IE 472

Operations of Manufacturing Systems

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	IE 472 **Operations of Manufacturing Systems** **Spring 2011** **Dr Ateekh-Ur-Rehman**	

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Purpose:

This course deals with the study of recent developments in manufacturing, Japanese manufacturing techniques, hybrid manufacturing management system, supply chain management, total quality management, design for manufacturing and assembly. Objective is to provide an opportunity to the student to gain in-depth knowledge of ERP, Just in time, Push – Pull and hybrid production systems, total quality manufacturing, and Supply chain management. In fact, it leads one towards lean manufacturing that meets high throughput or service demands with little inventory.

Textbooks:

1) Factory Physics by Wallace J. Hopp and Mark L. Spearman, McGraw-Hill, 2001.
2) Manufacturing Planning and Control by Vollmann, Barry and Whybark, 1997, McGraw-Hill.

Grades:

Course will be determined by the following weights:

Attendance	5%
Weekly Examination	15%
Mid-term Examination	25%
Lecturer	15%
Final Exam	40%

Course Outline:

1. Introduction to Operations and advancement of/in manufacturing system (Book Chapter 1)
2. Inventory Models Material requirements planning, manufacturing resource planning, enterprise resource planning (Book Chapters 1 and 2)
3. Just in time: History of JIT system, Why JIT, Classic Kanban system, Kanban Cards, Lessons from JIT (Book Chapter 4)
4. Science of Manufacturing, Basic Factory Dynamics, Operations and manufacturing variability (Book Chapters 6, 7 and 8)
5. Push (MRP), Pull (Kanban) and Hybrid (CONWIP) production systems (Book Chapter 10)
6. Supply chain management: managing raw materials, managing WIP, managing finished goods inventory, multi-echelon supply chains

Chapter 1: Introduction to Operations and Advancement in Manufacturing Systems

Manufacturing System?

Definition:

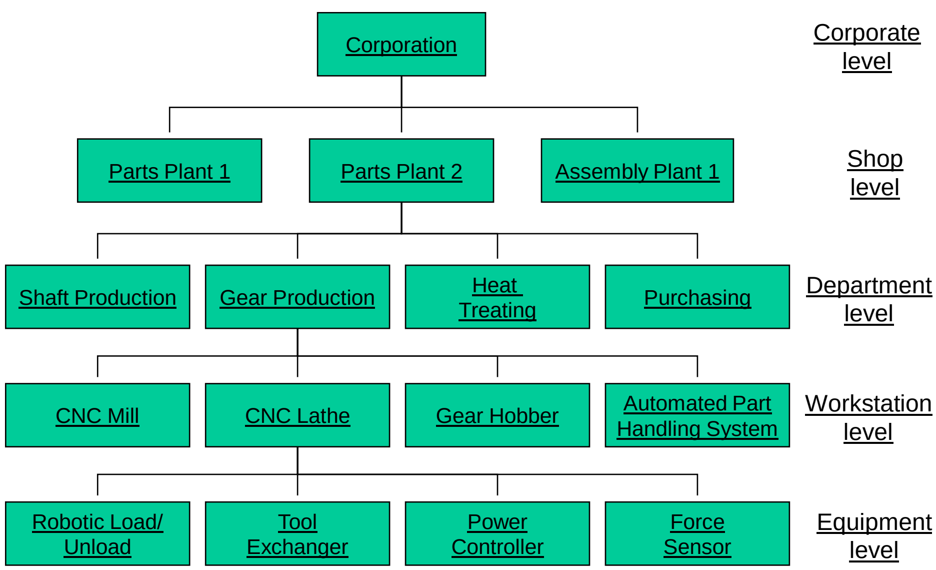
- The set of resources and procedures involved in converting raw material into products and delivering them to customers
- Production/Manufacturing and delivery of products are central to the firm
- Firm Functions have value only if they enhance the ability to do profit

Manufacturing System Objectives?

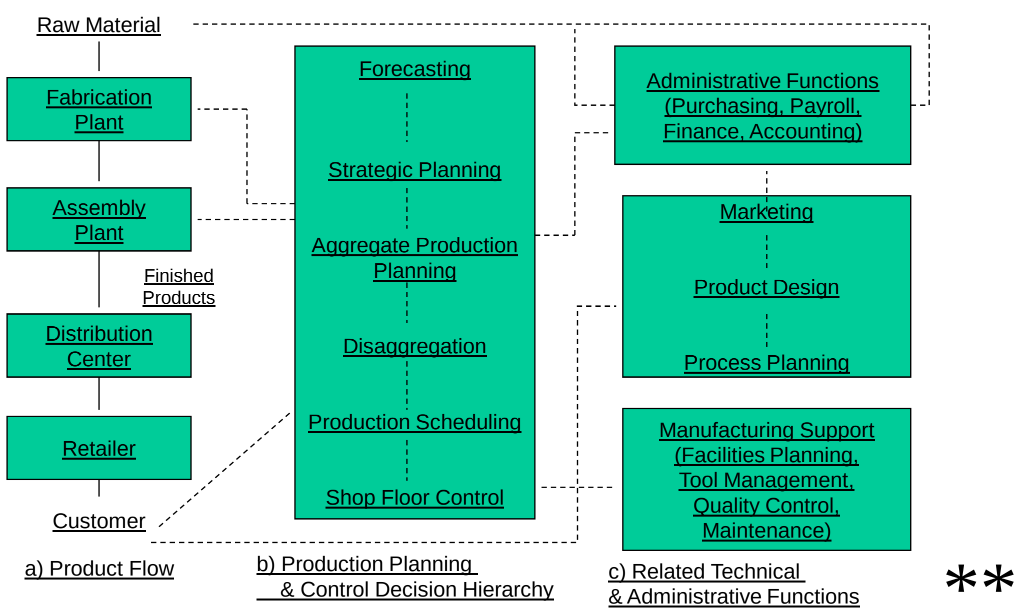
Planning and execution of the activities that use workers, energy, information, and equipment to convert raw materials into finished products

Deliver products with the desired functions, aesthetics, and quality to the customers at right place and the right time and for right cost

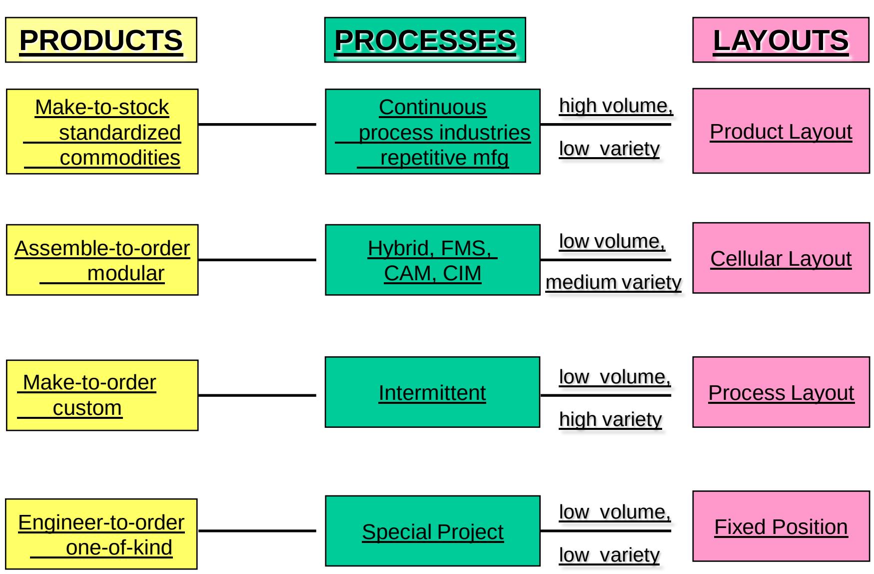
System Components and Hierarchy



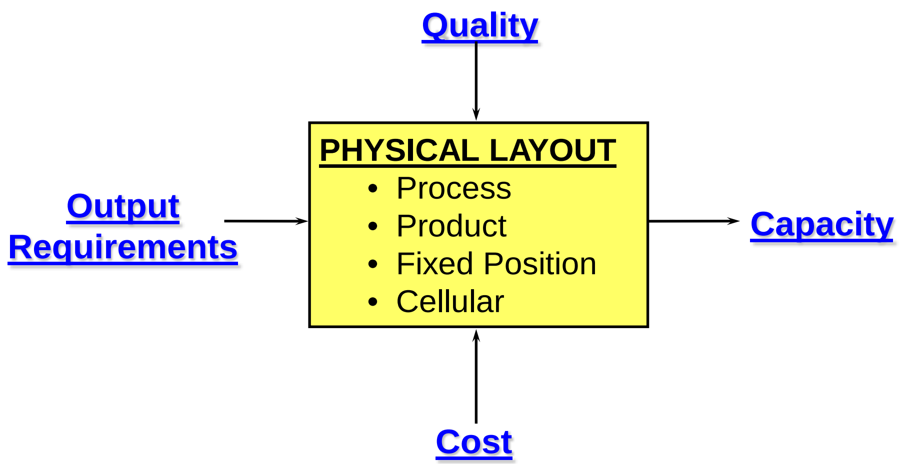
Production Activity and Information Flows



Products, Processes, and Layouts

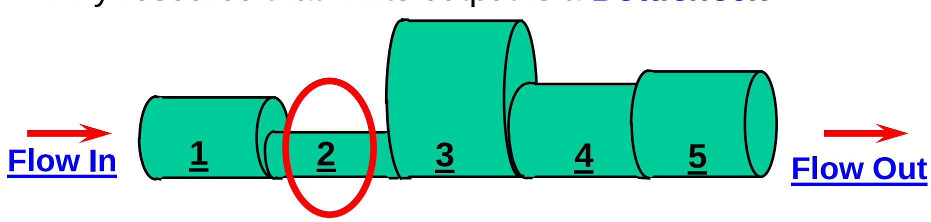


The Layout Function



Key Resources

- Labor
- Equipment
- Any resource that limits output is a ***Bottleneck***

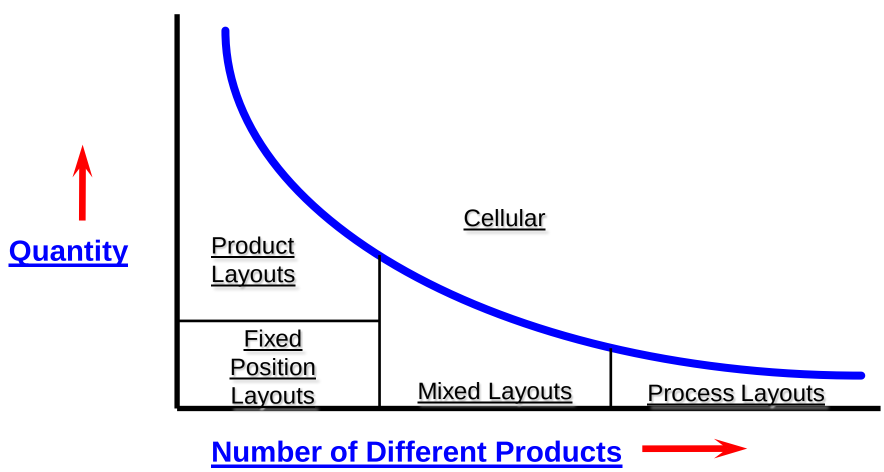


- Assembly and light manufacturing are labor-intensive
  - Equipment small and inexpensive
  - Capacity can be modified by hiring and training workers or through layoffs

Production Authorization

- **Make-to-stock**
  - Number of units of each product to keep on hand at all times
  - Quick delivery to customers upon receipt of an order
  - When delivery response time is a key competitive factor
  - Limited number of products manufactured repeatedly
  - An idea what customers will want
  - Allows to schedule production in advance
- **Make-to-order**
  - Only produce items after they have been ordered
  - Production system must respond quickly
  - Products have high degree of customization
  - Shelf life of products is short
- **Assemble-to-order**
  - Assembled to form variety of configurations

Product Volume and Variety



Recent Developments in Operations of Manufacturing Systems

- **Inventory Models**
- **MRP-I**
- **MRP-II**
- **ERP**
- **OPT**
- **JIT**
- **KANBAN**
- **CONWIP**
- **TQM**
- **SQC**
- **SCM**

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Modeling Matters!

I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but have scarcely, in your thoughts, advanced to the stage of Science, whatever the matter may be.

- Lord Kelvin

Why Models?

State of world:

- Data (not information!) overload
- Reliance on computers
- Allocation of responsibility (must justify decisions)

Decisions and numbers:

- Decisions are numbers
  - How many distribution centers do we need?
  - Capacity of new plant?
  - No. workers assigned to line?
- Decisions depend on numbers
  - Whether to introduce new product?
  - Make or buy?
  - Replace MRP with Kanban?

