# Inventory Management

## Material Requirements Planning

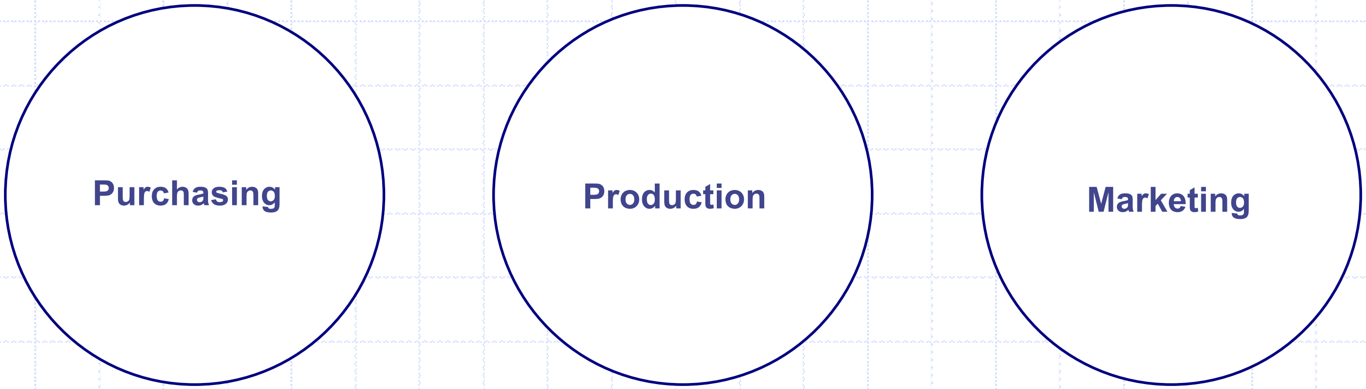
Lecture 10
ESD.260 Fall 2003

Caplice

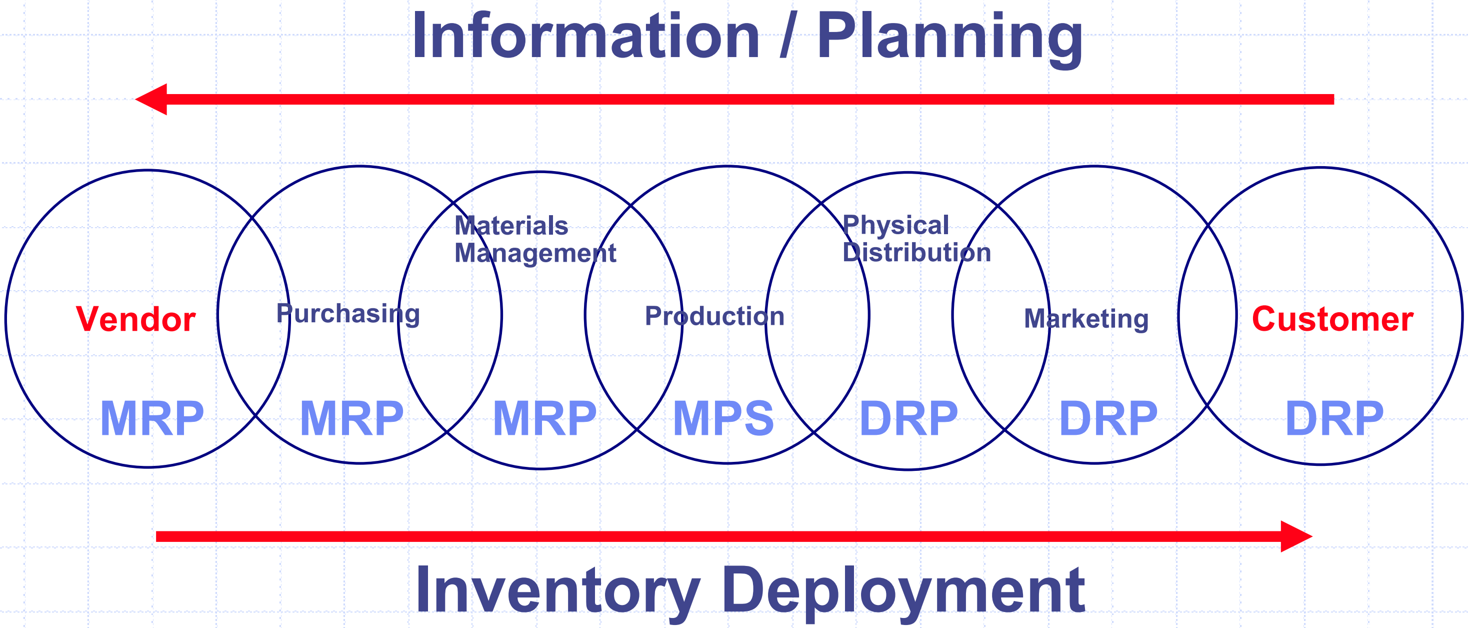
# Assumptions: Basic MRP Model

- Demand
  - Constant vs **Variable**
  - **Known** vs Random
  - Continuous vs **Discrete**
- Lead time
  - Instantaneous
  - **Constant** or **Variable** (deterministic/stochastic)
- Dependence of items
  - Independent
  - Correlated
  - **Indentured**
- Review Time
  - **Continuous** vs Periodic
- Number of Echelons
  - **One** vs Many
- Capacity / Resources
  - **Unlimited** vs Limited
