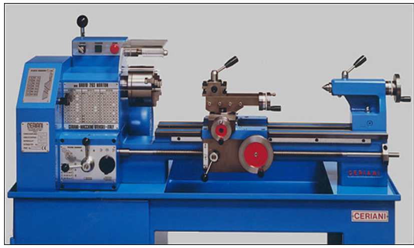
Period	1	2	3	4	5	6	7	8	9	10
Gross requirements of B coming from A		330		330			330			
Gross requirements of B coming from other products than A or external	*100*	*200*	*170*			*40*	*100*	*260*		
Gross total requirements of B	100	530	170	330		40	430	260		

C

Period	1	2	3	4	5	6	7	8	9	10
Gross requirements of C coming from A			150		150			150		
Gross requirements of C coming from other products than A or external		*180*			*40*	*60*			*80*	*60*
Gross total requirements of C		180	150		190	60		150	80	60

MRP running: some remarks

- Orders issuing is “timed” (i.e. placed in a given time bucket of the horizon) according to the **lead** time, which has not to be confused with the processing time
  - The lead time is the time span between the time an order of a given product / item is issued by a customer and the time the product is available for use (i.e. it is sent, received and “approved”) by the customer
    - i.e. the order is fulfilled
  - The processing time is the “technical” time required to finish a given phase of a production / logistic process, without setting reference to the queues
    - e.g., the tool-piece contact time during lathe machining



- Various reports are available at the end of the iterative running
  - Production and/or purchasing orders to issue
    - i.e. the ones that fall in “period 1” (none in the example)
  - Urgent orders to issue
  - Customers orders tracking
    - if the specific MRP software tool keeps the connection (i.e. pegs) between the quantity of customers orders and the requirements of the products

Limits of MRP procedures

- Three major areas are referred to as “critical system design features” (Orlicky, 1974)
    1. **Production capacity**
    2. **Lead times**
    3. **Data**

1.MRP basically operates at **infinite** capacity

- Loading of work centers is optimized only indirectly, through lot-sizing rules

2.Lead times are assumed as **fixed** and pre-determined

- Lead times are used as input variables and they are not considered as function of (dependent on) the work load

3.MRP requires a **high volume** of data and it needs a tight control and a careful updating and management of information

Limits of MRP procedure: production capacity

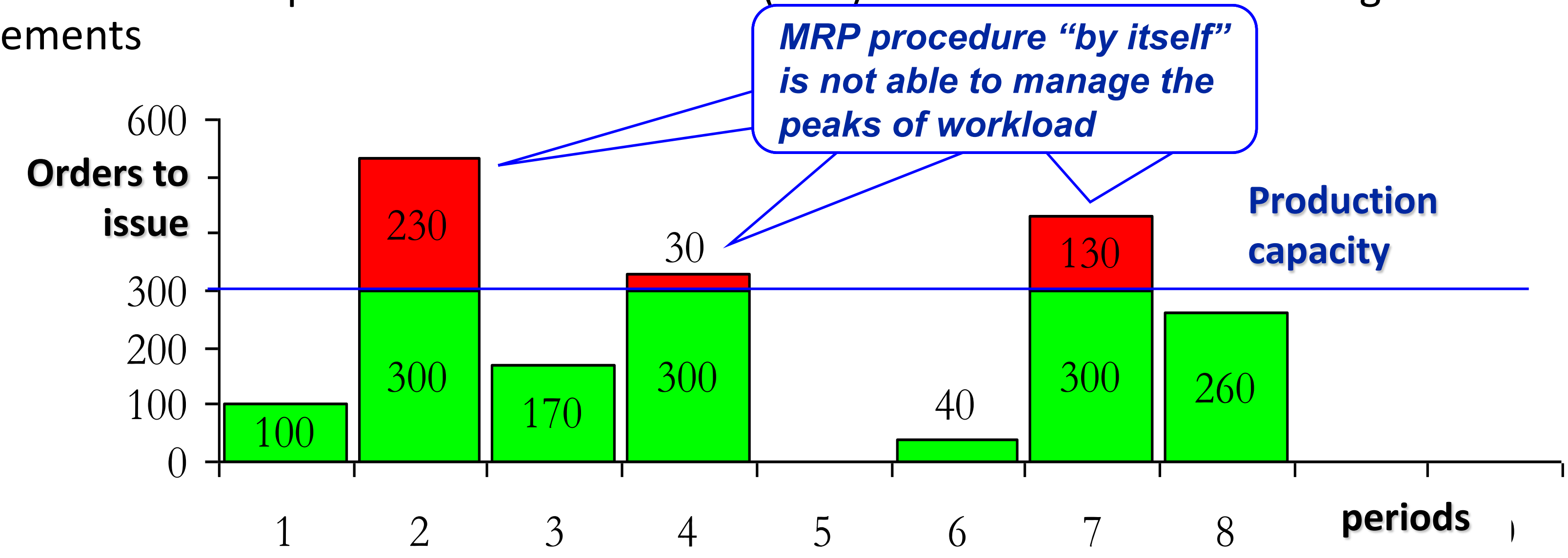
- Let refer to the previous example of MRP running