Why Models? (cont.)

Data + Model = Information: Managers who don't understand models either:

- Abhor analysis, lose valuable information, or
- Put too much trust in analysis, are swayed by stacks of computer output

END

Chapter 2

Inventory Models
Material Requirement Planning
Manufacturing Resource Planning
Enterprise Resource Planning

The Role of Inventory

Inventory consists of physical items moving through the production system

Originates with shipment of raw material and parts from the supplier

Ends with delivery of the finished products to the customer

Costs of storing inventory accounts for a substantial proportion of manufacturing cost

- Often 20% or more

Optimal level of inventory

- Allows production operations to continue smoothly

A common control measure is *Inventory Turns*

Inventory Definitions and Decisions

Batch or order size

- Batch size is the number of units released to the shop floor to be produced

Reorder point

- Specifies the timing for placing a new order

Inventory Position

Inventory Position = Inventory On Hand + On Order – Backorders

Units on order

- Have been ordered but not yet arrived

Backorders

- Items promised to customers but not yet shipped
- New units are shipped out to cancel backorders

Inventory Definitions and Decisions (Cont)

Lead time

- Time between placing an order and the availability of those items for use

Cycle time

- Time between producing or ordering successive batches of an item

$$\text{Cycle time} = \frac{\text{Batch Size}}{\text{Demand Rate}} \frac{(\text{units})}{(\frac{\text{units}}{\text{time}})}$$

- **Safety Stock (SS)**
  - Number of units of inventory on hand when order arrives
  - SS = Reorder level – Lead time * Mean demand rate

Types of Inventory

Raw Materials

- Essential to the production process
- Often kept in large quantities on site

Finished Goods

- Completed products awaiting shipment to customers

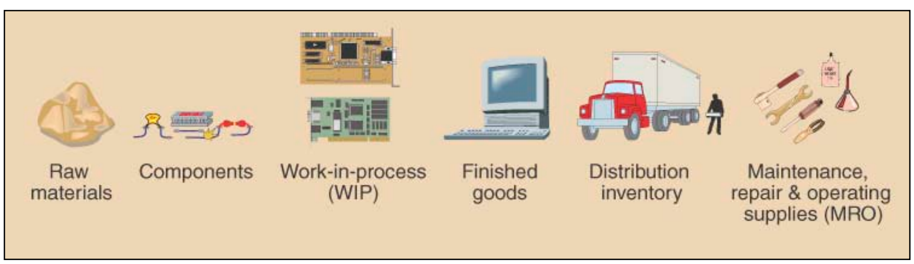
Work-in-Process (WIP)

- Batches of semi finished products currently in production
- Batches of parts from time of release until finished goods status

Pipeline

- Goods in transit between facilities
- Raw materials being delivered to the plant
- Finished goods being shipped to warehouse or customer

Types of Inventory



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EOQ Modeling Assumptions

1. *Production is instantaneous* – there is no capacity constraint and the entire lot is produced simultaneously.
2. *Delivery is immediate* – there is no time lag between production and availability to satisfy demand.
3. *Demand is deterministic* – there is no uncertainty about the quantity or timing of demand.
4. *Demand is constant over time* – in fact, it can be represented as a straight line, so that if annual demand is 365 units this translates into a daily demand of one unit.
5. *A production run incurs a fixed setup cost* – regardless of the size of the lot or the status of the factory, the setup cost is constant.
6. *Products can be analyzed singly* – either there is only a single product or conditions exist that ensure separability of products.

Notation

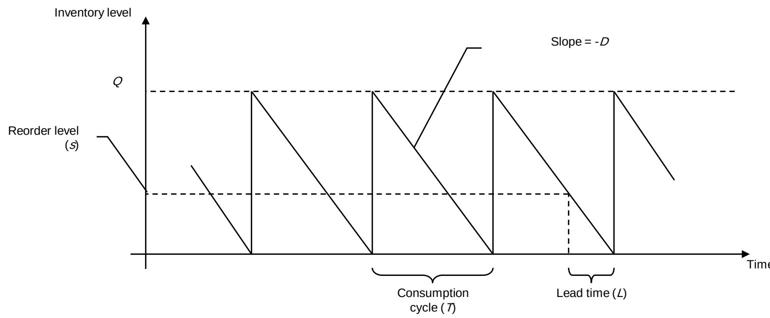
D demand rate (units per year)

C unit production cost, not counting setup or inventory costs (SR per unit)

A fixed or setup cost to place an order (SR)

h holding cost (SR per year); if the holding cost is consists entirely of interest on money tied up in inventory, then $h = iC$ where i is an annual interest rate.

Q the *unknown* size of the order or lot ⇐ *decision variable*



Costs

Holding Cost:

$$\text{average inventory} = \frac{Q}{2}$$

$$\text{annual holding cost} = \frac{hQ}{2}$$

$$\text{unit holding cost} = \frac{hQ}{2D}$$

Setup Costs: A per lot, so

$$\text{unit setup cost} = \frac{A}{Q}$$

Production Cost: c per unit

Cost Function:

$$\boxed{Y(Q) = \frac{hQ}{2D} + \frac{A}{Q} + c}$$

Economic Order Quantity

$$0 = \frac{dY(Q)}{dQ} = \frac{h}{2D} - \frac{A}{Q^2} \quad \Rightarrow \quad Q^2 = \frac{2AD}{h} \quad \Rightarrow \quad Q = \sqrt{\frac{2AD}{h}}$$

$$\forall Q \geq 0, \frac{d^2Y(Q)}{dQ^2} = \frac{2A}{Q^3} \geq 0 \quad \Rightarrow \quad Q^* \text{ is a minimum.}$$

$$\boxed{Q^* = \sqrt{\frac{2AD}{h}}}$$

EOQ Square Root Formula

Total cost TC(Q)= $A \times \frac{D}{Q} + h \times \frac{Q}{2} + c \times D$

Accordingly TRC(Q) =* $\sqrt{2ADh}$

Exercises 1

Q1: A gift shop sells dolls stuffed at a very steady pace of 10 per day, 310 days per year. The wholesale cost of the dolls is SR 5, and the shop uses an annual interest rate of 20 percent to compute holding costs.

a) If the shop wants to place an average of 20 replenishment orders per year, what order quantity should it use?
b) If the shop orders dolls in quantities of 100, what is the implied fixed order cost?
c) If the shop estimates the cost of placing a purchase order to be $10, what is the optimal order quantity?

Q2: Quarter-inch stainless-steel bolts, one and one-half inches long are consumed in a factory at a fairly steady rate of 60 per week. The bolts cost the plant two cents each. It costs the plant SR 12 to initiate an order, and holding costs are based on an annual interest rate of 25 percent. Determine the optimal number of bolts for the plant to purchase and the time between placements of orders. What is the yearly holding and setup cost for this item?

Q3: Reconsider the bolt example in Problem 2. Suppose that although we have estimated demand to be 60 per week, it turns out that it is actually 120 per week (i.e., we have a 100 percent forecasting error).

a) If we use the lot size calculated in the previous problem (using the erroneous demand estimate), what will the setup plus holding cost be under the true demand rate?
b) What would the cost be if we had used the optimum lot size?
c) What percentage increase in cost was caused by the 100 percent demand forecasting error? What does this tell you about the sensitivity of the EOQ model to errors in the data?

Q4: A Hyper Mall sells 8000 Samsung brand TV screens per year. Each screen carries a variable cost of SR 8, while the fixed cost to restock the shelves amounts to SR 10. Assume the cost of capital is 10%.

a) Calculate the Economic Order Quantity (EOQ) and the corresponding number of annual orders
b) Calculate the Total Cost (TC) associated with the EOQ calculated in part (a).
c) Calculate the best order quantity now, considering a 10% discount on orders greater than or equal 200.

Q5: A production line is currently used to produce three different models of a washing machine (W1, W2 and W3). The production line needs to be reconfigured (set up) by changing dies on presses every time a different model is decided to be produced. This setup process consumes almost constant time for all product models. Accordingly, the setup cost of the production line has been estimated at SR500. The unit production costs and annual demand for the washing machine models are given in the table below. The cost of capital is 15%.

	W1	W2	W3
Unit cost (SR/unit)	500	350	200
Annual demand (units/year)	10,000	15,000	30,000

a) Determine the economic production quantity for each washing machine model.
b) If the management decided to use a quicker technique for setting up the dies on presses which will reduce the setup cost to SR50, show how this decision will affect the economic production quantities and comment on your calculated values.

Q6: Al Jameel Steel, Inc. fabricates various products from two basic inputs, bar stock and sheet stock. Bar stock is used at a steady rate of 1,000 units per year and costs SR 200 per bar. Sheet stock is used at a rate of 500 units per year and costs SR 150 per sheet. The company uses a 20 percent annual holding cost rate, and the fixed cost to place an order is SR 50, of which SR 10 is the cost of placing the purchase order and SR 40 is the fixed cost of a truck delivery. The variable (i.e., per unit charge) trucking cost is included in the unit price. The plant runs 365 days per year.

a) Use the EOQ formula with the full fixed order cost of SR 50 to compute the optimal order quantities, order intervals, and annual cost for bar stock and sheet stock. What fraction of the total annual (holding plus order) cost consists of fixed trucking cost?
b) Using a week (seven days) as the base interval, round the order intervals for bar stock and sheet stock to the nearest power of 2. If you charge the fixed trucking fee only once for deliveries that coincide, what is the annual cost now?
c) Leave the order quantity for bar stock as in part b, but reduce the order interval for sheet stock to match that of bar stock. Re-compute the total annual cost and compare to part b.

Topics

- The definition of the lot sizing problem
- Differences from the EOQ model
- Solution algorithms
  - Lot-for-lot
  - Fixed order quantity
  - Fixed order period
  - Fixed EOQ

Lot Sizing Problem

- The lot sizing problem is concerned with determining the order quantity and the period in which an order will be placed to satisfy given demand requirements for that period in the planning horizon.

Difference from EOQ

- The lot sizing problem does not require that the demand rate is constant and fixed throughout the planning horizon as in case of EOQ.
- Incase of lot sizing problem demand rate is not constant throughout the planning horizon
- The demand replenishments are made at specific points in time.
- Demand occurs at discrete points of time and it is not continuous.
- Different cost parameters may exist at each period

Notations

t = A time period (day, week or month), where t = 1,…, T, where T represents the planning horizon.

D_t = Demand in period t

c_t = Unit production cost (purchase cost) in SR/unit, not counting setup (ordering) cost

A_t = Setup (order) cost to produce (purchase) a lot in period t (in SR)

h_t = Holding cost (SR/unit/period)
If it depends solely on the cost of capital, it is calculated as
$h_t = i\, c_t$ / (no. of periods per year)

I_t = Inventory in units leftover at the end of period t

Q_t = size (in units) ordered in period t for all t = 1,…, T

Exercises 2

Q1: Consider the R-mall, where a item carries a variable cost of SR 0.50, while the fixed cost to restock the shelves amounts to SR 4. Assume the cost of capital is 8%. If the actual forecasted demand values throughout the year is given by the following table:

Month	1	2	3	4	5	6	7	8	9	10	11	12
Demand	80	64	56	50	45	35	5	0	70	65	60	70

Determine when and how much to order such that the total cost is minimized

{Hint: Use algorithms for lot for lot, FOQ, FOP, Fixed EOQ, and Improved EOQ and compare total cost}

Q2: Consider the following demand information for a specific inventory item.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Demand	20	50	40	70	60	30	80	40	20	60	40	90

If the inventory carrying cost is SR 0.50 per unit per month and the purchase order cost is SR50 per order, determine the total inventory and ordering costs over the 12 months if the EOQ and FOP (of 3 periods) lot-sizing rules are used. Which lot-sizing rule gives the lower cost?

Q3: Consider an item with the following properties:
A = SR50; v = SR4.00/unit; i = 0.36 SR/SR/year.
At time 0, the inventory has dropped to zero and replenishment with negligible lead-time must be made. The demand pattern for the next 12 months is:

Month	1	2	3	4	5	6	7	8	9	10	11	12
Demand	100	75	50	100	50	40	80	80	0	50	75	100

All the requirements of each month must be available at the beginning of the month. Replenishments are restricted to the beginning of each month. Using each of the following methods, develop a list of orders to meet the demand and determine the total cost of the order schedule. In each case, there should be no inventory at the end of month 12.

a) One replenishment at the start of month 1 to cover all the demand requirements
b) Lot-for-lot
c) Fixed EOQ
d) Fixed order period of 3 months

Q4: Consider the following demand information for a specific inventory item.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Demand	20	50	40	70	60	30	80	40	20	60	40	90

If the inventory carrying cost is SR 0.50 per unit per month and the purchase order cost is SR50 per order, determine the total inventory and ordering costs over the 12 months if the EOQ and FOP (of 3 periods) lot-sizing rules are used. Which lot-sizing rule gives the lower cost?

