MIT 2.853/2.854
Introduction to Manufacturing Systems
Material Requirements Planning

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MRP Overview

- *Primary source: Factory Physics* by Hopp and Spearman.

- *Basic idea:* Once the final due date for a product is known, and the time required for each production step is known, then intermediate due dates and material requirement times can be determined.

- *Original goal:* To determine when material for production is required.

MRP Overview

Demand

- ... from outside the system is *independent* demand.
- ... for components or raw material is *dependent* demand.

Before MRP, buyers were not synchronized with producers.

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MRP Overview

- Start at the due date for a finished product (or *end item*) (T_k).

- Determine the last operation, the time required for that operation (t_{k-1}), and the material required for that operation.

- The material may come from outside, or from earlier operations inside the factory.

- Subtract the last operation time from the due date to determine when the last operation should start.

MRP Overview

$$T_{k-1} = T_k - t_{k-1}$$

- The material required must be present at that time.

- Continue working backwards.

- *However, since more than one component may be needed at an operation, the planning algorithm must work its way backwards along each branch of a tree — the* <u>*bill of materials*</u>*.*

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MRP Overview

Planning Algorithm

Time

- In some MRP systems, time is divided into *time buckets* — days, weeks, or whatever is convenient.
- In others, time may be chosen as a continuous variable.

MRP Overview

- What assumptions are being made here ...

  ⋆ ... about predictability?

  ⋆ ... about capacity?

- How realistic are those assumptions?

- Is it more flexible to use time buckets or continuous time?

MRP Overview

- *Push system:* one in which material is loaded based on planning or forecasts, not on *current* demand.

  ★ MRP is a push system.

- *Pull system:* one in which production occurs in response to the consumption of finished goods inventory by demand.

- *Which is better?*

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Bill of Materials (BOM)

Level 0
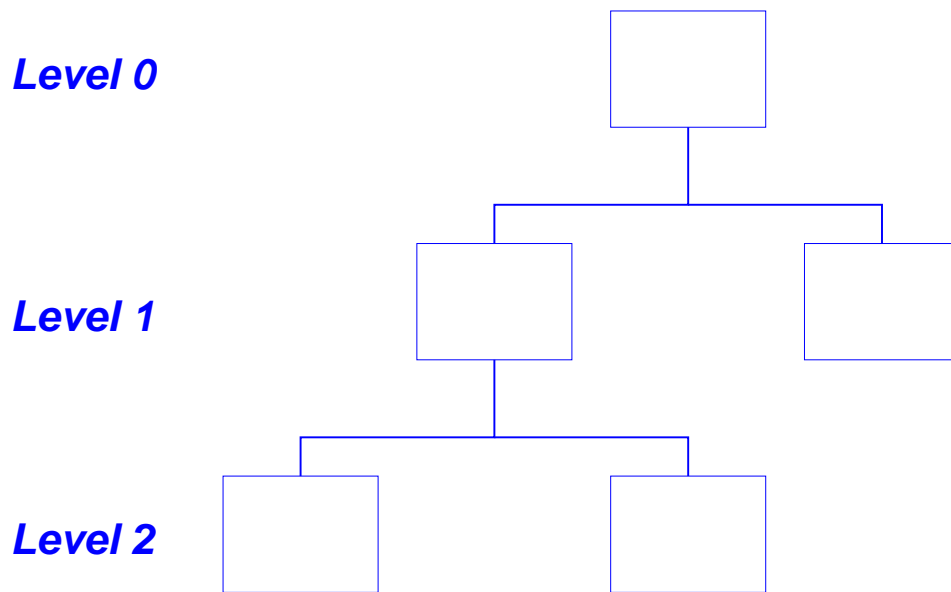
Level 1

Level 2

- Top level is end item.
- Items are given a *low-level code* corresponding to the lowest level they appear at, for any end item in the factory.

The BOM must be maintained as the product mix changes.

Master Production Schedule

- Information concerning independent demand.

- *Gross requirements:* What must be delivered in the future, and when.

- *On-hand inventory:* Finished good already available.

- *Net requirements:* (Gross requirements) – (On-hand inventory).

Master Production Schedule

	Week							
	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

- 15 of the initial 30 units of inventory are used to satisfy Week 1 demand.

- The remaining 15 units are 5 less than required to satisfy Week 2 demand.