- Discounts
  - **None**
  - All Units or Incremental
- Excess Demand
  - **None**
  - All orders are backordered
  - Lost orders
  - Substitution
- Perishability
  - **None**
  - Uniform with time
- Planning Horizon
  - Single Period
  - **Finite Period**
  - Infinite
- Number of Items
  - One
  - **Many**

# Traditional Management



# Supply Chain Integration



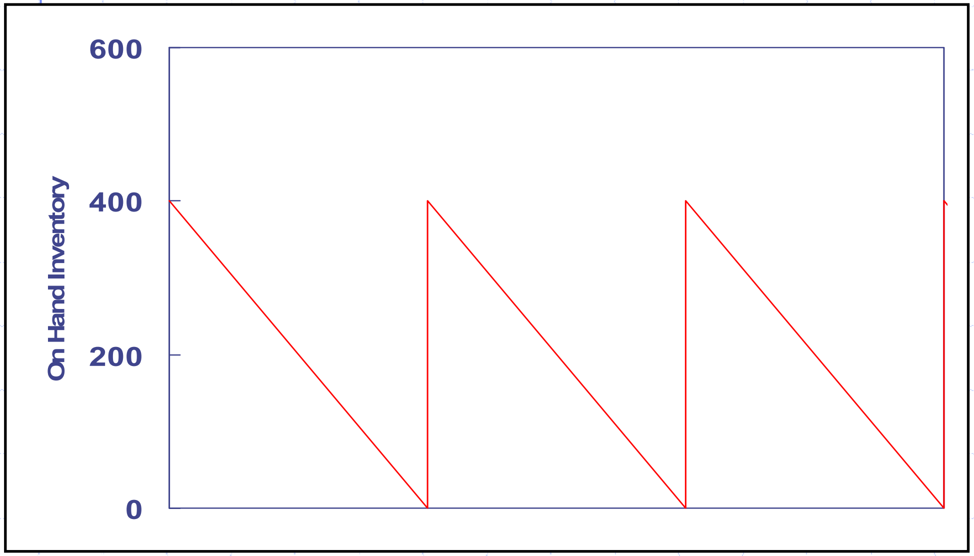

Material Requirements Planning
Master Production Scheduling
Distribution Requirements Planning

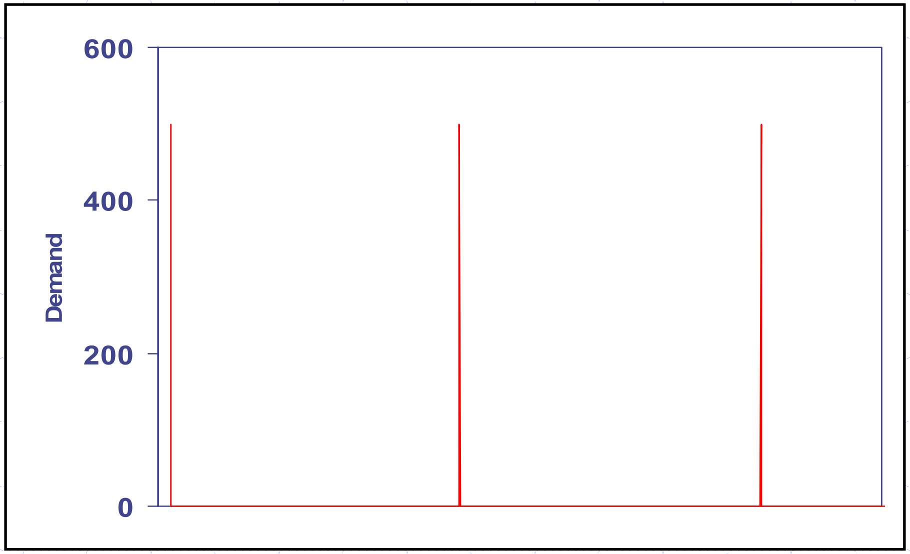
# Inventory Management so far . . .