Q 5: Consider an inventory item with the following properties:
A = SR50; c = SR4.00/unit; i = 0.36 SR/SR/year
At time 0, the there was no inventory. The demand pattern for the next 6 months is:

Month	1	2	3	4	5	6
Demand	100	75	50	100	50	40

All the requirements of each month must be available at the beginning of the month. Replenishments are restricted to the beginning of each month. Using the fixed EOQ lot-sizing rule, develop a list of orders to meet the demand and determine the total cost of the order schedule. There should be no inventory at the end of month 6.

EOQ Assumptions

1. Instantaneous production.
2. Immediate delivery.
3. Deterministic demand.
4. **Constant demand.** ⟸ ***WW model relaxes this one***
5. Known fixed setup costs.
6. Single product or separable products.

Dynamic Lot Sizing Notation

t a period (e.g., day, week, month); we will consider $t = 1, \ldots, T$, where T represents the *planning horizon*.

D_t demand in period t (in units)

c_t unit production cost (in dollars per unit), not counting setup or inventory costs in period t

A_t fixed or setup cost (in dollars) to place an order in period t

h_t holding cost (in dollars) to carry a unit of inventory from period t to period t +1

Q_t the *unknown* size of the order or lot size in period t ⟸ ***decision variables***

Wagner-Whitin Example

Data

t	1	2	3	4	5	6	7	8	9	10
D_t	20	50	10	50	50	10	20	40	20	30
c_t	10	10	10	10	10	10	10	10	10	10
A_t	100	100	100	100	100	100	100	100	100	100
h_t	1	1	1	1	1	1	1	1	1	1

Lot-for-Lot Solution

t	1	2	3	4	5	6	7	8	9	10	Total
D_t	20	50	10	50	50	10	20	40	20	30	300
Q_t	20	50	10	50	50	10	20	40	20	30	300
I_t	0	0	0	0	0	0	0	0	0	0	0
Setup cost	100	100	100	100	100	100	100	100	100	100	1000
Holding cost	0	0	0	0	0	0	0	0	0	0	0
Total cost	100	100	100	100	100	100	100	100	100	100	1000

Fixed Order Quantity Solution

t	1	2	3	4	5	6	7	8	9	10	Total
D_t	20	50	10	50	50	10	20	40	20	30	300
Q_t	100	0	0	100	0	0	100	0	0	0	300
I_t	80	30	20	70	20	10	90	50	30	0	0
Setup cost	100	0	0	100	0	0	100	0	0	0	300
Holding cost	80	30	20	70	20	10	90	50	30	0	400
Total cost	180	30	20	170	20	10	190	50	30	0	700

Under an optimal lot-sizing policy either the inventory carried to period t+1 from a previous period will be zero or the production quantity in period t+1 will be zero.

Basic Idea of Wagner-Whitin Algorithm

By WW Property I, either $Q_t=0$ or $Q_t=D_1+\ldots+D_k$ for some k. If

j_k^* = last period of production in a k period problem

then we will produce exactly $D_k+\ldots D_T$ in period j_k^*.

We can then consider periods $1, \ldots, j_k^*-1$ as if they are an independent j_k^*-1 period problem.

Step 1: Obviously, just satisfy D_1 (note we are neglecting production cost, since it is fixed).

$$Z_1^* = A_1 = 100$$
$$j_1^* = 1$$

Step 2: Two choices, either $j_2^* = 1$ or $j_2^* = 2$.

$$\begin{aligned} Z_2^* &= \min\begin{cases} A_1 + h_1 D_2, & \text{produce in 1} \\ Z_1^* + A_2, & \text{produce in 2} \end{cases} \\ &= \min\begin{cases} 100+1(50)=150 \\ 100+100=200 \end{cases} \\ &= 150 \end{aligned}$$

$$j_2^* = 1$$

Step3: Three choices, $j_3^* = 1, 2, 3$.

$$Z_3^* = \min\begin{cases} A_1 + h_1 D_2 + (h_1 + h_2) D_3, & \text{produce in 1} \\ Z_1^* + A_2 + h_2 D_3, & \text{produce in 2} \\ Z_2^* + A_3, & \text{produce in 3} \end{cases}$$

$$= \min\begin{cases} 100 + 1(50) + (1+1)10 = 170 \\ 100 + 100 + (1)10 \quad = 210 \\ 150 + 100 \quad = 250 \end{cases}$$

$$= 170$$

$$j_3^* = 1$$

Step 4: Four choices, $j_4^* = 1, 2, 3, 4$.

$$Z_4^* = \min\begin{cases} A_1 + h_1 D_2 + (h_1 + h_2) D_3 + (h_1 + h_2 + h_3) D_4, & \text{produce in 1} \\ Z_1^* + A_2 + h_2 D_3 + (h_2 + h_3) D_4, & \text{produce in 2} \\ Z_2^* + A_3 + h_3 D_4, & \text{produce in 3} \\ Z_3^* + A_4, & \text{produce in 4} \end{cases}$$

$$= \min\begin{cases} 100 + 1(50) + (1+1)10 + (1+1+1)50 = 320 \\ 100 + 100 + (1)10 + (1+1)50 \quad = 310 \\ 150 + 100 + (1)50 \quad = 300 \\ 170 + 100 \quad = 270 \end{cases}$$

$$= 270$$

$$j_4^* = 4$$

Step 5: Only two choices, $j_5^* = 4, 5$.

$$Z_5^* = \min\begin{cases} Z_3^* + A_4 + h_4 D_5, & \text{produce in 4} \\ Z_4^* + A_5, & \text{produce in 5} \end{cases}$$

$$= \min\begin{cases} 170 + 100 + 1(50) = 320 \\ 270 + 100 \quad = 370 \end{cases}$$

$$= 320$$

$$j_5^* = 4$$

Step 6: Three choices, $j_6^* = 4, 5, 6$.

And so on.

Last Period with Production	Planning Horizon (t)									
	1	2	3	4	5	6	7	8	9	10
1	100	150	170	320						
2		200	210	310						
3			250	300						
4				270	320	340	400	560		
5					370	380	420	540		
6						420	440	520		
7							440	480	520	610
8								500	520	580
9									580	610
10										620
Z_t	100	150	170	270	320	340	400	480	520	580
j_t	1	1	1	4	4	4	4	7	7 or 8	8

Produce in period 1 for 1, 2, 3 (20 + 50 + 10 = 80 units)

Produce in period 4 for 4, 5, 6, 7 (50 + 50 + 10 + 20 = 130 units)

Produce in period 8 for 8, 9, 10 (40 + 20 + 30 = 90 units

Optimal Policy:

- Produce in period 8 for 8, 9, 10 (40 + 20 + 30 = 90 units)
- Produce in period 4 for 4, 5, 6, 7 (50 + 50 + 10 + 20 = 130 units)
- Produce in period 1 for 1, 2, 3 (20 + 50 + 10 = 80 units)

t	1	2	3	4	5	6	7	8	9	10	Total
D_t	20	50	10	50	50	10	20	40	20	30	300
Q_t	80	0	0	130	0	0	0	90	0	0	300
I_t	60	10	0	80	30	20	0	50	30	0	0
Setup cost	100	0	0	100	0	0	0	100	0	0	300
Holding cost	60	10	0	80	30	20	0	50	30	0	280
Total cost	160	10	0	180	30	20	0	150	30	0	580

Note: we produce in 7 for an 8 period problem, but this never comes into play in optimal solution.

Exercise 3

Q1: Consider the following table resulting from lot sizing by the Wagner Whitin algorithm:

Month	**Demand**	**Min.** Cost	**Order Period**
1	69	85	1
2	29	114	1
3	36	186	1
4	61	277	3
5	61	348	4
6	26	400	4
7	34	469	5
8	67	555	8
9	45	600	8
10	67	710	10
11	79	789	10
12	56	864	11

a. Develop the optimal ordering schedule.
b. What will the schedule be if your planning horizon was only six months?

Q2: Nozone, Inc., a manufacturer of Freon recovery units (for automotive air conditioner maintenance), experiences a strongly seasonal demand pattern, driven by the summer air conditioning season. This year Nozone has put together a six-month production plan, where the monthly demands *D,* for recovery units are given in the table below. Each recovery unit is manufactured from one chassis assembly plus a variety of other parts. The chassis assemblies are produced in the machining center. Since there is a single chassis assembly per recovery unit, the demands in the table below also represent demands for chassis assemblies. The unit cost, fixed setup cost and monthly holding cost for chassis assemblies are also given in this table. The fixed setup cost is the firm's estimate of the cost to change over the machining center to produce chassis assemblies, including labor and materials cost and the cost of disruption of other product lines.

t	1	2	3	4	5	6
D_t	1,000	1,200	500	200	800	1,000
c_t	50	50	50	50	50	50
A_t	2,000	2,000	2,000	2,000	2,000	2,000
h_t	1	1	1	1	1	1

Use the Wagner Whitin algorithm to compute an optimal six-month production schedule for chassis assemblies.

Q3: Consider an item with the following properties:

A = SR50; v = SR4.00/unit; i = 0.36 SR/SR/year.

At time 0, the inventory has dropped to zero and replenishment with negligible lead-time must be made. The demand pattern for the next 12 months is:

Month	1	2	3	4	5	6	7	8	9	10	11	12
Demand	100	75	50	100	50	40	80	80	0	50	75	100

All the requirements of each month must be available at the beginning of the month. Replenishments are restricted to the beginning of each month. Using each of the following methods, develop a list of orders to meet the demand and determine the total cost of the order schedule. In each case, there should be no inventory at the end of month 12. Use Wagner-Whitin algorithm to find ordering schedule.

Material Requirement Planning

Elements of MRP process

- **Gross Requirements** – demand for an item by time period
- **Scheduled Receipts** – material already ordered
- **Projected on Hand** – expected ending inventory
- **Net Requirements** – number of items to be provided and when
- **Planned Order Receipts** – net requirements adjusted for lot size
- **Planned Order Releases** – planned order receipts offset for lead times

Master Production Schedule (MPS)