Master Production Schedule
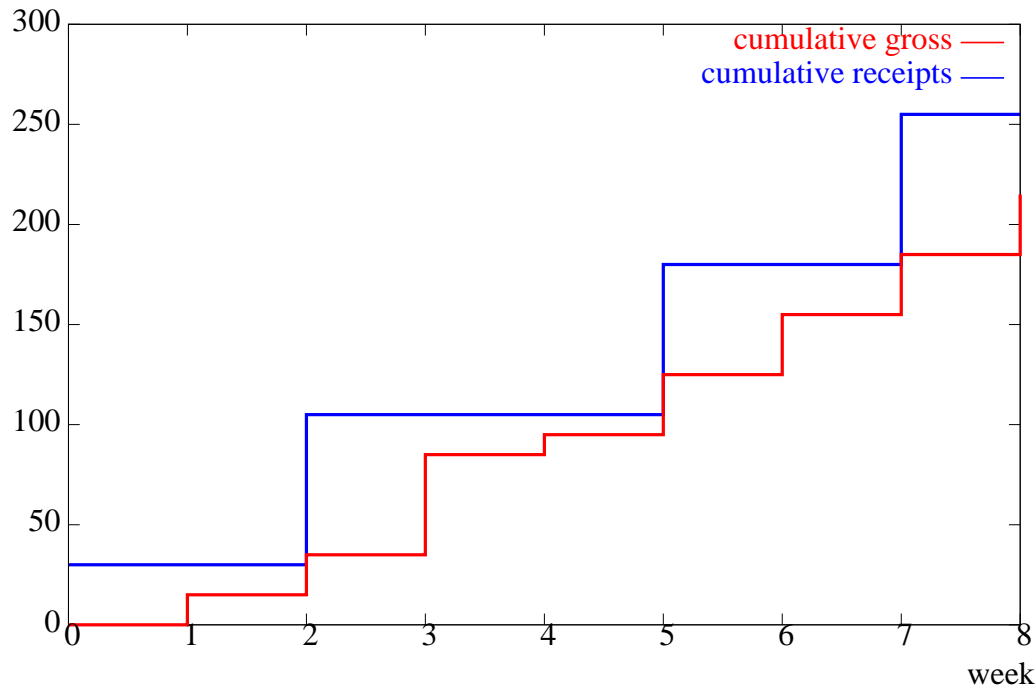
Example

Lot Sizing

- Lot sizes are 75. The first arrival must occur in Week 2.

- 75 units last until Week 4, so plan arrival in Week 5.

- Similarly, deliveries needed in Weeks 5 and 7.

		Week							
		1	2	3	4	5	6	7	8
Gross requirements		15	20	50	10	30	30	30	30
Cumulative gross		15	35	85	95	125	155	185	215
Planned order receipts	30	0	75	0	0	75	0	75	0
Cumulative receipts		30	105	105	105	180	180	255	255

Master Production Schedule

Cumulatives

Material requirements are determined by considering whether inventory would otherwise become negative.

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Master Production Schedule

- Lead times are 1 week. Therefore, order *release* must occur one week before delivery is required.

		Week						
	1	2	3	4	5	6	7	8
Gross requirements	15	20	50	10	30	30	30	30
Cumulative gross	15	35	85	95	125	155	185	215
Planned receipts 30	0	75	0	0	75	0	75	0
Cumulative receipts	30	105	105	105	180	180	255	255
Planned release	75	0	0	75	0	75	0	0

Master Production Schedule

- Now, do exactly the same thing for all the components required to produce the finished goods (level 1).

- Do it again for all the components of those components (level 2).

- Et cetera.

Data

- *Master Production Schedule* — demand – quantities and due dates

- *Item Master File* — for each part number: description, BOM, lot-sizing, planning lead times

- *Inventory Status* – finished goods, work-in-progress

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Data

- *Planned order releases*

- *Change notices*

- *Exception reports* — discrepancies, consequences of unexpected events

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Master Production Schedule

- Define

  - D_t = Demands, or gross requirements for week t

  - S_t = Quantity that will be completed in week t

  - I_t = Projected finished inventory in week t

  - N_t = Net requirements in week t

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- Inventory dynamics: Starting with $t = 1$ (where $t = 0$ means *now*) and incrementing t by 1,

$$I_t = I_{t-1} - D_t, \text{ as long as } I_{t-1} - D_t \geq 0$$

$$I_t = I_{t-1} - D_t + S_t, \text{ if } I_{t-1} - D_t < 0$$

where S_t is minimal amount needed to make the inventory positive, which is consistent with lot-sizing requirements.