- Traditional techniques . . .
  - Forecast demand independently for each item based on usage history
  - Establish lot sizes independently for each item based on demand forecasts
  - Establish safety stocks independently for each item based on forecast errors
- Which make the following assumptions . . .
  - Demand is "Continuous"
    [usage occurs in every period]
  - Demand is "Uniform"
    [average usage per period is stable over time]
  - Demand is "Random"
    [usage in any given period is not known in advance]

# Cycle Stock with a Fixed Lot Size

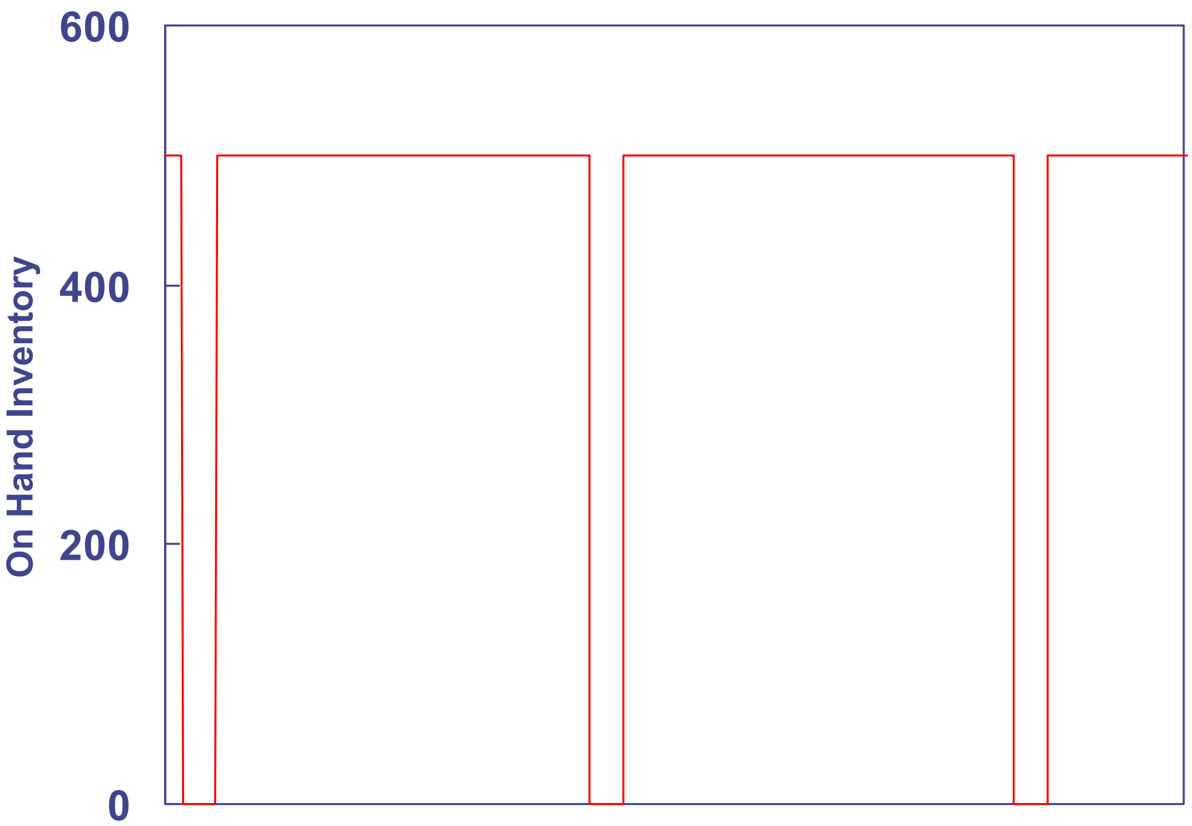
Co= \$500, Ch=25%, Cp= \$50,
D = 2000 units/yr, **Q*=400 units**




Problem: Intermittent Demand
4 production periods, 500 units/period,
Demand rate 2000/year

# Fixed Lot Size with Intermittent Demand results in . . .




Can we do better?

