

Production Planning and Control

MATERIAL REQUIREMENT PLANNING

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Introduction

Material Requirements Planning

- First widely available software implementation of a manufacturing planning system (IBM 1960's)
- APICS 'MRP Crusade' launched in 1972
 - Quickly became the manufacturing planning paradigm in the U.S.
 - The problems of production planning were all solved, right?
 - By 1989 total sales and support for MRP systems exceeded \$1 Billion

Introduction

- Many products are not single entities, they are composed of subassemblies and parts, some purchased and some manufactured.
- A production plan specifies quantities of each final product (end item), subassemblies, and parts needed at distinct points in time.
- To generate a production plan two things are required: estimates for the end-product demand, and a master production schedule (**MPS**)

MRP Systems

- The inventory control mechanisms we studied to this point are much better for single-item planning
- Many products manufacturers produce have a complex bill-of-materials (recipe of components)
- Demand for components is *dependent* on end-product demand (which we'll call *independent* demand items)
- MRP systems encode the interdependence among various end-items and components

Introduction

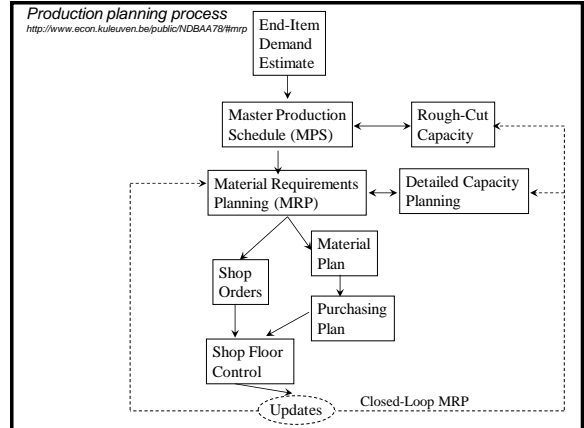
- Forecast independent demand – plan dependent demand
 - The need for one item is created by the need for another item
- The MPS is a delivery plan for the manufacturing organization:
 - includes exact amounts and delivery timings for each end product
 - is derived from the demand estimates, but is not necessarily equal to them
 - MPS must account for manufacturing constraints (such as *capacity*) and on-hand finished-goods inventory

Introduction

- Breaking the MPS into a production schedule for each component of an end-item is achieved by the **material requirements planning (MRP)** system
- The MRP system determines material requirements and timings for each phase of production. Material shortage is another major manufacturing constraint

MRP Overview

- MRP is known as a push system, since it plans production according to forecasts of future demand and pushes out products accordingly
- MRP planning is based on time buckets (or periods)
- Orders (current demand) and forecasts (future demand) for end-items drive the system
- These requirements drive the need for subassemblies and components at lower levels of the bill-of-materials (BOM)



MRP Procedure

- **Purchase orders** – outside orders
- **Jobs** – orders from within the plant
- **Buckets** – time is divided into discrete chunks
- **End items** – finished products
- **Lower-level items** – constituent parts of the end items
- **Bill of material (BOM)** – relationship between end and the lower-level items

MRP Procedure

The basic MRP procedure is simple: for each level in the bill of material, beginning with end items, MRP does the following:

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 level(s)
5. **Iterate:** Repeat these steps until all levels are processed.

MRP Procedure: Lot Sizing

Determining the lot size (order quantity or production quantity) of an item

Static lot sizing rule:

- A decision rule that orders the same quantity each time an order is placed
- Tend to generate higher average on-hand inventory because they create inventory remnants
- Can provide extra *safety stock*

Dynamic lot sizing rule:

- A decision rule that changes the order quantity with each order, typically so that each order is just large enough to prevent shortages over a specified time period
- Tend to cause instability by tying lot-size to gross requirements
- Lower-level components may not be able to respond sufficiently fast to changes in requirements

MRP Procedure: Static Lot Sizing

1. Fixed order quantity (FOQ)

Order (or produce) a fixed quantity, or a multiple of that fixed quantity by combining the net requirements of P periods

If $P = 1$ FOP is equivalent to lot-for-lot (LFL) method

2. Economic Order Quantity (EOQ)

Order (or produce) the economic order quantity, plus any additional items needed to replenish safety stock if it has fallen below its desired level

Yields minimum total setup/ordering costs and the holding costs

Assumes relatively constant demand

MRP Procedure: Dynamic Lot-Sizing

1. Lot-for-Lot (L4L)

Produce exactly the quantity required in each period to satisfy gross requirements, and used if setup cost < carrying cost for 1 period of demand