Master Production Schedule

- Net requirements: Let t^* be the first time when $I_{t-1} - D_t < 0$. Then,

$$N_t = \begin{cases} 0 & \text{if } t < t^* \\ I_{t-1} - D_t < 0 & \text{if } t = t^* \\ D_t & \text{if } t > t^* \end{cases}$$

- From net requirements, we calculate required production (scheduled receipts) $S_t, t > t^*$.

- S_t is adjusted for new orders or new forecasts.

- Then procedure is repeated for the next T^*.

Master Production Schedule

Netting

Example

		Week								
		1	2	3	4	5	6	7	8
Gross requirements		15	20	50	10	30	30	30	30
Projected on-hand	20	5	5	55	45	15	-15		
Adjusted scheduled receipts			20	100					
Net requirements		0	0	0	0	0	15	30	30

Master Production Schedule

		Week							
		1	2	3	4	5	6	7	8
Gross requirements		15	20	50	10	30	30	30	30
Projected on-hand	20	5	5	55	45	15	-15		
Net requirements		0	0	0	0	0	15	30	30
Scheduled receipts*		10	10		100				
Adjusted scheduled receipts		0	20	100					

original plan

- The 10 units planned for week 1 were *deferred* to week 2.

- The 100 units planned for week 4 were *expedited* to week 3.

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Possible rules:

- *Lot-for-lot:* produce in a period the net requirements for that period. *Maximum* setups.

- *Fixed order period:* produce in a period the net requirements for P periods.

- *Fixed order quantity:* always produce the same quantity, whenever anything is produced. EOQ formula can be used to determine lot size.

Which satisfy the Wagner-Whitin property?

Lot Sizing

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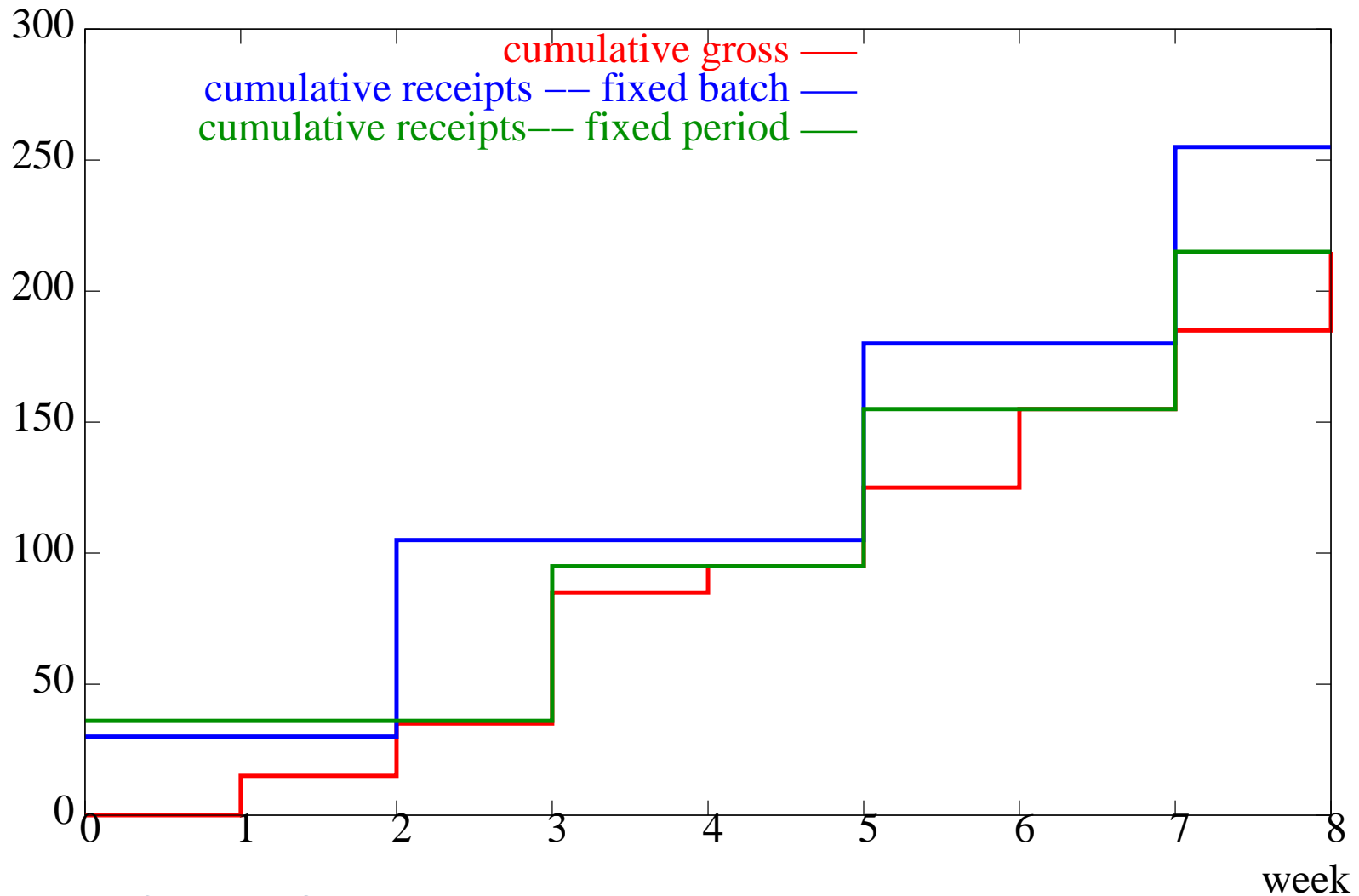
Master Production Schedule