# Another Wrinkle . . . Product Indenture

- Bicycle Model 1234
  - Frame
    - Fork
    - Front fender
    - Rear Fender
    - Sprocket
    - Crank
    - Pedal
    - Chain guard
  - Front Wheel
    - Rim
    - Axle
    - Spoke
    - Tire
    - Tube
  - Saddle
    - Shaft
    - Seat
    - Cover
  - Rear Wheel
    - Rim
    - Axle
    - Spoke
    - Tire
    - Tube
    - Sprocket
  - Handlebars
    - Bar
    - Gooseneck
    - Grip

Note that each item, sub-assembly, component etc. might feed into multiple end products

# Push versus Pull Systems

- Simple Example
  - You make shovels that have 4 parts:
    - Metal Digger
    - Wooden Pole
    - 2 Screws
  - Production is 100 shovels per week:
    - Metal part is made in 400 item batches on first 2 days of the month
    - Handles are procured from Pole Co.
    - Assembly occurs during first week of each month
  - How should I manage my inventory for screws?
    - Co=\$0.25, Cp=\$0.01,
    - Ch=25%, D = 800*12=9600 units
    - LT = 1 week, d' =~192 units

# Push versus Pull Systems

- Simple Example
  - Following standard EOQ?
    - Order ~1400 (~every other month)
    - What would the Inv On Hand look like?
  - Use a (Q,R) System?
    - So, since $\sigma = 350$, pick k=3
    - R=192 + (3)350 = 1242
  - Other methods?
- Push vs Pull Systems
  - Push – MRP
    - "initiates production in anticipation of future demand"
  - Pull – JIT
    - "initiates production as a reaction to present demand"

# Material Requirements Planning

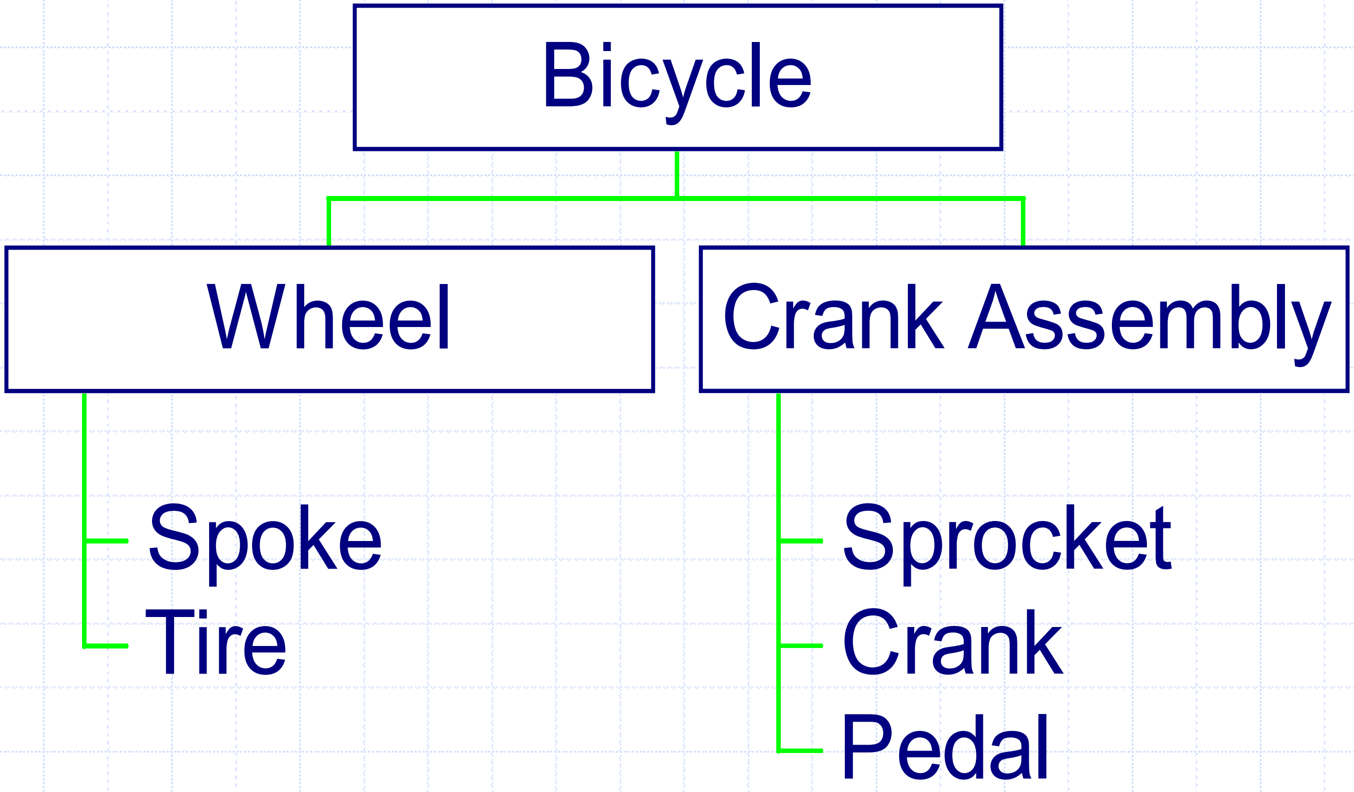
- Major Premises
  - Inventory control in a production environment
  - Many products, many component parts
  - Complex product indenture structure
  - Production creates "lumpy" demand