Simple to use, and agrees with Just-In-Time philosophy of ordering (or producing) only when required

Lot size can be modified easily for purchase discounts or restrictions, scrap allowances, process constraints, etc

Minimizes on-hand inventory, but maximizes number of orders placed (so can be expensive if setup/ordering costs are significant)

MRP Procedure: Dynamic Lot-Sizing

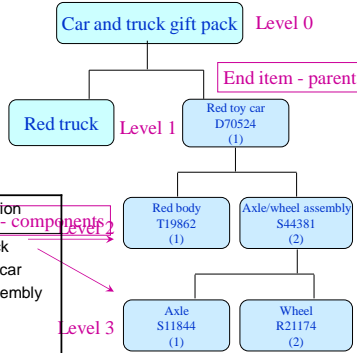
2. Periodic Order Quantity (POQ)

Order (or produce) a quantity equal to the gross requirements for P periods **minus** any items in on-hand inventory **plus** any additional items needed to replenish safety stock if it has fallen below its desired level

Restores safety stock and covers exactly P periods of gross requirements.

When trying to guarantee any level of service for an assembly, the service for the component parts must be much greater

MRP Example 1: The Product Structure Diagram



| Part Number | Description |
|----------------|--------------|
| External Sales | Red truck |
| D70524 | Red toy car |
| S44381 | A/W assembly |
| S11844 | Axle |
| R21174 | Wheel |
| T19862 | Red body |

MRP Example 1: Bill of Materials

| Part Number | Leading Time | Number of Units | Description |
|----------------|--------------|-----------------|-------------------------|
| D63321 | | 1 | Car and truck gift pack |
| External Sales | | 1 | Red truck |
| D70524 | 1 period | 2 | Red toy car |
| S44381 | 2 periods | 1 | A/W assembly |
| S11844 | 3 periods | 2 | Axle |
| R21174 | 1 period | 1 | Wheel |
| T19862 | 1 period | 1 | Red body |

Red toy car is sold in three forms:

- a car and truck gift pack - D63321
- a multicar gift pack - D63322
- an individual item - D70524

One unit of D70524 is used in each of D63321 and D63322

MRP Example 1:

Derivation of Gross Requirements for Car

| Source | Time Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------------|--|---|-----------|-----------|-----------|---|-----------|-----------|-----------|
| Parent | Car and truck gift pack D63321, planned order releases | | 50 | | 20 | | 40 | | 60 |
| Parent | Multicar pack D63322, planned order releases | | | 30 | | | 30 | | |
| External | Regular Pack, D70524, direct external demand for red toy car | | | 10 | | | | 10 | |
| Total | Red toy car, D70524, projected gross requirements | | 50 | 40 | 20 | | 70 | 10 | 60 |

MRP Example 1 (cont):

Material Requirements Plan for Toy Car

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|----|----|----|----|----|----|----|----|----|
| 1. Projected gross requirements | 0 | 0 | 50 | 40 | 20 | 0 | 70 | 10 | 60 |
| 2. Scheduled receipts | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | 10 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4. Net requirements, prior to planned order receipts | 0 | 0 | 40 | 40 | 20 | 0 | 70 | 10 | 60 |
| 5. Planned order receipts | 0 | 0 | 40 | 40 | 20 | 0 | 70 | 10 | 60 |
| 6. Planned order releases | 0 | 40 | 40 | 20 | 0 | 70 | 10 | 60 | 0 |

Lead Time = 1 period

Order quantity = not fixed (use LFL)

MRP Example 1 (cont): Additional Info

- The setup cost for the car assembly operation is \$7.50
- The added variable cost at this operation is \$8 / unit
- The inventory carrying charge is set at 0.005 \$ / \$ / period
- Using EOQ or some heuristic may give some savings comparing to LFL by calculating "best" Q and T

The Silver-Meal, or Least Period Cost, Heuristic

Calculate the average holding and setup cost per period if the current order spans the next T periods as

$$C(T) = \frac{K + \sum_{j=2}^T (j-1)hr_j}{T}, \text{ where } T \geq 2 \text{ and } C(1) = K$$

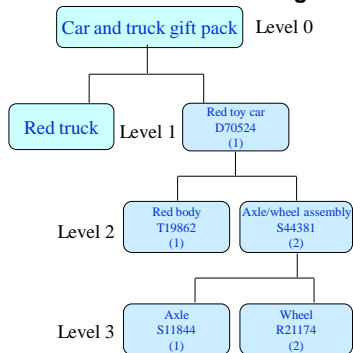
Stop when $C(j) > C(j-1)$, set $Q(1) = \sum_{i=1}^{j-1} r_i$, and begin process again for $Q(j)$