☑ Specifies what is to be made and when

☑ Must be in accordance with the aggregate production plan

☑ The MPS is the result of the production planning process

MPS Examples

Gross Requirements for item A

Day	6	7	8	9	10	11	12	13	14	and so on
Quantity	50		100	47	60		110	75		

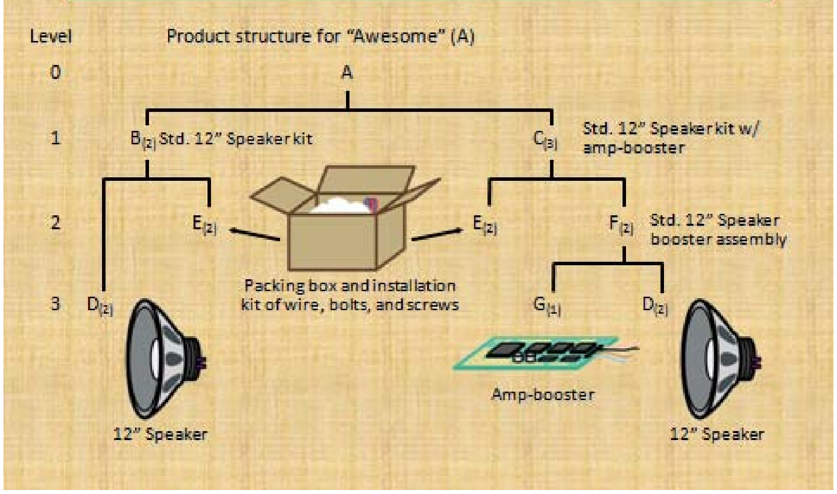
Gross Requirements for Item B

Day	7	8	9	10	11	12	13	14	15	16	and so on
Quantity	100	200	150			60	75		100		

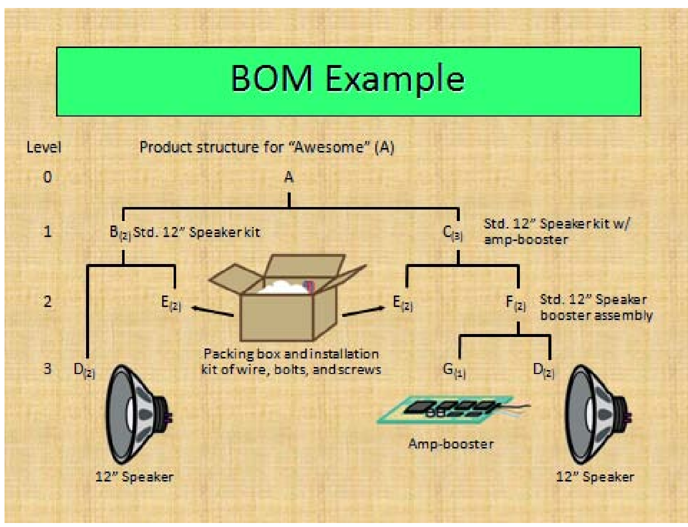
Bills of Material

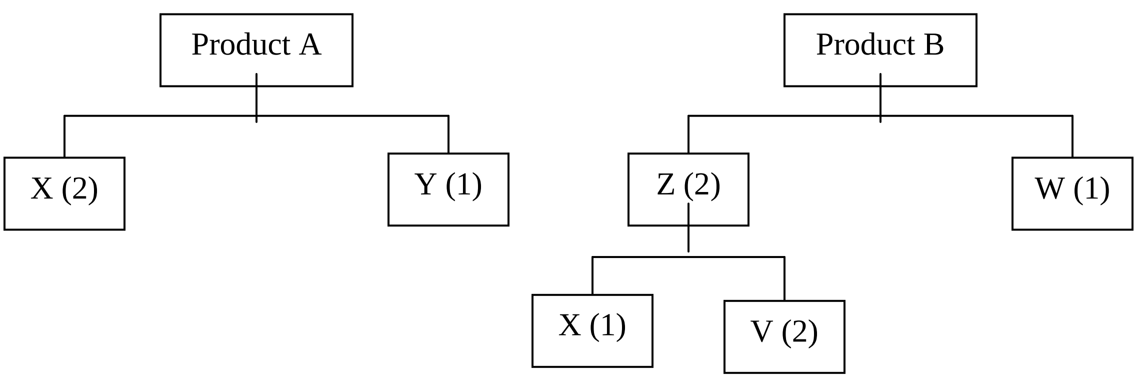
- ☑ List of components, ingredients, and materials needed to make product
- ☑ Provides product structure
  - ☑ Items above given level are called parents
  - ☑ Items below given level are called children

BOM Example



Part B:	2 x number of As =	(2)(50) =	100
Part C:	3 x number of As =	(3)(50) =	300
Part D:	2 x number of Bs		
	+ 2 x number of Fs =	(2)(100) + (2)(300) =	800
Part E:	2 x number of Bs		
	+ 2 x number of Cs =	(2)(100) + (2)(150) =	500
Part F:	2 x number of Cs =	(2)(150) =	300
Part G:	1 x number of Fs =	(1)(300) =	300





Net Requirements Plan

The logic of net requirements

$$\underbrace{\left[(\text{gross requirements}) + (\text{allocations})\right]}_{\text{total requirements}} - \underbrace{\left[(\text{on hand}) + (\text{scheduled receipts})\right]}_{\text{available inventory}} = \text{net requirements}$$

MRP Calculation Table

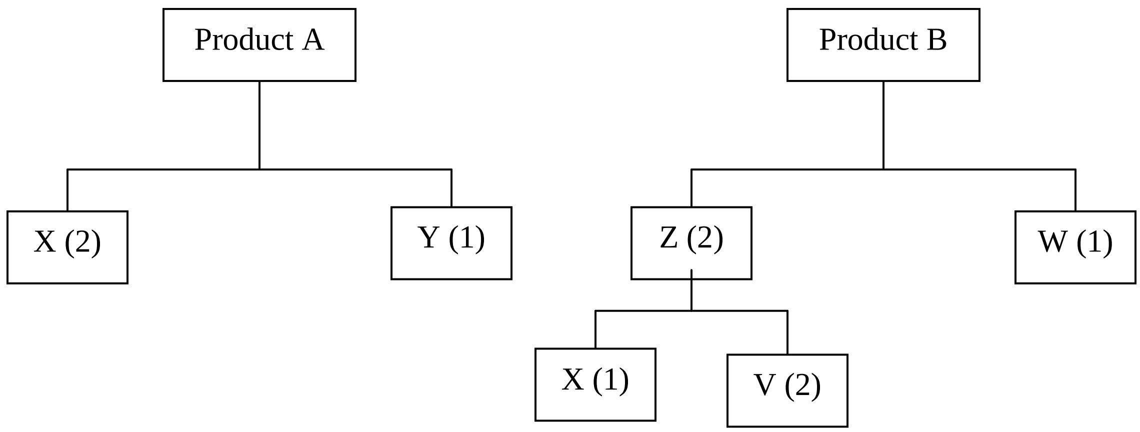
Week	1	2	3	4	5	6	7	8	9	10	11	12	13
Gross requirements													
Scheduled receipts													
Adjusted Scheduled rec.													
Projected on hand													
Net requirements													
Planned order receipts													
Planned order releases													

IE 472
Operations of Manufacturing Systems

Spring 2011
Dr Ateekh-Ur-Rehman

Exercise 4

Q1: Consider the following product structure trees.



The master production schedule for the next 13 weeks is given as follows:

Week	1	2	3	4	5	6	7	8	9	10	11	12	13
Product A	20		30	50		80	40	40	40		20	10	
Product B	30	20		90	120				60	60		60	60

Furthermore, the following information regarding quantity on hand, scheduled receipts, lead time and lot sizing rules are provided.

Part	Current on-hand	Scheduled receipts		Lot-sizing rule	Lead time
		Due	Quantity		
Product A	20	4	200	FOP, 2 weeks	1 week
Product B	40	2	100	FOP, 4 weeks	2 weeks
X	120	--	--	Lot-for-lot	2 weeks
Y	150	2	100	Lot-for-lot	1 week
Z	40	--	--	Lot-for-lot	1 week
W	50	--	--	Lot-for-lot	2 weeks
V	120	--	--	Lot-for-lot	2 weeks

Construct the MRP for products A, B, V, W, X, Y and Z

Q2: Demand for a power steering gear assembly is given by

Period	1	2	3	4	5	6	7	8	9	10
Demand	14	12	12	13	5	90	20	20	20	20

A) Currently, there are 50 parts on hand. The lot-sizing rule is fixed order period using two periods. Lead time is three periods. Construct an MRP planning sheet and show the planned order release schedule for the gear.

B) Let's say each gear assembly requires 2 pinions. Currently there are 100 pinions on hand, the lot-sizing rule is lot-for-lot and the lead time is two periods. Plan the order release schedule for the pinions.

Q3:

Generate the MRP output for items A, 200, 300, and 400 using the following information. (*Note:* End item A is the same as in Problem 3.)

- Bills of material:

A: Two 200 and one 400
200: Raw material
300: Raw material
400: One 200 and one 300

- Master production schedule:

Week	1	2	3	4	5	6	7	8	9	10
Demand (A)	41	44	84	42	84	86	7	18	49	30

- Item Master and Inventory Data:

Item	Amount on Hand	Amount on Order	Due	Lead Time (Weeks)	Lot Sizing Rule (Setup/Hold)
A	120	0		2	PPB (200)
200	300	200 100	3 5	2	Lot-for-lot
300	140	100 100	4 7	2	Lot-for-lot
400	200	0		3	Lot-for-lot

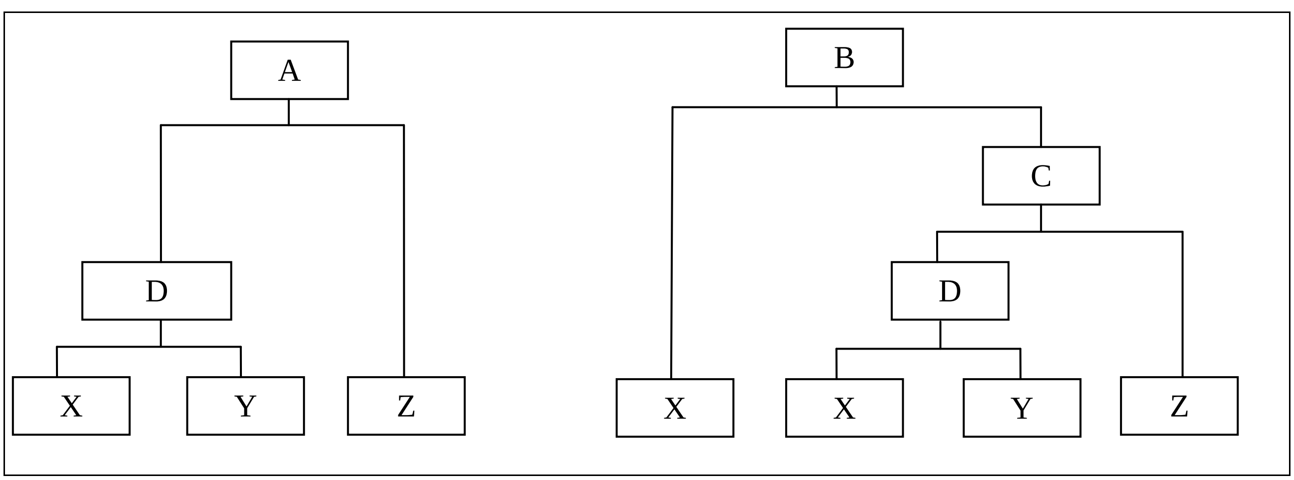
Q4: Consider the following product structure trees. The master production schedule for the next 8 weeks is given as follows:

Week	1	2	3	4	5	6	7	8
Product A	15	20	50	10	30	30	30	30
Product B	10	15	10	20	20	15	15	15

Furthermore, the following information regarding quantity on hand, scheduled receipts, lead time and lot sizing rules are provided.

Part number	Current on-hand	Scheduled receipts		Lot-sizing rule	Lead time
		Due	Quantity		
A	20	1 2 4	10 10 100	FOP, 2 weeks	2 weeks
B	40	0		FOP, 2 weeks	2 weeks
X	40	0		Lot-for-lot	2 weeks
Y	50	2	100	Lot-for-lot	1 week
Z	40	0		Lot-for-lot	4 weeks

Construct the MRP schedule for parts A, B, C, D, X, Y and Z



Issues with MRP

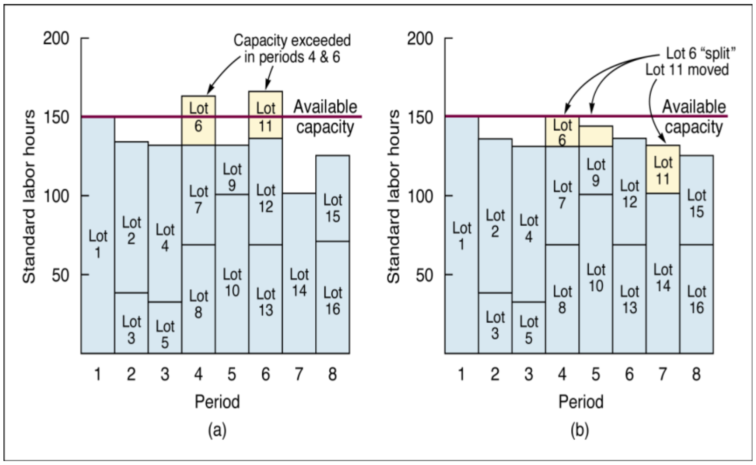
- **Capacity infeasibility**
- **Long planned lead times**
- **System nervousness**

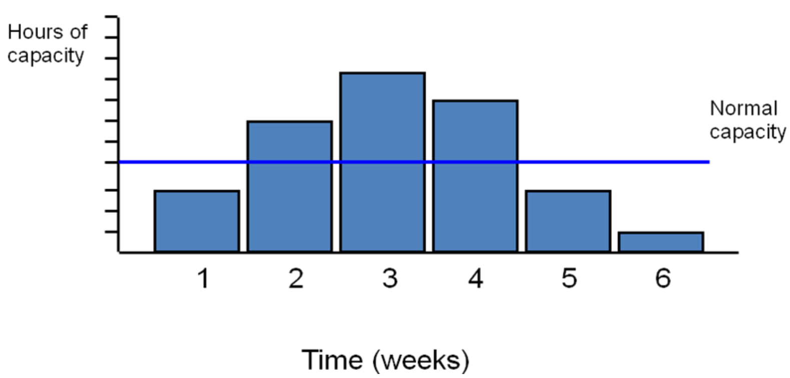
- The basic working model for MRP is a production line with a fixed lead time. Since this lead time does not depend on how much work is in the plant, there is an implicit assumption that the line will always have sufficient capacity. This can create problems when production levels are at or near capacity.
- MRP uses constant lead times while in fact the lead time could vary considerably. Also, MRP sometimes uses long lead times in order to provide some sort of safety. Such long lead times results in increased levels of inventory
- System Nervousness in MRP system occurs when a small change in the master production schedule leads to a large change in planned order releases

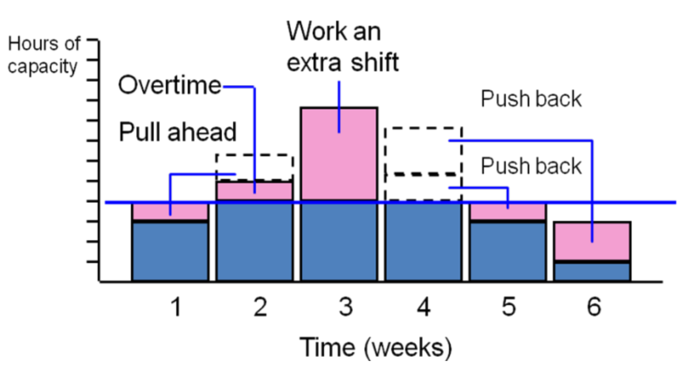
- Tactics for smoothing the load and minimizing the impact of changed lead time include:
  - Overlapping - reduces the lead time, entails sending pieces to the second operation before the entire lot has completed the first operation
  - Operations splitting - sends the lot to two different machines for the same operation
  - Lot splitting - breaking up the order and running part of it ahead of the schedule

Extension of MRP

- CRP is a computerized system that projects loads, creates load profile and identifies under and over loads.