- The example has given the following profile over time of gross total requirements for product B

Period	1	2	3	4	5	6	7	8	9	10
Gross total requirements of B	100	530	170	330		40	430	260		

- For the sake of simplicity, let suppose initial availability, scraps and orders in progress are null, and the lot sizing rule is L4L (lot for lot)

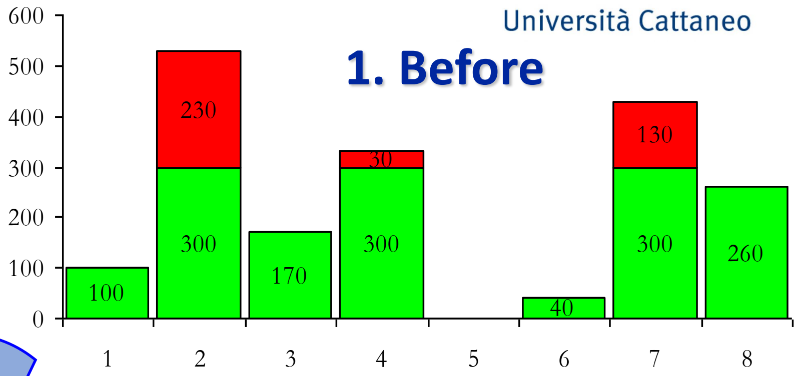
- This means that the profile of orders to issue (of B) is the same of the one of gross requirements