MRP Example 1 (cont): Silver-Meal

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|----|----|----|---|----|----|----|
| 4. Net requirements, prior to planned order receipts, r_t | 0 | 0 | 40 | 40 | 20 | 0 | 70 | 10 | 60 |

- The setup cost for the car assembly operation is \$7.50 $\rightarrow K = 7.5$
- The added variable cost at this operation is \$8 / unit
- The inventory carrying charge is set at 0.005 \$ / \$ / period $\rightarrow h = 0.005 \cdot 8 = 0.04$
- $C(T) = \frac{K + \sum_{j=2}^T (j-1)hr_j}{T}$
- $C(1) = 0$; $C(2) = 7.5$; $C(3) = 4.55$; $C(4) = 3.567$; $C(5) = 2.675$; $C(6) = 4.38$
- Stop: in period 2 order of 100 toy cars (40+40+20+0) should be at hand
- Starting from period 6: $C(6) = 7.5$; $C(7) = 3.95$; $C(8) = 4.233$;
- Stop: in period 6 order of 80 toy cars (70+10) should be at hand
- Starting from period 8: $C(8) = 7.5$;
- Stop, last period: in period 8 order of 60 toy cars (60) should be at hand

MRP Example 1: The Product Structure Diagram



MRP Example 1 (cont): Material Requirements Plan for Toy Car

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|----|-----|-----|----|----|----|----|----|----|
| 1. Projected gross requirements | 0 | 0 | 50 | 40 | 20 | 0 | 70 | 10 | 60 |
| 2. Scheduled receipts | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | 10 | 10 | 60 | 20 | 0 | 0 | 10 | 0 | 0 |
| 4. Net requirements, prior to planned order receipts | 0 | 0 | 40 | 40 | 20 | 0 | 70 | 10 | 60 |
| 5. Planned order receipts | 0 | 0 | 100 | 0 | 0 | 0 | 80 | 0 | 60 |
| 6. Planned order releases | 0 | 100 | 0 | 0 | 0 | 80 | 0 | 60 | 0 |

Lead Time = 1 period Order quantity = not fixed (use Silver-Meal)

The Explosion Calculus

- The explosion calculus is a set of rules for converting the master production schedule to a requirements schedule for all subassemblies, components, and raw materials necessary to produce the end item
- There are two basic operations comprising the explosion calculus:
 - Time phasing.** Requirements for lower level items must be shifted backwards by the lead time required to produce the items
 - Multiplication.** A multiplicative factor must be applied when more than one subassembly is required for each higher level item

Example 1 (cont): MRP for Red Car Body (1 per car)

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|---|-----|---|---|---|----|---|----|---|
| 1. Projected gross requirements | 0 | 100 | 0 | 0 | 0 | 80 | 0 | 60 | 0 |
| 2. Scheduled receipts | 0 | 150 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | | | | | | | | | |
| 4. Net requirements, prior to planned order receipts | | | | | | | | | |
| 5. Planned order receipts | | | | | | | | | |
| 6. Planned order releases | | | | | | | | | |

Lead Time = 1 period Order quantity = not fixed (use LFL)

**Example 1 (cont):
MRP for Red Car Body (1 per car)**

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|---|-----|----|----|----|----|---|----|---|
| 1. Projected gross requirements | 0 | 100 | 0 | 0 | 0 | 80 | 0 | 60 | 0 |
| 2. Scheduled receipts | 0 | 150 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | 0 | 50 | 50 | 50 | 50 | 0 | 0 | 0 | 0 |
| 4. Net requirements, prior to planned order receipts | | | | | | | | | |
| 5. Planned order receipts | | | | | | | | | |
| 6. Planned order releases | | | | | | | | | |

Lead Time = 1 period Order quantity = not fixed (use LFL)

**Example 1 (cont):
MRP for Wheel/Axel Assembly (2 per car)**

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|---|-----|---|---|---|-----|---|-----|---|
| 1. Projected gross requirements | 0 | 200 | 0 | 0 | 0 | 160 | 0 | 120 | 0 |
| 2. Scheduled receipts | 0 | 260 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | | | | | | | | | |
| 4. Net requirements, prior to planned order receipts | | | | | | | | | |
| 5. Planned order receipts | | | | | | | | | |
| 6. Planned order releases | | | | | | | | | |

Lead Time = 2 periods Order quantity = not fixed (use LFL)