- After scheduling production for all the top level (Level 0) items, do the same for Level 1 items.

- *The planned order releases for Level 0 are the gross requirements for Level 1.*

- Do the same for Level 2, 3, etc.

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Reality

- MRP is deterministic but reality is not. Therefore, the system needs *safety stock* and *safety lead times* .

- Safety stock protects against quantity uncertainties.

  ★ You don't know how much you will make, so plan to make a little extra.

- Safety lead time protects against timing uncertainties.

  ★ You don't know exactly when you will make it, so plan to make it a little early.

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Reality

Uncertainty/Variability

Safety Stock

- Instead of having a minimal planned inventory of zero, the (positive) safety stock is the planned minimal inventory level.

- Whenever the actual minimal inventory differs from the safety stock, adjust planned order releases accordingly.

Reality

Uncertainty/Variability

Safety Lead Time

- Add some extra time to the planned lead time.

Uncertainty/Variability

Yield Loss

- *Yield* = expected fraction of parts started that are successfully produced.

- Actual yield is random.

- If you need to end up with N items, and the yield is y, start with N/y.

- However, the actual production may differ from N, so safety stock is needed.

Reality

- Capacity is actually finite.

- Planned lead times tend to be long (to compensate for variability).

  ★ Also, workers *should* start work on a job as soon as it is released, and relax later (usually possible because of safety lead time). Often, however, they relax first, so if a disruption occurs, the job is late.

Reality

Other problems

Nervousness

- *Nervousness* — drastic changes in schedules due to small deviations from plans — *(chaos?)*

- Nervousness results when a deterministic calculation is applied to a random system, and local perturbations lead to global changes.

Reality

- Possible consequences:

  ★ Drastic changes in plans for the near future, which will confuse workers;

  ★ Excessive setups, consuming excess expense or capacity.

- *Solution:* Freeze the early part of the schedule (ie, the near future). Do not change the schedule even if there is a change in requirements; or do not accept changes in requirements.

  ★ *But:* What price is paid for freezing?