- Major Concepts
  - Dependent demand versus independent demand
  - Requirements calculation versus demand forecasting
  - Schedule flow versus stockpile assets
  - Information replaces inventory

# Material Requirements Planning

- Primary Questions
  - What are we going to make? => use forecast
  - What does it take to make it? => use res. req's & BOM
  - What do we have? => use inventory records
  - What do we need and when? => use mfg schedules
- Information Requirements
  - Master Production Schedule
  - Product Indenture Structure
  - Inventory Status
  - Ordering Data
- MRP Process
  - Requirements Explosion
  - Net from Gross Requirements
  - Requirements Time Phasing
  - Planned Order Release

# Example: Bike Co.



# Bill of Materials

| Product | Sub-assembly | Component | Quantity | Lead Time |
|---|---|---|---|---|
| Bicycle | | | [1] | 2 |
| | Wheel | | 2 | 1 |
| | | Spoke | 86 | 3 |
| | | Tire | 1 | 2 |
| | Crank Asm | | 1 | 1 |
| | | Sprocket | 1 | 4 |
| | | Crank | 2 | 3 |
| | | Pedal | 2 | 3 |

Gross Requirement

On Hand

Net Requirement

Planned Order Release

| Item | Period: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Bicycle | GR | | | | | | | | 25 |
| | OH | | | | | | | | |
| | NR | | | | | | | | 25 |
| | POR | | | | | | 25 | | |
| Wheel | GR | | | | | | 50 | | |
| | OH | | | | | | | | |
| | NR | | | | | | 50 | | |
| | POR | | | | | 50 | | | |
| Spoke | GR | | | | | 4300 | | | |
| | OH | | | | | | | | |
| | NR | | | | | 4300 | | | |
| | POR | | 4300 | | | | | | |
| Tire | GR | | | | | 50 | | | |
| | OH | | | | | | | | |
| | NR | | | | | 50 | | | |
| | POR | | | 50 | | | | | |
| Crank Asm | GR | | | | | | 25 | | |
| | OH | | | | | | | | |
| | NR | | | | | | 25 | | |
| | POR | | | | | 25 | | | |
| Sprocket | GR | | | | | 25 | | | |
| | OH | | | | | | | | |
| | NR | | | | | 25 | | | |
| | POR | 25 | | | | | | | |
| Crank | GR | | | | | 50 | | | |
| | OH | | | | | | | | |
| | NR | | | | | 50 | | | |
| | POR | | 50 | | | | | | |
| Pedal | GR | | | | | 50 | | | |
| | OH | 20 | 20 | 20 | 20 | 20 | | | |
| | NR | | | | | 30 | | | |
| | POR | | 30 | | | | | | |

# The MRP Plan for the Bicycle

| ITEM | PERIOD: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Bicycle | Rqmt | | | | | | | | 25 |
| | On Hand | | | | | | | | |
| | Due In | | | | | | | | 25 |
| | POR | | | | | | 25 | | |
| | | | | | | | | | |
| Wheel | Rqmt | | | | | | 50 | | |
| | On Hand | | | | | | | | |
| | Due In | | | | | | 50 | | |
| | POR | | | | | 50 | | | |
| | | | | | | | | | |
| Spoke | Rqmt | | | | | 4300 | | | |
| | On Hand | | | | | | | | |
| | Due In | | | | | 4300 | | | |
| | POR | | 4300 | | | | | | |

# The MRP Plan for the Bicycle

| ITEM | PERIOD: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Bicycle | Rqmt | | | | | | | | 25 |
| | POR | | | | | | 25 | | |
| | | | | | | | | | |
| Wheel | Rqmt | | | | | | 50 | | |
| | POR | | | | | 50 | | | |
| | | | | | | | | | |
| Spoke | Rqmt | | | | | 4300 | | | |
| | POR | | 4300 | | | | | | |
| | | | | | | | | | |
| Tire | Rqmt | | | | | 50 | | | |
| | POR | | | 50 | | | | | |
| | | | | | | | | | |
| Crank Asm | Rqmt | | | | | | 25 | | |
| | POR | | | | | 25 | | | |
| | | | | | | | | | |
| Sprocket | Rqmt | | | | | 25 | | | |
| | POR | 25 | | | | | | | |
| | | | | | | | | | |
| Crank | Rqmt | | | | | 50 | | | |
| | POR | | 50 | | | | | | |
| | | | | | | | | | |
| Pedal | Rqmt | | | | | 50 | | | |
| | POR | | 30 | | | | | | |

# Two Issues

- How do we handle capacity constraints?