**Example 1 (cont):
MRP for Wheel/Axel Assembly (2 per car)**

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|---|-----|----|-----|----|-----|---|-----|---|
| 1. Projected gross requirements | 0 | 200 | 0 | 0 | 0 | 160 | 0 | 120 | 0 |
| 2. Scheduled receipts | 0 | 260 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | 0 | 60 | 60 | 60 | 60 | 0 | 0 | 0 | 0 |
| 4. Net requirements, prior to planned order receipts | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 120 | 0 |
| 5. Planned order receipts | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 120 | 0 |
| 6. Planned order releases | 0 | 0 | 0 | 100 | 0 | 120 | 0 | 0 | 0 |

Lead Time = 2 periods Order quantity = not fixed (use LFL)

**Example 1 (cont):
MRP for Axel (1 per Wheel/Axle Assembly)**

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|-----|-----|-----|-----|---|-----|---|---|---|
| 1. Projected gross requirements | 0 | 0 | 0 | 100 | 0 | 120 | 0 | 0 | 0 |
| 2. Scheduled receipts | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | 150 | 150 | 150 | | | | | | |
| 4. Net requirements, prior to planned order receipts | | | | | | | | | |
| 5. Planned order receipts | | | | | | | | | |
| 6. Planned order releases | | | | | | | | | |

Lead Time = 3 periods Order quantity = 100

**Example 1 (cont):
MRP for Axel (1 per Wheel/Axle Assembly)**

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|-----|-----|-----|-----|----|-----|----|----|----|
| 1. Projected gross requirements | 0 | 0 | 0 | 100 | 0 | 120 | 0 | 0 | 0 |
| 2. Scheduled receipts | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | 150 | 150 | 150 | 50 | 50 | 30 | 30 | 30 | 30 |
| 4. Net requirements, prior to planned order receipts | 0 | 0 | 0 | 0 | 0 | 70 | 0 | 0 | 0 |
| 5. Planned order receipts | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| 6. Planned order releases | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |

Lead Time = 3 periods Order quantity = 100

**Example 1 (cont):
MRP for Wheel (2 per Wheel/Axle Assembly)**

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|------|-----|---|-----|---|-----|---|---|---|
| 1. Projected gross requirements | 0 | 0 | 0 | 200 | 0 | 240 | 0 | 0 | 0 |
| 2. Scheduled receipts | 0 | 260 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | -200 | | | | | | | | |
| 4. Net requirements, prior to planned order receipts | | | | | | | | | |
| 5. Planned order receipts | | | | | | | | | |
| 6. Planned order releases | | | | | | | | | |

Lead Time = 1 period Order quantity = not fixed (use LFL)

Example 1 (cont): MRP for Wheel (2 per Wheel/Axle Assembly)

| Time Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--|------|-----|-----|-----|-----|-----|---|---|---|
| 1. Projected gross requirements | 0 | 0 | 0 | 200 | 0 | 240 | 0 | 0 | 0 |
| 2. Scheduled receipts | 0 | 260 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Projected net inventory at end of period (Net Inventory=(On-hand)-(Backorders)) | -200 | 60 | 60 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4. Net requirements, prior to planned order receipts | 0 | 0 | 0 | 140 | 0 | 240 | 0 | 0 | 0 |
| 5. Planned order receipts | 0 | 0 | 0 | 140 | 0 | 240 | 0 | 0 | 0 |
| 6. Planned order releases | 0 | 0 | 140 | 0 | 240 | 0 | 0 | 0 | 0 |

Lead Time = 1 period

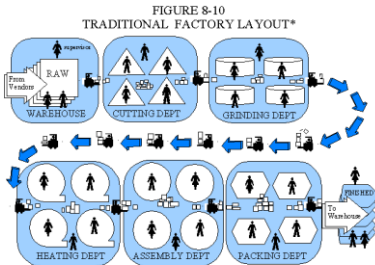
Order quantity = not fixed (use LFL)

Shortcomings of Material Requirement Plan

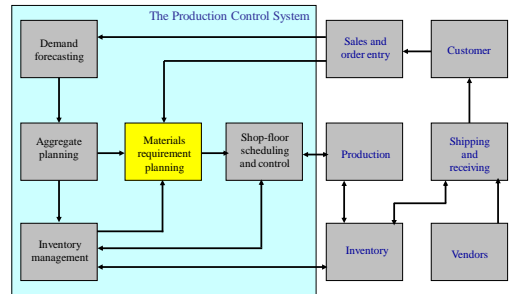
- **Uncertainty:** MRP ignores demand uncertainty, supply uncertainty, and internal uncertainties that arise in the manufacturing process
- **Capacity Planning:** Basic MRP does not take capacity constraints into account
- **Rolling Horizons:** MRP is treated as a static system with a fixed horizon of n periods. The choice of n is arbitrary and can affect the results
- **Lead Times Dependent on Lot Sizes:** In MRP lead times are assumed fixed, but they clearly depend on the size of the lot required
- **Quality Problems:** Defective items can destroy the linking of the levels in an MRP system
- **Data Integrity:** Real MRP systems are big (perhaps more than 20 levels deep) and the integrity of the data can be a serious problem
- **Order Pegging:** A single component may be used in multiple end items, and each lot must then be pegged to the appropriate item

Why Push and Pull?