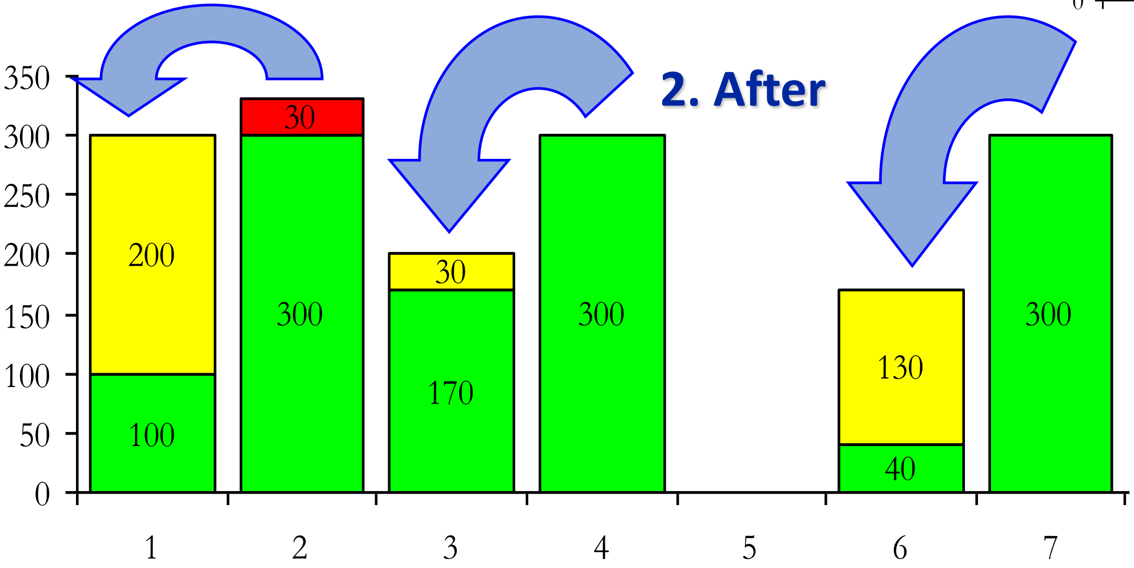


MRP procedure "by itself" is not able to manage the peaks of workload

Limits of MRP procedure: production capacity

- Production capacity is managed through finite-capacity post-processors





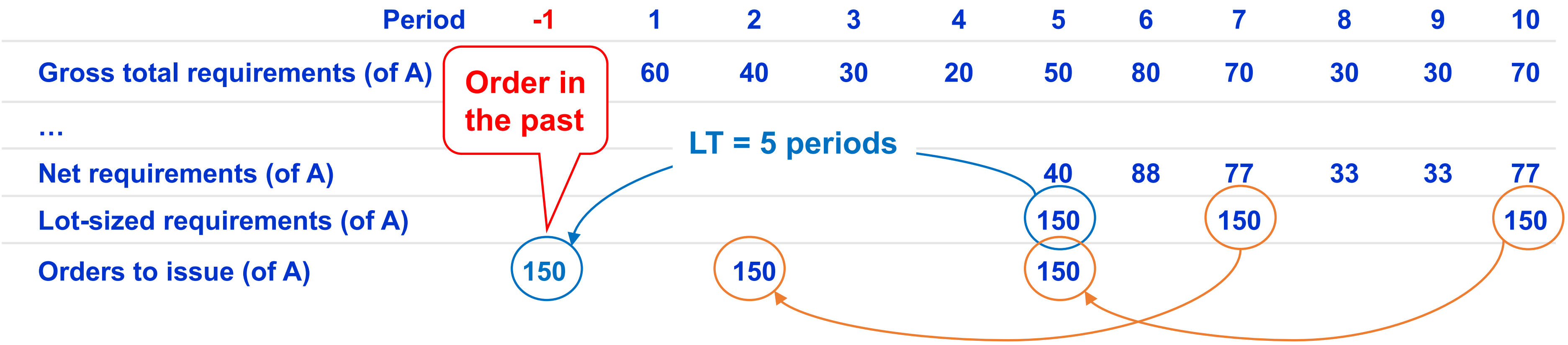
Overload is either avoided or reduced by shifting orders backward

Overloaded is removed by shifting orders forward

Post processors are often based on linear programming (LP) approach

Limits of MRP procedure: lead times

- Let refer to the previous example of MRP running
  - Suppose now the lead time of A is 5 periods (instead of 3): this generates the “order in the past” phenomenon, inherently due to the “shift” phase of MRP



Period	-1	1	2	3	4	5	6	7	8	9	10
Gross total requirements (of A)		60	40	30	20	50	80	70	30	30	70
…											
Net requirements (of A)						40	88	77	33	33	77
Lot-sized requirements (of A)						150		150			150
Orders to issue (of A)	150		150			150					

- MRP uses lead times as input, while their actual value is an output
  - Lead times are variable “by nature”, due to technology and organization-related factors

Limits of MRP procedure: lead times

- In the end, lead times estimation is critical:
  - **Underestimating** lead times leads to stock-out (of components) and therefore it puts the entire logic of the "production dates" in crisis
  - **Overestimating** lead times causes the planning horizon expansion, which implies:
    - A lower data reliability, since in the long term the portfolio will be composed of forecasts and fewer certain orders
    - An increase of components stock holding costs as they are manufactured longer before the time they are actually needed

- Accurate lead times estimation can be managed through accurate forecasts, frequent updating and by **shortening time buckets**
    - e.g. by using days as buckets instead of weeks
  - Notice that shortening time buckets requires (more) accurate forecasts (more) frequently updated

Limits of MRP procedure: data

- The required volume of data is relevant, mainly in the bills of materials (BOMs) area.
- Some of the problems connected to MRP (but also MPS) can be solved by rationalizing the technical and management data.
- This can be achieved by means of the PLANNING BILLS
  - Planning bills are “artificial” groups of items used to facilitate and enhance the planning process …
  - ... moreover they are used to integrate the different phases of the planning of production of complex products.