- How do we handle uncertainty?
  - Safety Stock
    - Add to existing stock
    - Where would this be applied?
  - Safety Times
    - Pad the planned lead times
    - Where would this be applied?

# Optimal Lead Time Padding

Let:

| | |
|---|---|
| $t$ | = Delivery Time, a random variable |
| $t'$ | = Forecasted Delivery Time |
| $\sigma$ | = Standard Deviation of the Forecast Error |
| $T_p$ | = Padded Lead time = $t' + k\sigma$ |
| $Q$ | = Lot Size in units |
| $C_p$ | = Unit Cost |
| $C_{hp}$ | = Holding Cost per unit per time period |
| $C_d$ | = Shortage Cost per time period |

$$TC[T_p] = \sum_{t=0}^{T_p} C_{hp} Q\left(T_p - t\right) P[t] + \sum_{t=T_p+1}^{\infty} C_d (t - T_p) P[t]$$

$$SL^* = \frac{C_d}{C_d + C_{hp} Q}$$

# Optimal Lead Time Padding

Example:

| | | | |
|---|---|---|---|
| $C_p$ | = \$5.00/unit | $Q$ | = 1000 units |
| $C_h$ | = 36% annual | $t'$ | = 10 days |
| $C_{hp}$ | = .005 dollars/unit/day | $\sigma$ | = 3 days |
| $C_d$ | = \$500 per day | ($t \sim$ normal) | |

$$SL^* = (500/(500+5)) = 0.99$$

$$K^* = 2.33$$

$$T_p^* = 10 + (2.33 \times 3) = 17 \text{ days}$$

# MRP: Consider Capacity Restrictions

| C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAL COST | | | | | | | | | | | | |
| $ 10,500.00 | | | | | | SIMPLE MRP SOLUTION | | | | | | |
| END ITEM | | Lead Time | | 2 | | | | | | | | |
| $ 7,000.00 | | Setup | | $ 1,000 | | | | | | | | |
| | | Holding | | $ 5.00 | | | | | | | | |
| | | Capacity | | 1000 | | | | | | | | |
| | | | | | | | | | | | | |
| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Gross Rqmt | 0 | 0 | 0 | 0 | 0 | 30 | 50 | 200 | 30 | 70 | 180 | 40 |
| Begin Inv | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ORDER | | | 0 | 0 | 0 | 30 | 50 | 200 | 30 | 70 | 180 | 40 |
| Ending Inv | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| POR | 0 | 0 | 0 | 30 | 50 | 200 | 30 | 70 | 180 | 40 | 0 | 0 |
| | | | | | | | | | | | | |
| COMPONENT | | Lead Time | | 2 | | | | | | | | |
| $ 3,500.00 | | QPA | | 3 | | | | | | | | |
| | | Setup | | $ 500 | | | | | | | | |
| | | Holding | | $ 1.00 | | | | | | | | |
| | | Capacity | | 2000 | | | | | | | | |
| | | | | | | | | | | | | |
| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Gross Rqmt | 0 | 0 | 0 | 90 | 150 | 600 | 90 | 210 | 540 | 120 | 0 | 0 |
| Begin Inv | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ORDER | 0 | 0 | 0 | 90 | 150 | 600 | 90 | 210 | 540 | 120 | 0 | 0 |
| Ending Inv | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| POR | 0 | 90 | 150 | 600 | 90 | 210 | 540 | 120 | 0 | 0 | 0 | 0 |