- MRP is the classic *push* system. The MRP system computes production schedules for all levels based on forecasts of sales of end items. Once produced, subassemblies are *pushed* to next level whether needed or not.

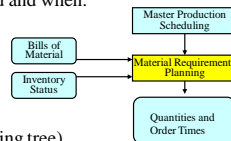


MRP in Production Planning and Control



Material Requirements Planning

Given a master schedule, what raw materials and components quantities are needed and when.



Requires:

- Bill of material (Manufacturing tree)
- Inventory status
- Lead times

Assumptions

1. Known deterministic demands.
2. Fixed, known production leadtimes.
3. Infinite capacity.

Idea is to "back out" demand for components by using leadtimes and bills of material.

MRP Procedure

1. **Netting:** net requirements against projected inventory
2. **Lot Sizing:** planned order quantities
3. **Time Phasing:** planned orders backed out by leadtime
4. **BOM Explosion:** gross requirements for components

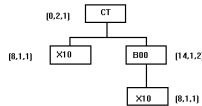
Inputs

- **Master Production Schedule (MPS):** due dates and quantities for all top level items
- **Bills of Material (BOM):** for all parent items
- **Inventory Status:** (on hand plus scheduled receipts) for all items
- **Planned Leadtimes:** for all items

Material Requirements Planning

Example

Consider the manufacturing tree (BOM) and the accompanying information.



| Period | GR |
|--------|----|
| 1 | 10 |
| 2 | 15 |
| 3 | 12 |
| 4 | 16 |
| 5 | 15 |
| 6 | 12 |
| 7 | 18 |
| 8 | 14 |

| Period | Scheduled Order Receipts (SOR) | | | | | | | |
|--------|--------------------------------|----|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| CT | 12 | 14 | 0 | 0 | 0 | 0 | 0 | 0 |
| B00 | 8 | 2 | 2 | 0 | 0 | 0 | 0 | 0 |
| X10 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 |

Material Requirements Planning

Example

CT
LT = 2

| Time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------|----|----|----|----|----|----|----|----|
| GR | 10 | 15 | 12 | 16 | 15 | 12 | 18 | 14 |
| SOR | 12 | 14 | 0 | 0 | 0 | 0 | 0 | 0 |
| BI | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| NR | -2 | -1 | 11 | 16 | 15 | 12 | 18 | 14 |
| POR | 0 | 0 | 11 | 16 | 15 | 12 | 18 | 14 |
| EI | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| PORE | 11 | 16 | 15 | 12 | 18 | 14 | ? | ? |

B00
LT = 1

| Time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------|----|----|----|----|----|----|---|---|
| GR | 22 | 32 | 30 | 24 | 36 | 28 | ? | ? |
| SOR | 8 | 2 | 2 | 0 | 0 | 0 | 0 | 0 |
| BI | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NR | 0 | 30 | 28 | 24 | 36 | 28 | ? | ? |
| POR | 0 | 30 | 28 | 24 | 36 | 28 | ? | ? |
| EI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PORE | 30 | 28 | 24 | 36 | 28 | ? | ? | ? |

Material Requirements Planning

Example

X10
LT = 1

| Time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------|----|----|----|----|----|----|---|---|
| GR | 41 | 44 | 39 | 48 | 44 | 14 | ? | ? |
| SOR | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 |
| BI | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NR | 31 | 42 | 38 | 47 | 44 | 14 | 0 | 0 |
| POR | 31 | 42 | 38 | 47 | 44 | 14 | 0 | 0 |
| EI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PORE | 42 | 38 | 47 | 44 | 14 | 0 | 0 | ? |

33 X10 cannot be scheduled.

How many CTs will be affected?

How can we fix the problem?

Rough Cut Capacity Planning (RCCP)

- Quick check on capacity of key resources
- Use Bill of Resource (BOR) for each item in MPS
- Generates usage of resources by exploding MPS against BOR (offset by lead times)
- Infeasibilities addressed by altering MPS or adding capacity (e.g., overtime)