- **Remedies for underloads:**
- 1. Acquire more work
- 2. Pull work ahead that is scheduled for later time periods
- 3. Reduce normal capacity
- **Remedies for overloads:**
- 1. Eliminate unnecessary requirements
- 2. Reroute jobs to alternative machines or work centers
- 3. Split lots between two or more machines
- 4. Increase normal capacity
- 5. Subcontract
- 6. Increase the efficiency of the operation
- 7. Push work back to later time periods
- 8. Revise master schedule

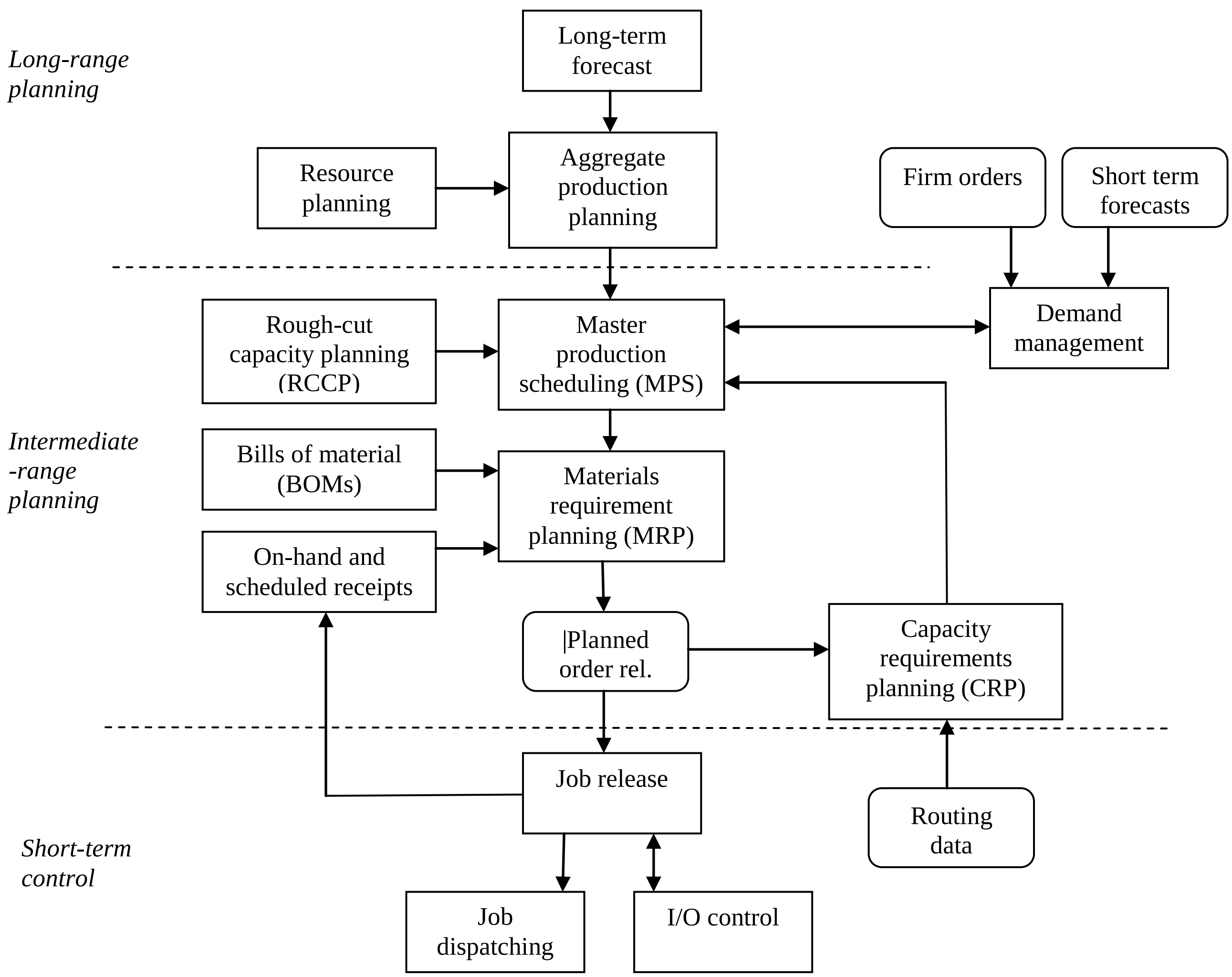
Extension for MRP-I

MRP-II
ERP

Manufacturing resources planning (MRP II)

MRP II was introduced to fix some of the problems that are faced by MRP, specifically, capacity, long lead times and nervousness problems.

- Beyond simply addressing deficiencies of MRP, MRP II also brought together other functions to make a truly integrated manufacturing management system. The additional functions subsumed by MRP II included demand management, forecasting, capacity planning, master production scheduling, rough-cut capacity planning, capacity requirements planning, dispatching and input/output control.
- The hierarchy of MRP II is represented in the following diagram.



Enterprise resource planning (ERP)

Ideally, ERP delivers a single database that contains all data for the software modules, which would include:

Manufacturing: Engineering, bills of material, scheduling, capacity, workflow management, quality control, cost management, manufacturing process, manufacturing projects, manufacturing flow

Supply chain management: Order to cash, inventory, order entry, purchasing, product configuration, supply chain planning, supplier scheduling, inspection of goods, claim processing, commission calculation

Financials: General ledger, cash management, accounts payable, accounts receivable, fixed assets

Project management: Costing, billing, time and expense, performance units, activity management

Human resources: Human resources, payroll, training, time and attendance, rostering, benefits

Customer relationship management (CRM): Sales and marketing, commissions, service, customer contact and call centre support

Data warehouse and various self-service interfaces for customers, suppliers, and employees

Access control - user privilege as per authority levels for process execution

Customization - to meet the extension, addition, change in process flow

Some organizations — typically those with sufficient in-house IT skills to integrate multiple software products — choose to implement only portions of an

ERP system and develop an external interface to other ERP or stand-alone systems for their other application needs. For example, one may choose to use human resource management system from one vendor, and the financial systems from another, and perform the integration between the systems themselves

ERPs are cross-functional and enterprise wide. All functional departments that are involved in operations or production are integrated in one system. In addition to manufacturing, warehousing, logistics, and information technology, this would include accounting, human resources, marketing and strategic management

Because of their wide scope of application within a business, ERP software systems are typically complex and usually impose significant changes on staff work practices. Implementing ERP software is typically too complex for "in-house" skill, so it is desirable and highly advised to hire outside consultants who are professionally trained to implement these systems. This is typically the most cost effective way. There are three types of services that may be employed for - Consulting, Customization, Support. The length of time to implement an ERP system depends on the size of the business, the number of modules, they extent of customization, the scope of the change and the willingness of the customer to take ownership for the project. ERP systems are modular, so they don't all need be implemented at once. It can be divided into various stages, or phase-ins. The typical project is about 14 months and requires around 150 consultants. A small project (e.g., a company of less than 100 staff) may be planned and delivered within 3-9 months; however, a large, multi-site or multi-country implementation may take years.[citation needed] The length of the implementations is closely tied to the amount of customization desired.

To implement ERP systems, companies often seek the help of an ERP vendor or of third-party consulting companies. These firms typically provide three areas of professional services: consulting, customization and support. The client organisation may also employ independent program management, business analysis, change management and UAT specialists to ensure their business requirements remain a priority during implementation.

IE 472
Operations of Manufacturing Systems

Spring 2011
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Chapter 4

Basic Factory Dynamics

Physics should be explained as simply as possible, but no simpler. – Albert Einstein

Basic Definitions

Workstation: a collection of one or more identical machines.

Part: a component, sub-assembly, or an assembly that moves through the workstations.

End Item: part sold directly to customers; relationship to constituent parts defined in *bill of material*.

Consumables: bits, chemicals, gasses, etc., used in process but do not become part of the product that is sold.

Routing: sequence of workstations needed to make a part.

Order: request from customer.

Job: transfer quantity on the line.

Basic Measures

Throughput (TH): for a line, throughput is the average quantity of *good* (non-defective) parts produced per unit time.

Work in Process (WIP): inventory between the start and endpoints of a product routing.

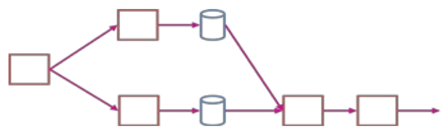
Raw Material Inventory (RMI): material stocked at beginning of routing.

Crib and Finished Goods Inventory (FGI): crib inventory is material held in a stockpoint at the end of a routing; FGI is material held in inventory prior to shipping to the customer.

Cycle Time (CT): time between release of the job at the beginning of the routing until it reaches an inventory point at the end of the routing.

Factory Physics

A production system is a ***goal-oriented network*** of ***processes*** and ***stockpoints*** through which ***parts flow***. Network is made up of routings (lines), which in turn are made up of processes. ***Factory Physics*** is concerned with the network and flows at the routing (line) level.



Parameters

Descriptors of a Line:

1) **Bottleneck Rate (r_b):** Rate (parts/unit time or jobs/unit time) of the workstation with the highest *long-term* utilization.

2) **Raw Process Time (T_0):** Sum of the *long-term average* process times of each station in the line.

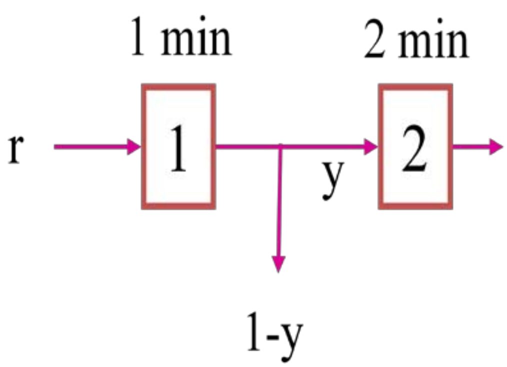
3) **Congestion Coefficient (α):** A unitless measure of congestion.

- Zero variability case, $\alpha = 0$.
- "Practical worst case," $\alpha = 1$.
- "Worst possible case," $\alpha = W_0$.

Note that lines with same r_b and T_0 can behave very differently.

Definition of Bottleneck

We use highest utilization instead of slowest to define the bottleneck
If yield loss is greater than 50% then station 1 becomes the bottleneck because it processes more jobs than station 2. The same thing happens with systems that have multiple routings.



$$u = \frac{\text{rate in}}{\text{capacity}}$$

$$u(1) = \frac{r}{1} = r$$

$$u(2) = \frac{r \times y}{0.5} = 2ry$$

$$u(1) \leq u(2) \quad \text{if} \quad y \geq 0.5$$

Critical WIP (W_0): WIP level in which a line having no congestion would achieve maximum throughput (i.e., r_b) with minimum cycle time (i.e., T_0).

$$W_0 = r_b T_0$$

Best Case Law: ***The minimum cycle time (CT_{best}) for a given WIP level, w, is given by***

$$\mathrm{CT}_{\mathrm{best}}(w) = \begin{cases} T_0, & \text{if } w \le W_0 \\ w/r_b, & \text{otherwise.} \end{cases}$$

The maximum throughput (TH_{best}) for a given WIP level, w is given by,

$$\mathrm{TH}_{\mathrm{best}}(w) = \begin{cases} w/T_0, & \text{if } w \le W_0 \\ r_b, & \text{otherwise.} \end{cases}$$

Example: For Penny Fabricator , given

$r_b = 0.5$ and $T_0 = 8$, so $W_0 = 0.5 \times 8 = 4$,

$$\mathrm{CT}_{\mathrm{best}}(w) = \begin{cases} 8, & \text{if } w \le 4 \\ 2w, & \text{otherwise.} \end{cases}$$

$$\mathrm{TH}_{\mathrm{best}}(w) = \begin{cases} w/8, & \text{if } w \le 4 \\ 0.5, & \text{otherwise.} \end{cases}$$

.