Reality

- *MRP is a solution to a problem whose formulation is based on an unrealistic model,* one which is
  - ★ deterministic
  - ★ infinite capacity
- As a result,
  - ★ it frequently produces non-optimal or infeasible schedules, and
  - ★ it requires constant manual intervention to compensate for poor schedules.
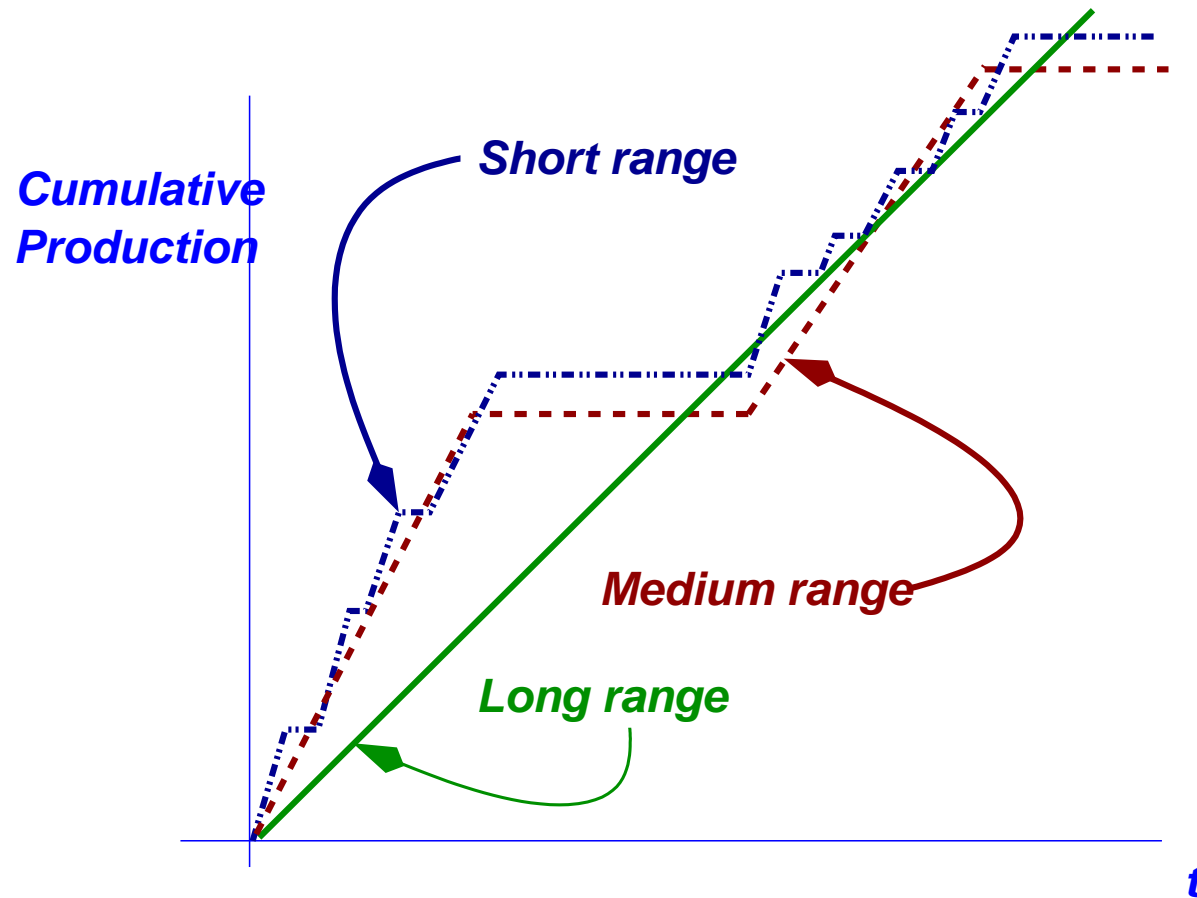- *On top of that, nervousness amplifies inevitable variability.*

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MRP II

- **Manufacturing Resources Planning**
  - ★ MRP, and correction of some its problems,
  - ★ demand management,
  - ★ forecasting,
  - ★ capacity planning,
  - ★ master production scheduling,
  - ★ rough-cut capacity planning,
  - ★ capacity requirements planning (CRP),
  - ★ dispatching,
  - ★ input-output control.