# MRP: Consider Capacity Restrictions

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAL COST | | | | | | | | | | | | |
| $ 5,800.00 | | | | | OPTIMIZE THE ITEM SCHEDULES | | | | | | | |
| END ITEM | | Lead Time | 2 | | | | | | | | | |
| $ 4,300.00 | | Setup | $ 1,000 | | [NO BINDING CAPACITY RESTRICTIONS] | | | | | | | |
| | | Holding | $ 5.00 | | | | | | | | | |
| | | Capacity | 1000 | | | | | | | | | |
| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Gross Rqmt | 0 | 0 | 0 | 0 | 0 | 30 | 50 | 200 | 30 | 70 | 180 | 40 |
| Begin Inv | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 100 | 70 | 0 | 40 |
| ORDER | | | 0 | 0 | 0 | 80 | 0 | 300 | 0 | 0 | 220 | 0 |
| Ending Inv | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 100 | 70 | 0 | 40 | 0 |
| POR | 0 | 0 | 0 | 80 | 0 | 300 | 0 | 0 | 220 | 0 | 0 | 0 |
| COMPONENT | | Lead Time | 2 | | | | | | | | | |
| $ 1,500.00 | | QPA | 3 | | | | | | | | | |
| | | Setup | $ 500 | | | | | | | | | |
| | | Holding | $ 1.00 | | | | | | | | | |
| | | Capacity | 2000 | | | | | | | | | |
| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Gross Rqmt | 0 | 0 | 0 | 240 | 0 | 900 | 0 | 0 | 660 | 0 | 0 | 0 |
| Begin Inv | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ORDER | 0 | 0 | 0 | 240 | 0 | 900 | 0 | 0 | 660 | 0 | 0 | 0 |
| Ending Inv | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| POR | 0 | 240 | 0 | 900 | 0 | 0 | 660 | 0 | 0 | 0 | 0 | 0 |

WB! Status | Sheet1 | Sheet2 | Sheet3

# MRP: Consider Capacity Restrictions

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAL COST | | | | | | | | | | | | |
| $ 7,660.00 | | | | | | OPTIMIZE ITEM SCHEDULES | | | | | | |
| END ITEM | | Lead Time | | 2 | | | | | | | | |
| $ 4,300.00 | | Setup | | $ 1,000 | | [Component capacity constraint binding] | | | | | | |
| | | Holding | | $ 5.00 | | | | | | | | |
| | | Capacity | | 1000 | | | | | | | | |
| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| GR | 0 | 0 | 0 | 0 | 0 | 30 | 50 | 200 | 30 | 70 | 180 | 40 |
| BINV | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 100 | 70 | 0 | 40 |
| ORDER | | | 0 | 0 | 0 | 80 | 0 | 300 | 0 | 0 | 220 | 0 |
| EINV | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 100 | 70 | 0 | 40 | 0 |
| POR | 0 | 0 | 0 | 80 | 0 | 300 | 0 | 0 | 220 | 0 | 0 | 0 |
| COMPONENT | | Lead Time | | 2 | | | | | | | | |
| $ 3,360.00 | | QPA | | 3 | | | | | | | | |
| | | Setup | | $ 500 | | | | | | | | |
| | | Holding | | $ 1.00 | | | | | | | | |
| | | Capacity | | 400 | | | | | | | | |
| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| GR | 0 | 0 | 0 | 240 | 0 | 900 | 0 | 0 | 660 | 0 | 0 | 0 |
| BINV | 0 | 0 | 0 | 0 | 100 | 500 | 0 | 0 | 260 | 0 | 0 | 0 |
| ORDER | 0 | 0 | 0 | 340 | 400 | 400 | 0 | 260 | 400 | 0 | 0 | 0 |
| EINV | 0 | 0 | 0 | 100 | 500 | 0 | 0 | 260 | 0 | 0 | 0 | 0 |
| POR | 0 | 340 | 400 | 400 | 0 | 260 | 400 | 0 | 0 | 0 | 0 | 0 |

Introduce binding constraint

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# MRP: Consider Capacity Restrictions

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAL COST | | | | | | | | | | | | |
| $ 8,700.00 | | | | | OPTIMIZE ITEM SCHEDULES | | | | | | | |
| END ITEM | | Lead Time | | 2 | | | | | | | | |
| $ 4,800.00 | | Setup | | $ 1,000 | [Component capacity constraint "more binding"] | | | | | | | |
| | | Holding | | $ 5.00 | | | | | | | | |
| | | Capacity | | 1000 | NOTE: Component constraint redefines the End Item schedule. | | | | | | | |

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GR | 0 | 0 | 0 | 0 | 0 | 30 | 50 | 200 | 30 | 70 | 180 | 40 |
| BINV | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 | 70 | 0 | 40 |
| ORDER | | | 0 | 0 | 0 | 80 | 0 | 200 | 100 | 0 | 220 | 0 |
| EINV | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 | 70 | 0 | 40 | 0 |
| POR | 0 | 0 | 0 | 80 | 0 | 200 | 100 | 0 | 220 | 0 | 0 | 0 |

| | | | |
|---|---|---|---|
| COMPONENT | | Lead Time | 2 |
| $ 3,900.00 | | QPA | 3 |
| | | Setup | $ 500 |
| | | Holding | $ 1.00 |
| | | Capacity | 300 |