Little's Law: ***The fundamental relation between WIP, CT, and TH over the long-term is:***

$$\mathrm{WIP} = \mathrm{TH} \times \mathrm{CT}$$

$$parts = \frac{parts}{hr} \times hr$$

The Best Case yields the minimum cycle time and maximum throughput for each WIP level.

While worst case would cause the *maximum* cycle time and *minimum* throughput
Practical worst case is between the Best Case and Worst Case performance.

Worst Case Law: ***The worst case cycle time for a given WIP level, w, is given by,***

$$CT_{worst}(w) = w\,T_0$$

The worst case throughput for a given WIP level, w, is given by,

$$TH_{worst}(w) = 1 / T_0$$

Practical Worst Case Definition: ***The practical worst case (PWC) cycle time for a given WIP level, w, is given by,***

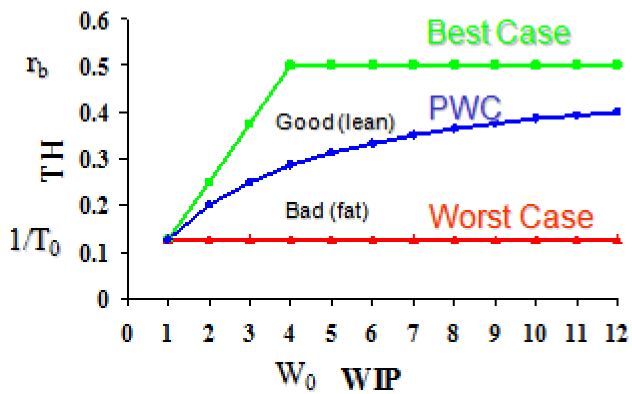
$$\mathrm{CT}_{\mathrm{PWC}}(w) = T_0 + \frac{w-1}{r_b}$$

The PWC throughput for a given WIP level, w, is given by,

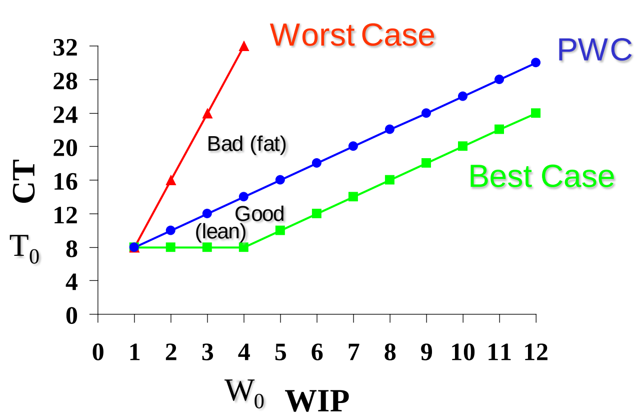
$$\mathrm{TH}_{\mathrm{PWC}}(w) = \frac{w}{W_0 + w - 1} r_b,$$

where W_0 is the critical WIP.

TH vs. WIP: Practical Worst Case



CT vs. WIP: Practical Worst Case



HAL Case

Large Panel Line: produces unpopulated printed circuit boards

Line runs 24 hr/day (but 19.5 hrs of productive time)

Recent Performance:
Throughput = 1,400 panels per day (71.8 panels/hr)
WIP = 47,600 panels
CT = 34 days (663 hr at 19.5 hr/day)
Customer service = 75% on-time delivery

The process is as

Lamination (Cores): press copper and prepreg into core blanks
Machining: trim cores to size
Internal Circuitize: etch circuitry into copper of cores
Optical Test and Repair (Internal): scan panels optically for defects
Lamination (Composites): press cores into multiple layer boards
External Circuitize: etch circuitry into copper on outside of composites
Optical Test and Repair (External): scan composites optically for defects
Drilling: holes to provide connections between layers
Copper Plate: deposits copper in holes to establish connections
Procoat: apply plastic coating to protect boards
Sizing: cut panels into boards
End of Line Test: final electrical test

Process	Rate (p/hr)	Time (hr)
Lamination	191.5	4.7
Machining	186.2	0.5
Internal Circuitize	114.0	3.6
Optical Test/Repair - Int	150.5	1.0
Lamination – Composites	158.7	2.0
External Circuitize	159.9	4.3
Optical Test/Repair - Ext	150.5	1.0
Drilling	185.9	10.2
Copper Plate	136.4	1.0
Procoat	117.3	4.1
Sizing	126.5	1.1
EOL Test	169.5	0.5
r_b, T_0	114.0	33.9

Critical WIP: $r_b T_0 = 114 \times 33.9 = 3{,}869$

Actual Values:

- CT = 34 days = 663 hours (at 19.5 hr/day)
- WIP = 47,600 panels
- TH = 71.8 panels/hour

Conclusions:

- Throughput is 63% of capacity
- WIP is 12.3 times critical WIP
- CT is 24.1 times raw process time

Variability Basics

God does not play dice with the universe.

– Albert Einstein

Stop telling God what to do.

– Niels Bohr

Variability Makes a Difference!

Little's Law: TH = WIP/CT, so same throughput can be obtained with large WIP, long CT or small WIP, short CT. The difference?

Penny Fab One: achieves full TH (0.5 j/hr) at WIP=W_0=4 jobs if it behaves like Best Case, but requires WIP=27 jobs to achieve 95% of capacity if it behaves like the Practical Worst Case. Why?

Tortise and Hare Example

Two machines:

- subject to same workload: 69 jobs/day (2.875 jobs/hr)
- subject to unpredictable outages (availability = 75%)

Hare X19:

- long, but infrequent outages

Tortoise 2000:

- short, but more frequent outages

Performance: Hare X19 is substantially worse on all measures than Tortoise 2000. Why?

Variability Views

Variability:

- Any departure from uniformity
- Can be random or controllable

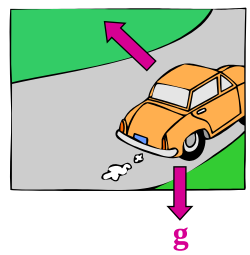
Randomness:

- Essential reality?
- Artifact of incomplete knowledge?
- Management implications: robustness is key

Probabilistic Intuition

Uses of Intuition:

- Driving a car
- Throwing a ball
- Making investments



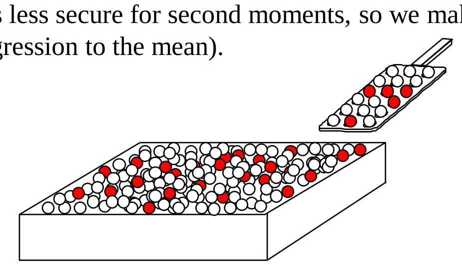
First Moment Effects:

- Throughput increases with machine speed
- Throughput increases with availability
- Inventory increases with lot size
- Our intuition is good for first moments

Probabilistic Intuition (cont.)

Second Moment Effects:

- Which are more variable – processing times of parts or batches?
- Which are more disruptive – long, infrequent failures or short frequent ones?
- Which helps more – increasing times to failure or reducing times to repair?
- Our intuition is less secure for second moments, so we make more errors (e.g., regression to the mean).



Variability

Definition: Variability is anything that causes the system to depart from regular, predictable behavior.

Sources of Variability:

- machine failures
- setups
- material shortages
- yield loss
- rework
- operator unavailability
- workpace variation
- differential skill levels
- material handling
- demand fluctuations
- engineering change orders
- product variety

May be consequence of manufacturing practices (machine failures)

May be consequence of business strategy (product variety)

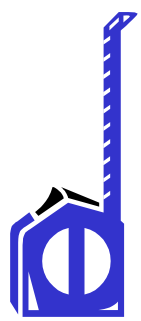
Measuring Process Variability

$$t_e = \text{mean process time of a job}$$

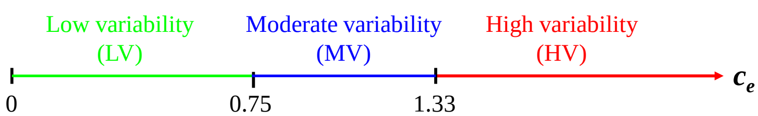
$$\sigma_e = \text{standard deviation of process time}$$

$$c_e = \frac{\sigma_e}{t_e} = \text{coefficient of variation, CV}$$

Note: we often use the "squared coefficient of variation" (SCV), c_e^2



Variability Classes in Factory Physics



Effective Process Times:

- ***actual*** process times are generally LV
- ***effective*** process times include setups, failure outages, etc.
- HV, LV, and MV are all possible in effective process times

Relation to Performance Cases: For balanced systems

- MV – Practical Worst Case
- LV – between Best Case and Practical Worst Case
- HV – between Practical Worst Case and Worst Case

Measuring Process Variability – Example

Trial	Machine 1	Machine 2	Machine 3
1	22	5	5
2	25	6	6
3	23	5	5
4	26	**35**	**35**
5	24	7	7
6	28	**45**	**45**
7	21	6	6
8	30	6	6
9	24	5	5
10	28	4	4
11	27	7	7
12	25	**50**	**500**
13	24	6	6
14	23	6	6
15	22	5	5
t_e	25.1	13.2	43.2
s_e	2.5	15.9	127.0
c_e	0.1	1.2	2.9
Class	LV	MV	HV

Natural Variability

Definition: variability without explicitly analyzed cause

Sources:

- operator pace
- material fluctuations
- product type (if not explicitly considered)
- product quality

Observation: natural process variability is usually in the LV category.

Down Time – Mean Effects

Definitions:

$$t_0 = \text{base process time}$$

$$c_0 = \text{base process time coefficient of variability}$$

$$r_0 = \frac{1}{t_0} = \text{base capacity (rate, e.g., parts/hr)}$$

$$m_f = \text{mean time to failure}$$

$$m_r = \text{mean time to repair}$$

$$c_r = \text{coefficent of variability of repair times } (\sigma_r / m_r)$$

Down Time – Mean Effects (cont.)

Availability: Fraction of time machine is up

$$A = \frac{m_f}{m_f + m_r}$$

Effective Processing Time and Rate:

$$r_e = A r_0$$

$$t_e = t_0 / A$$

Totoise and Hare - Availability

Hare X19:

t_0 = 15 min
σ_0 = 3.35 min
$c_0 = \sigma_0 / t_0$ = 3.35/15 = 0.05
m_f = 12.4 hrs (744 min)
m_r = 4.133 hrs (248 min)
c_r = 1.0

Tortoise:

t_0 = 15 min
σ_0 = 3.35 min
$c_0 = \sigma_0 / t_0$ = 3.35/15 = 0.05
m_f = 1.9 hrs (114 min)
m_r = 0.633 hrs (38 min)
c_r = 1.0

Availability:

A = ________________ A = ________________

Down Time – Variability Effects

Effective Variability:

$$t_e = t_0 / A$$

$$\sigma_e^2 = \left(\frac{\sigma_0}{A}\right)^2 + \frac{(m_r^2 + \sigma_r^2)(1-A)t_0}{A}$$

$$c_e^2 = \frac{\sigma_e^2}{t_e^2} = c_0^2 + (1 + c_r^2)A(1-A)\frac{m_r}{t_0}$$

Variability depends on repair times in addition to availability

Conclusions:

- Failures inflate mean, variance, and CV of effective process time
- Mean (t_e) increases proportionally with $1/A$
- SCV (c_e^2) increases proportionally with m_r
- SCV (c_e^2) increases proportionally in c_r^2
- For constant availability (A), long infrequent outages increase SCV more than short frequent ones

Tortoise and Hare - Variability

Hare X19:

t_e =

c_e^2 =

Tortoise 2000

t_e =

c_e^2 =

Impact of Variability

Hare X19

- CT = 28 hours
- WIP = 81 jobs

Tortoise 2000

- CT = 8 hours
- WIP = 23 jobs

Conclusion*: *Capacity and arrival variability are the same. CT and WIP are greatly inflated by process variability due to failures

Setups – Mean and Variability Effects

Analysis:

N_s = average no. jobs between setups

t_s = average setup duration

σ_s = std. dev. of setup time

$$c_s = \frac{\sigma_s}{t_s}$$

$$t_e = t_0 + \frac{t_s}{N_s}$$

Capacity Effect – setups inflate average process time

$$\sigma_e^2 = \sigma_0^2 + \frac{\sigma_s^2}{N_s} + \frac{N_s - 1}{N_s^2} t_s^2$$

$$c_e^2 = \frac{\sigma_e^2}{t_e^2}$$

Variability Effect – setups also inflate process time CV

Setups – Mean and Variability Effects (cont.)