MRP II Hierarchy
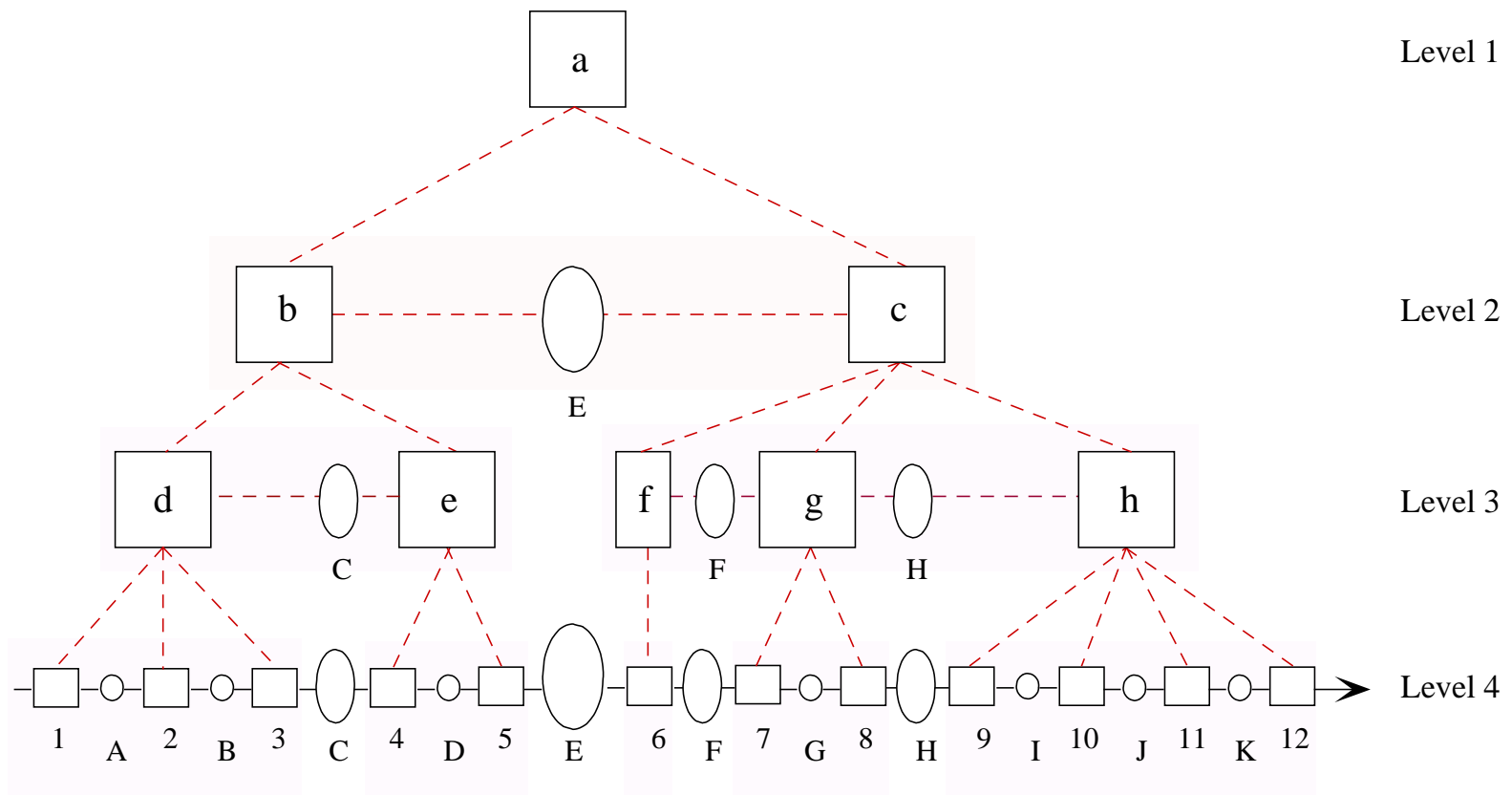
Hierarchical Planning and Scheduling

Cumulative Production

Short range

Medium range

Long range

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Planning/Scheduling/Control Hierarchy