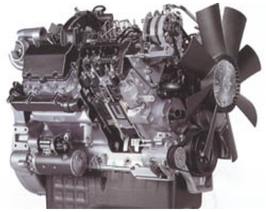
Super bills

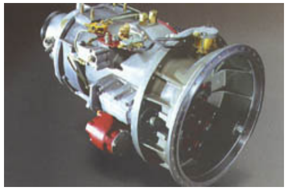
- A type of “planning bill” is called “SUPER BILL”. It is particularly useful in the phases before the MRP (and it is used to compute a more reliable MPS).
- The level 0 code of a super bill is the “AVERAGE PRODUCT” that, in some cases, can coincide with the last level of the family bill.
- The super bills are used when the finished product can perform different functions, each of which has different options.

Super bills

Example of a 3-wheel tractor

- Consider the example of Taurus tractor, equipped with different devices that correspond to various configurations of the same "basic" product





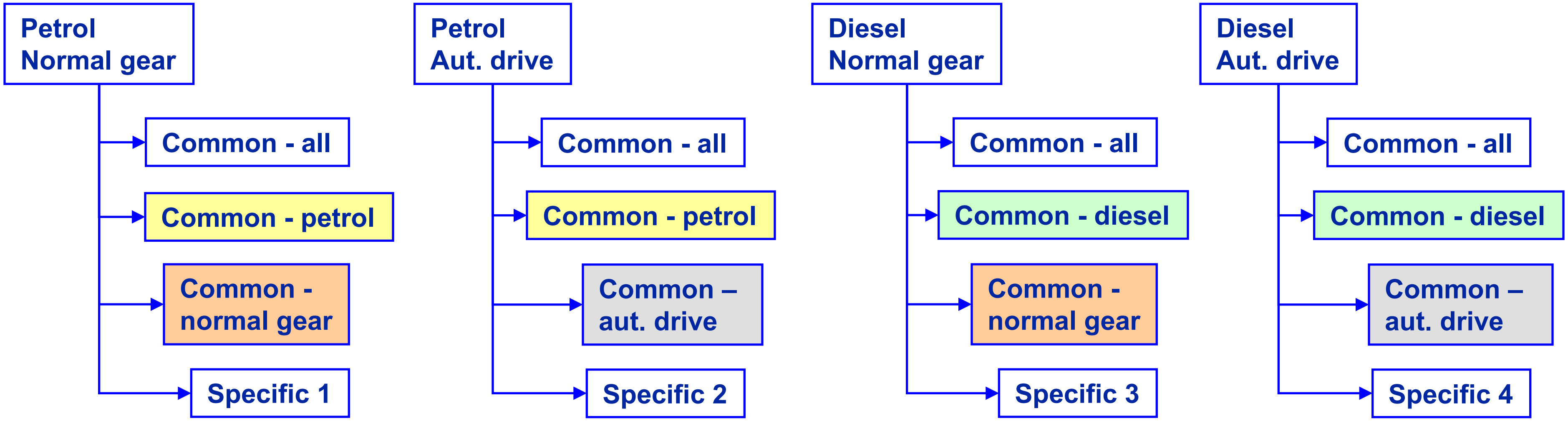
Options	Number of alternatives	Description
Number of wheels	3	4 (2-motion); 4-motion; 1 rear & 2 front
Fuel engine	2	Petrol; diesel
Power	5	20, 60, 80, 120, 200 kW
Gear	2	Normal; automatic drive
Steering	2	Normal; power-steering
Rear tow-hook	3	Normal; strengthened; special
Power takeoff	3	Absent; normal; special