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GR | 0 | 0 | 0 | 240 | 0 | 600 | 300 | 0 | 660 | 0 | 0 | 0 |
| BINV | 0 | 0 | 0 | 0 | 60 | 360 | 60 | 60 | 360 | 0 | 0 | 0 |
| ORDER | 0 | 0 | 0 | 300 | 300 | 300 | 300 | 300 | 300 | 0 | 0 | 0 |
| EINV | 0 | 0 | 0 | 60 | 360 | 60 | 60 | 360 | 0 | 0 | 0 | 0 |
| POR | 0 | 300 | 300 | 300 | 300 | 300 | 300 | 0 | 0 | 0 | 0 | 0 |

WB! Status | Sheet1 | Sheet2 | Sheet3

# MRP: Consider Capacity Restrictions

A1 =

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAL COST | | | | | | | | | | | | |
| $ 9,100.00 | | | | | NON-OPTIMAL SEQUENTIAL SOLUTION | | | | | | | |
| END ITEM | | Lead Time | 2 | | | | | | | | | |
| $ 4,300.00 | | Setup | $ 1,000 | | | | | | | | | |
| | | Holding | $ 5.00 | | | | | | | | | |
| | | Capacity | 1000 | | | | | | | | | |
| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| GR | 0 | 0 | 0 | 0 | 0 | 30 | 50 | 200 | 30 | 70 | 180 | 40 |
| BINV | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 100 | 70 | 0 | 40 |
| ORDER | | | 0 | 0 | 0 | 80 | 0 | 300 | 0 | 0 | 220 | 0 |
| EINV | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 100 | 70 | 0 | 40 | 0 |
| POR | 0 | 0 | 0 | 80 | 0 | 300 | 0 | 0 | 220 | 0 | 0 | 0 |
| COMPONENT | | Lead Time | 2 | | | | | | | | | |
| $ 4,800.00 | | QPA | 3 | | | | | | | | | |
| | | Setup | $ 500 | | | | | | | | | |
| | | Holding | $ 1.00 | | | | | | | | | |
| | | Capacity | 300 | | | | | | | | | |
| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| GR | 0 | 0 | 0 | 240 | 0 | 900 | 0 | 0 | 660 | 0 | 0 | 0 |
| BINV | 0 | 0 | 0 | 300 | 360 | 660 | 60 | 60 | 360 | 0 | 0 | 0 |
| ORDER | 0 | 0 | 300 | 300 | 300 | 300 | 0 | 300 | 300 | 0 | 0 | 0 |
| EINV | 0 | 0 | 300 | 360 | 660 | 60 | 60 | 360 | 0 | 0 | 0 | 0 |
| POR | 300 | 300 | 300 | 300 | 0 | 300 | 300 | 0 | 0 | 0 | 0 | 0 |

WB! Status | Sheet1 | Sheet2 | Sheet3

# Benefits of MRP

- Lower Inventory Levels
  - Able to better manage components
  - Increased visibility
- Fewer Stock outs
  - Relationships are defined and explicit
  - Allows for coordination with MPS
- Less Expediting
  - Due to increased visibility
- Fewer Production Disruptions
  - Input needs are explicitly modeled
  - Plans are integrated

# Shortcomings of MRP

- MRP is a scheduling, not a stockage, algorithm
  - Replaces the forecasting mechanism
  - Considers indentured structures
- MRP does not address how to determine lot size
  - Does not explicitly consider costs
  - Wide use of Lot for Lot in practice
- MRP systems do not inherently deal with uncertainty
  - User must enter these values – by item by production level
  - Typical use of "safety time" rather than "safety stock"
- MRP assumes constant, known leadtimes
  - By component and part and production level
  - But lead time is often a function of order size and other activity
- MRP does not provide incentives for improvement
  - Requires tremendous amount of data and effort to set up
  - Initial values are typically inflated to avoid start up issues
  - Little incentive to correct a system "that works"

# MRP: Evolution of Concepts

- Simple MRP
  - Focus on "order launching"
  - Used within production – not believed outside
- Closed Loop MRP
  - Focus on production scheduling
  - Interacts with the MPS to create feasible plans
- MRP II [Manufacturing Resource Planning]
  - Focus on integrated financial planning
  - Treats the MPS as a decision variable
  - Capacity is considered (Capacity Resource Planning)
- Enterprise Resource Planning Systems
  - Common, centralized data for all areas
  - Implementation is costly and effort intensive
  - Forces business rules on companies