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MRP II Hierarchy
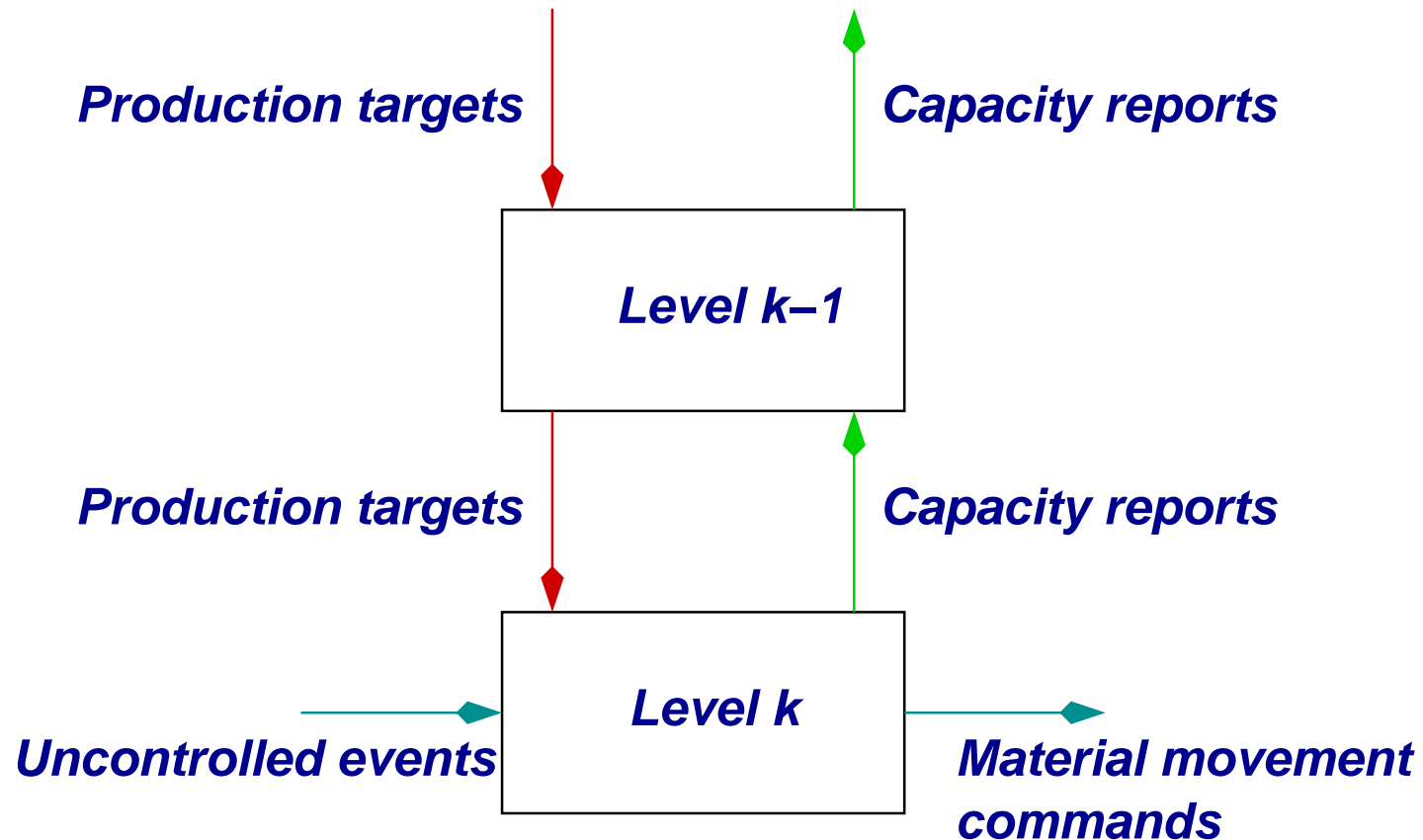
- Higher levels deal with longer time scales and more of the system (scope).

- Higher levels use more aggregated (coarse-grained) models.

- Higher levels send *production targets* down to lower levels.

  ★ Each level refines the target for the level below, with reduced time scale and reduced scope.

  ★ The bottom level actually implements the schedule.

MRP II Hierarchy

MRP II Hierarchy

Hierarchical Planning

Long-Range Planning

- Range: six months to five years.

- Recalculation frequency: 1/month to 1/year.

- Detail: part family.

- Forecasting

- Resource planning — build a new plant?

- Aggregate planning — determines rough estimates of production, staffing, etc.

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MRP II Hierarchy

Hierarchical Planning

Intermediate-Range Planning

- Demand management — converts long range forecast and actual orders into detailed forecast.

- Master production scheduling

- Rough-cut capacity planning — capacity check for feasibility.

- CRP — better than rough cut, but still not perfect. Based on infinite capacity assumption.

MRP II Hierarchy

- Daily Plan

  ★ Production target for the day

- Shop Floor Control

  ★ Job dispatching — which job to run next?

  ★ Input-output control — release

  ★ Often based on simple rules

  ★ Sometimes based on large deterministic mixed (integer and continuous variable) optimization

MRP II Hierarchy

- The high level and low level models sometimes don't match.

  ★ The high level aggregation is not done accurately.

  ★ Actual events make the production target obsolete.

  ★ *Consequence:* Targets may be infeasible or too conservative.

- The short-term schedule may be recalculated too frequently.

  ★ *Consequence:* Instability.

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