- To fully represent all the available alternatives for this (very simplified) example the (huge) number of bills of materials required is:

3 x 2 x 5 x 2 x 2 x 3 x 3 = 1,080

Super bills

- Data volume is managed through **super bills** (products configurators)
  - Super bills are applied when the finished product is offered with a series of functions, each of them with different options.
- To introduce the planning bills first of all an analysis of the commonalities among components of each option is carried out
  - In the followings, the example of Taurus tractor is considered with reference only to fuel engine and gear options (for the sake of simplicity)


Petrol Normal gear
- Common - all
- Common - petrol
- Common - normal gear
- Specific 1

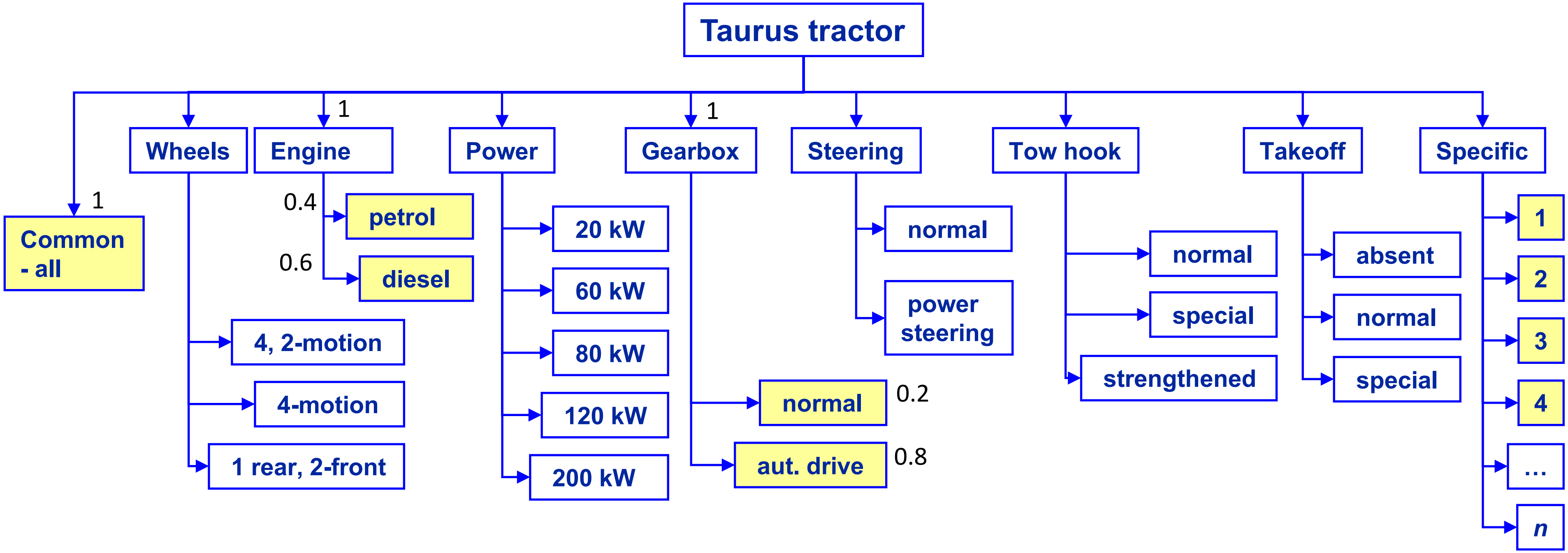
Petrol Aut. drive
- Common - all
- Common - petrol
- Common – aut. drive
- Specific 2

Diesel Normal gear
- Common - all
- Common - diesel
- Common - normal gear
- Specific 3

Diesel Aut. drive
- Common - all
- Common - diesel
- Common – aut. drive
- Specific 4

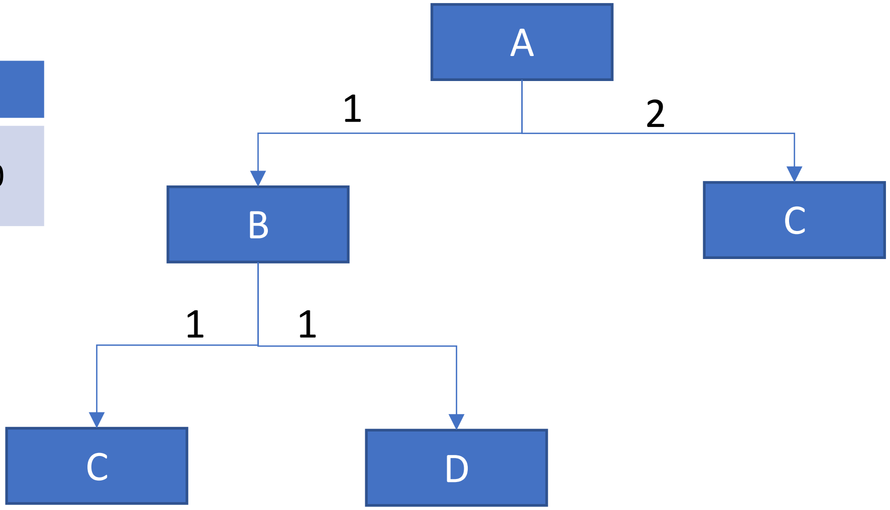
Super bills

- Through the analysis of commonalities, the bills of materials are arranged in modules
  - i.e. modular bills are obtained, which are fictitious (artificial) bills that contain all the codes of one option
- Then, by combining the modules, the super bill is built, considering the coefficient of use as AND (=1) for the functions and OR (e.g. 0.4 and 0.6, 0.2 and 0.8) for the modules



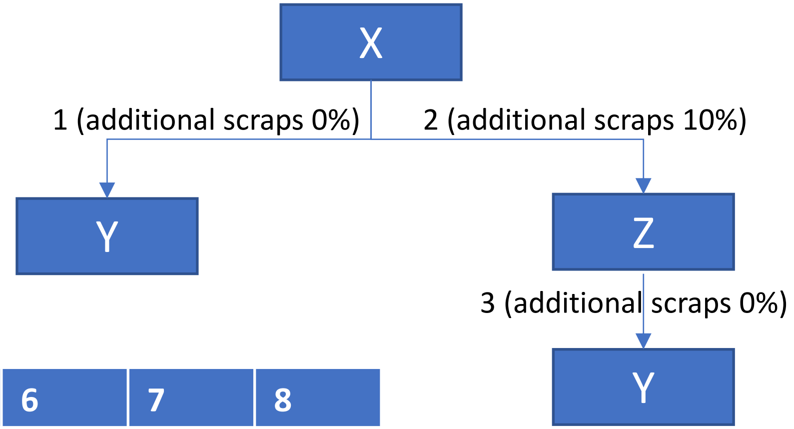
Exercise 1

Week	**1**	**2**	**3**	**4**	**5**
Gross internal requirements (A)	100	150	200	100	100



	A	**B**	**C**	**D**
Lead time [weeks]	1	1	2	2
Re-order policy	EOQ=100	EOQ=200	EOQ=50	EOQ=200
Initial inventory	300	400	500	200
Reserved stock	0	0	0	0
Orders in progress	0	0	200 (week 2)	0
Safety stock (*)	50	0	50	0
Scrap rate	0%	10%	0%	0%

Exercise 2



X

1 (additional scraps 0%)

2 (additional scraps 10%)

Y

Z

3 (additional scraps 0%)

Y

Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross internal requirements (X)	70	120	70	40	60	170	120	30
Gross external requirements (Y)	200	88	48	100	90	80	100	100

	X	**Z**	**Y**
Lead time [weeks]	1	3	2
Re-order policy	EOQ=110	L4L	EOQ=800
Initial inventory	350	400	1600
Reserved stock	110	0	50
Orders in progress	110 (week 3)	50 (week 5)	800 (week 3)
Safety stock (*)	40	100	250
Scrap rate	0%	10%	20%