Observations:

- Setups increase mean *and* variance of processing times.
- Variability reduction is one benefit of flexible machines.
- However, the interaction is complex.

Setup – Example

Data:

- Fast, inflexible machine – 2 hr setup every 10 jobs

$$t_0 = 1\text{ hr}$$
$$N_s = 10\text{ jobs/setup}$$
$$t_s = 2\text{ hrs}$$
$$t_e = t_0 + t_s / N_s = 1 + 2/10 = 1.2\text{ hrs}$$
$$r_e = 1/t_e = 1/(1+2/10) = 0.8333\text{ jobs/hr}$$

- Slower, flexible machine – no setups

$$t_0 = 1.2\text{ hrs}$$
$$r_e = 1/t_0 = 1/1.2 = 0.833\text{ jobs/hr}$$

Traditional Analysis? ***No difference!***

Setup – Example (cont.)

Factory Physics Approach: Compare mean *and* variance

- Fast, inflexible machine – 2 hr setup every 10 jobs

$$t_0 = 1 \text{ hr}$$
$$c_0^2 = 0.0625$$
$$N_s = 10 \text{ jobs/setup}$$
$$t_s = 2 \text{ hrs}$$
$$c_s^2 = 0.0625$$
$$t_e = t_0 + t_s / N_s = 1 + 2/10 = 1.2 \text{ hrs}$$
$$r_e = 1/t_e = 1/(1+2/10) = 0.8333 \text{ jobs/hr}$$
$$\sigma_e^2 = \sigma_0^2 + t_s^2 \left(\frac{c_s^2}{N_s} + \frac{N_s - 1}{N_s^2} \right) = 0.4475$$
$$c_e^2 = 0.31$$

Setup – Example (cont.)

- Slower, flexible machine – no setups

$$t_0 = 1.2 \text{ hrs}$$
$$c_0^2 = 0.0625$$

$$r_e = 1/t_0 = 1/1.2 = 0.833 \text{ jobs/hr}$$
$$c_e^2 = c_0^2 = 0.0625$$

Conclusion:

Other Process Variability Inflators

Sources:

- operator unavailability
- recycle
- batching
- material unavailability
- et cetera, et cetera, et cetera

Effects:

- inflate t_e
- inflate c_e

Consequences:

Flow Variability

Process Variability is bad enough…

- Inflates CT
- Inflates WIP
- Forces lower utilization of capacity

But, variability also propagates…

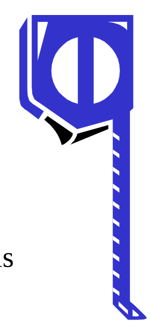
- Causes uneven arrivals downstream
- Inflates CT and WIP at other stations
- Forces lower utilization of capacity throughout the line

Illustrating Flow Variability

Low variability arrivals

High variability arrivals

Measuring Flow Variability



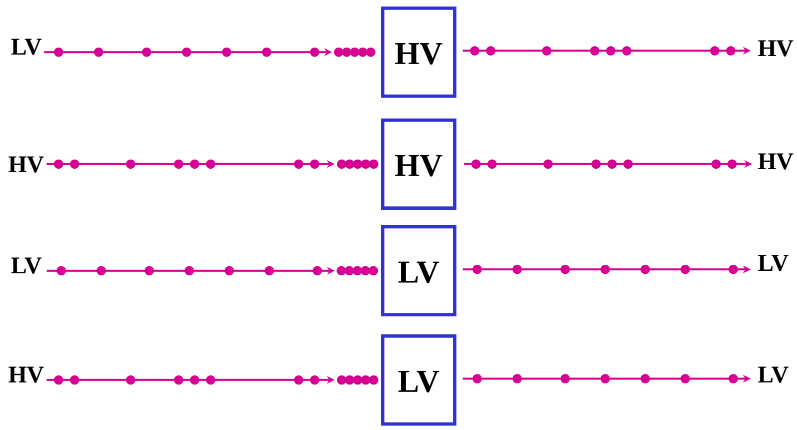
t_a = mean time between arrivals

$$r_a = \frac{1}{t_a} = \text{arrival rate}$$

σ_a = standard deviation of time between arrivals

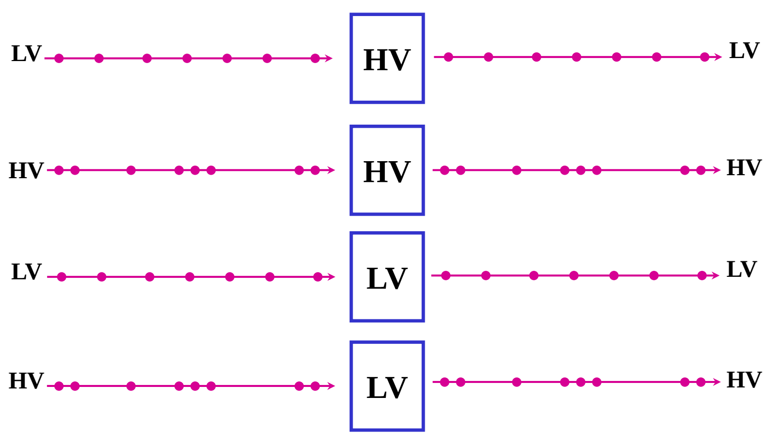
$$c_a = \frac{\sigma_a}{t_a} = \text{coefficient of variation of interarrival times}$$

Propagation of Variability – High Utilization Station



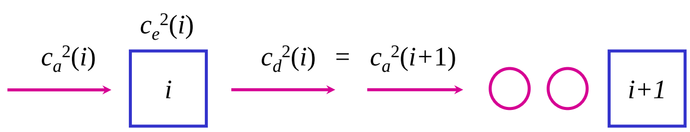
***Conclusion**: flow variability out of a high utilization station is determined primarily by process variability at that station.*

Propagation of Variability – Low Utilization Station



***Conclusion**: flow variability out of a low utilization station is determined primarily by flow variability into that station.*

Propagation of Variability



Single Machine Station:

$$c_d^2 = u^2 c_e^2 + (1-u^2)c_a^2$$

where u is the station utilization given by $u = r_a t_e$

departure var depends on arrival var and process var

Multi-Machine Station:

$$c_d^2 = 1 + (1-u^2)(c_a^2 - 1) + \frac{u^2}{\sqrt{m}}(c_e^2 - 1)$$

where m is the number of (identical) machines and $u = \frac{r_a t_e}{m}$

Variability Interactions

Importance of Queueing:

- manufacturing plants are ***queueing networks***
- queueing and waiting time comprise majority of cycle time

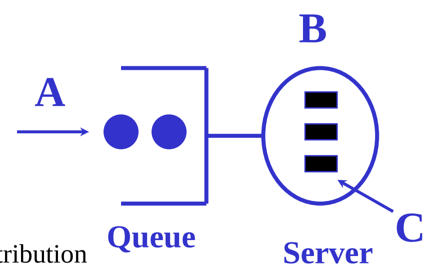
System Characteristics:

- Arrival process
- Service process
- Number of servers
- Maximum queue size (blocking)
- Service discipline (FCFS, LCFS, EDD, SPT, etc.)
- Balking
- Routing
- Many more

Kendall's Classification

A/B/C

A: arrival process
B: service process
C: number of machines



M: exponential (Markovian) distribution
G: completely general distribution
D: constant (deterministic) distribution.

Queueing Parameters

r_a = the rate of arrivals in customers (jobs) per unit time ($t_a = 1/r_a$ = the average time between arrivals).

c_a = the CV of inter-arrival times.

m = the number of machines.

r_e = the rate of the station in jobs per unit time = m/t_e.

c_e = the CV of ***effective*** process times.

Note: a station can be described with 5 parameters.

u = utilization of station = r_a/r_e.

Queueing Measures

Measures:

CT_q = the expected waiting time spent in queue.
CT = the expected time spent at the process center, i.e., queue time plus process time.
WIP = the average WIP level (in jobs) at the station.
WIP_q = the expected WIP (in jobs) in queue.

Relationships:

$CT = CT_q + t_e$
$WIP = r_a \times CT$
$WIP_q = r_a \times CT_q$

Result: If we know CT_q, we can compute WIP, WIP_q, CT.

The G/G/1 Queue

Formula:

$$CT_q \approx V \times U \times t \approx \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u}{1-u}\right)t_e$$

Observations:

- Useful model of single machine workstations
- Separate terms for variability, utilization, process time.
- CT_q (and other measures) increase with c_a^2 and c_e^2
- Flow variability, process variability, or both can combine to inflate queue time.
- ***Variability causes congestion!***

The G/G/m Queue

Formula:

$$\mathrm{CT}_q \approx V \times U \times t$$
$$\approx \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u^{\sqrt{2(m+1)}-1}}{m(1-u)}\right)t_e$$

Observations:

- Useful model of multi-machine workstations
- *Extremely* general.
- Fast and accurate.
- Easily implemented in a spreadsheet (or packages like MPX).

VUT Spreadsheet

	MEASURE:	STATION:	1	2	3	4	5
basic data	Arrival Rate (parts/hr)	r_a	10.000	9.800	9.310	8.845	7.960
	Arrival CV	c_a^2	1.000	0.181	0.031	0.061	0.035
	Natural Process Time (hr)	t_0	0.090	0.090	0.095	0.090	0.090
	Natural Process SCV	c_0^2	0.500	0.500	0.500	0.500	0.500
	Number of Machines	m	1	1	1	1	1
failures	MTTF (hr)	m_f	200	200	200	200	200
	MTTR (hr)	m_r	2	2	8	4	4
	Availability	A	0.990	0.990	0.962	0.980	0.980
	Effective Process Time (failures only)	t_e'	0.091	0.091	0.099	0.092	0.092
	Eff Process SCV (failures only)	$c_e^{2}{}'$	0.936	0.936	6.729	2.209	2.209
setups	Batch Size	k	100	100	100	100	100
	Setup Time (hr)	t_s	0.000	0.500	0.500	0.000	0.000
	Setup Time SCV	c_s^2	1.000	1.000	1.000	1.000	1.000
	Arrival Rate of Batches	r_a/k	0.100	0.098	0.093	0.088	0.080
	Eff Batch Process Time (failures+setups)	$t_e = kt_0/A+t_s$	9.090	9.590	10.380	9.180	9.180
	Eff Batch Process Time Var (failures+setups)	$k*\sigma_0^2/A^2+ 2m_r(1-A)kt_0/A+\sigma_s^2$	0.773	1.023	6.818	1.861	1.861
	Eff Process SCV (failures+setups)	c_e^2	0.009	0.011	0.063	0.022	0.022
	Utilization	u	0.909	0.940	0.966	0.812	0.731
	Departure SCV	c_d^2	0.181	0.031	0.061	0.035	0.028
yield	Yield	y	0.980	0.950	0.950	0.900	0.950
	Final Departure Rate	r_a*y	9.800	9.310	8.845	7.960	7.562
	Final Departure SCV	$yc_d^2+(1-y)$	0.198	0.079	0.108	0.132	0.077
measures	Utilization	u	0.909	0.940	0.966	0.812	0.731
	Throughput	TH	9.800	9.310	8.845	7.960	7.562
	Queue Time (hr)	CT_q	45.825	14.421	14.065	1.649	0.716
	Cycle Time (hr)	CT_q+t_e	54.915	24.011	24.445	10.829	9.896
	Cumulative Cycle Time (hr)	$\Sigma_i(CT_q(i)+t_e(i))$	54.915	78.925	103.371	114.200	124.096
	WIP in Queue (jobs)	r_aCT_q	458.249	141.321	130.948	14.587	5.700
	WIP (jobs)	r_aCT	549.149	235.303	227.586	95.780	78.773
	Cumulative WIP (jobs)	$\Sigma_i(r_a(i)CT(i))$	549.149	784.452	1012.038	1107.818	1186.591

Effects of Blocking

VUT Equation:

- characterizes stations with infinite space for queueing
- useful for seeing what will happen to WIP, CT without restrictions

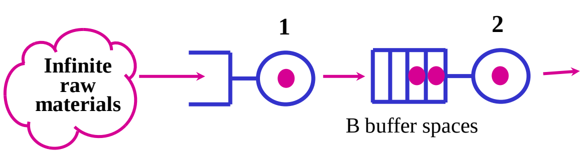
But real world systems often constrain WIP:

- physical constraints (e.g., space or spoilage)
- logical constraints (e.g., kanbans)

Blocking Models:

- estimate WIP and TH for given set of rates, buffer sizes
- much more complex than non-blocking (open) models, often require simulation to evaluate realistic systems

The M/M/1/b Queue



***Note:** there is room for b=B+2 jobs in system, B in the buffer and one at each station.*

Model of Station 2

$$WIP(M/M/1/b) = \frac{u}{1-u} - \frac{(b+1)u^{b+1}}{1-u^{b+1}}$$

← ***Goes to u/(1-u) as b→∞***
Always less than WIP(M/M/1)

$$TH(M/M/1/b) = \frac{1-u^{b}}{1-u^{b+1}} r_a$$

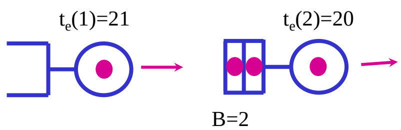
← ***Goes to r_a as b→∞***
Always less than TH(M/M/1)

$$CT(M/M/1/b) = \frac{WIP(M/M/1/b)}{TH(M/M/1/b)}$$

Little's law

where $u = t_e(2)/t_e(1)$ ***Note:** u>1 is possible; formulas valid for u≠1*

Blocking Example



$u = t_e(2)/t_e(1) = 20/21 = 0.9524$

$WIP(M/M/1) = \frac{u}{1-u} = 20$ jobs

$TH(M/M/1) = r_a = 1/t_e(1) = 1/21 = 0.0476$ job/min

$TH(M/M/1/b) = \frac{1\text{-}u^b}{1\text{-}u^{b+1}} r_a = \frac{1-0.9524^4}{1-0.9524^5}\left(\frac{1}{21}\right) = 0.039$ job/min

$WIP(M/M/1/b) = \frac{u}{1-u} - \frac{(b+1)u^{b+1}}{1-u^{b+1}} = 20 - \frac{5(0.9524^5)}{1-0.9524^5} = 1.8954$ jobs

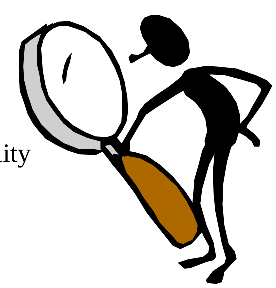
M/M/1/b system has less WIP and less TH than M/M/1 system

18% less TH

90% less WIP

Seeking Out Variability

General Strategies:



- look for long queues (Little's law)
- look for blocking
- focus on high utilization resources
- consider both flow and process variability
- ask "why" five times

Specific Targets:

- equipment failures
- setups
- rework
- operator pacing
- anything that prevents regular arrivals and process times

Variability Pooling

Basic Idea: independent sources of variability tend to cancel each other out, reducing total amount of variability.

Example (Time to process a batch of parts):

$$t_0 = \text{time to process single part}$$

$$\sigma_0 = \text{standard deviation of time to process single part}$$

$$c_0 = \frac{\sigma_0}{t_0} = \text{CV of time to process single part}$$

$$t_0(batch) = nt_0$$

$$\sigma_0^2(batch) = n\sigma_0^2$$

$$c_0^2(batch) = \frac{\sigma_0^2(batch)}{t_0^2(batch)} = \frac{n\sigma_0^2}{n^2 t_0^2} = \frac{\sigma_0^2}{nt_0^2} = \frac{c_0^2}{n} \Rightarrow \boxed{c_0(batch) = \frac{c_0}{\sqrt{n}}}$$

Batches are less variable than parts, because high and low process times "average out."

Safety Stock Pooling Example

- **PC's consist of 6 components (CPU, HD, CD ROM, RAM, removable storage device, keyboard)**
- **3 choices of each component: 3^6 = 729 different PC's**
- **Each component costs \$150 (\$900 material cost per PC)**
- **Demand for all models is normally distributed with mean 100 per year, standard deviation 10 per year**
- **Replenishment lead time is 3 months, so average demand during LT is $\theta = 25$ for computers and $\theta = 25(729/3) = 6075$ for components**
- **Use base stock policy with fill rate of 99%**

Pooling Example - Stock PC's

Base Stock Level for Each PC: (cycle stock, safety stock)

$R = \theta + z_s\sigma = 25 + 2.33(\sqrt{25}) = 37$

On-Hand Inventory for Each PC:

$I(R) = R - \theta + B(R) \approx R - \theta = z_s\sigma = 37 - 25 = 12$ units

Total (Approximate) On-Hand Inventory :

$12 \times 729 \times \$900 = \$7{,}873{,}200$

Pooling Example - Stock Components

Necessary Service for Each Component:

$S = (0.99)^{1/6} = 0.9983$ ⇨ $z_s = 2.93$

Base Stock Level for Each Component: (cycle stock, safety stock)

$R = \theta + z_s\sigma = 6075 + 2.93(\sqrt{6075}) = 6303$

On-Hand Inventory Level for Each Component:

$I(R) = R - \theta + B(R) \approx R - \theta = z_s\sigma = 6303\text{-}6075 = 228$ units

Total Safety Stock:

$228 \times 18 \times \$150 = \$615{,}600$ ***92% reduction!***

Basic Variability Takeaways

Variability Measures:

- CV of effective process times
- CV of interarrival times

Components of Process Variability

- failures
- setups
- many others - deflate capacity *and* inflate variability
- long infrequent disruptions worse than short frequent ones

Consequences of Variability:

- variability causes congestion (i.e., WIP/CT inflation)
- variability propagates
- variability and utilization interact
- pooled variability less destructive than individual variability

Exercise 4

Q1: Consider the following sets of inter output times from a machine. Compute the coefficient of variation for each sample, and suggest a situation under which such behavior might occur.

a. 5,5,5,5,5,5,5,5,5,5
b. 5.1,4.9,5.0,5.0,5.2,5.1,4.8,4.9,5.0,5.0
c. 5,5,5,35,5,5,5,5,5,42
d. 10,0,0,0,0,10,0,0,0,0

Q2: Suppose jobs arrive at a single-machine workstation at a rate of 20 per hour and the average process time is two and one-half minutes.

a. What is the utilization of the machine?
b. Suppose that inter arrival and process times are exponential,
   i. What is the average time a job spends at the station (i.e., waiting plus process time)?
   ii. What is the average number of jobs at the station?
   iii. What is the long-run probability of finding more than three jobs at the station?
c. Process times are not exponential, but instead have a mean of 2.5 minutes and a standard deviation of five minutes
   i. What is the average time a job spends at the station?
   ii. What is the average number of jobs at the station?
   iii. What is the average number of jobs in the queue?

Q3: The mean time to expose a single panel in a circuit-board plant is two minutes with a standard deviation of 1.5 minutes.

a. What is the natural coefficient of variation?
b. If the times remain independent, what will be the mean and variance of a job of 60 panels? What will be the coefficient of variation of the job of 60?
c. Now suppose times to failure on the expose machine are exponentially distributed with a mean of 60 hours and the repair time is also exponentially distributed with a mean of two hours. What are the effective mean and CV of the process time for a job of 60 panels?

Q4: Reconsider the expose machine of Problem 3 with mean time to expose a single panel of two minutes with a standard deviation of one and one-half minutes and jobs of 60 panels. As before, failures occur after about 60 hours of run time, but now happen only between jobs (i.e., these failures do not preempt the job). Repair times are the same as before. Compute the effective mean and CV of the process times for the 60 panel jobs. How do these compare with the results in Problem 3?

Q5: Consider two different machines A and B that could be used at a station. Machine A has a mean effective process time t_e of 1.0 hours and an SCV c_e^2 of 0.25. Machine B has a mean effective process time of 0.85 hour and an SCV of four.

a. For an arrival rate of 0.92 job per hour with $c_a^2 = 1$, which machine will have a shorter average cycle time?

b. Now put two machines of type A at the station and double the arrival rate (i.e., double the capacity and the throughput). What happens to cycle time? Do the same for machine B. Which type of machine produces shorter average cycle time?

c. With only one machine at each station, let the arrival rate be 0.95 job per hour with $c_a^2=1$. Recompute the average time spent at the stations for both machine A and machine B. Compare with a.

d. Consider the station with one machine of type A.

i. Let the arrival rate be one-half. What is the average time spent at the station? What happens to the average time spent at the station if the arrival rate is increased by one percent (i.e., to 0.505)? What percentage increase in wait time does this represent?

ii. Let the arrival rate be 0.95. What is the average time spent at the station? What happens to the average time spent at the station if the arrival rate is increased by one percent (i.e., to 0.9595)? What percentage increase in wait time does this represent?

Push and Pull Production Systems

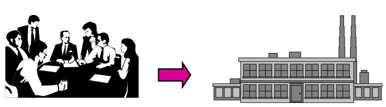
You say yes.
I say no.
You say stop.
and I say go, go, go!

– The Beatles

The Key Difference Between Push and Pull

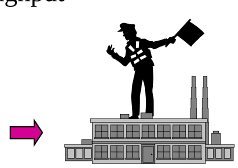
Push Systems: ***schedule*** work releases based on demand.

- inherently due-date driven
- control release rate, observe WIP level

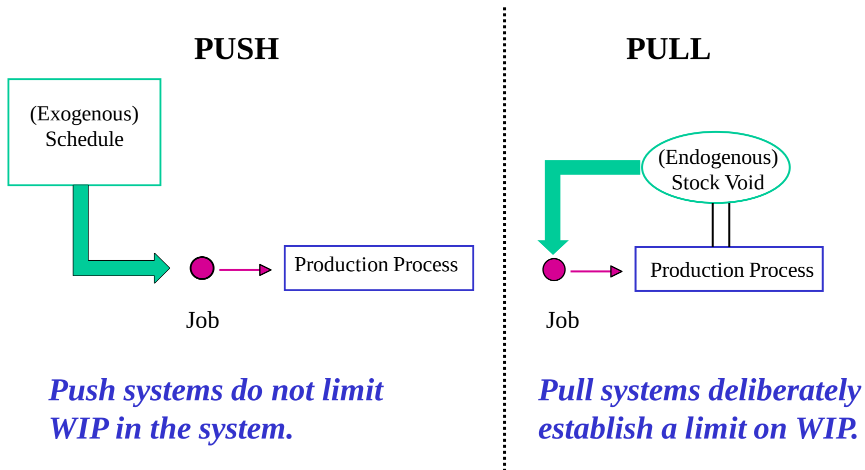


Pull Systems: ***authorize*** work releases based on system status.

- inherently rate driven
- control WIP level, observe throughput



Push vs. Pull Mechanics



What Pull is Not!

Make-to-Order:

- MRP with firm orders on MPS is make-to-order.
- But it does not limit WIP and is therefore a push system.

Make-to-Stock:

- Pull systems do replenish inventory voids.
- But jobs can be associated with customer orders.

Forecast Free:

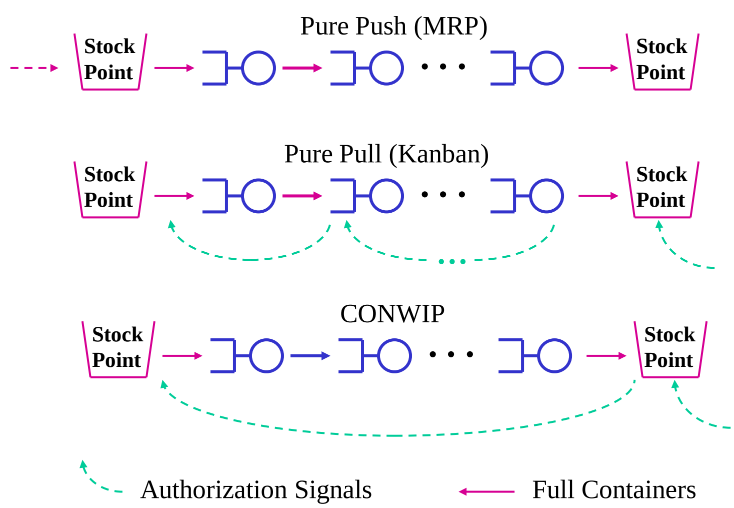
- Toyota’s classic system made cars to forecasts.
- Use of takt times or production smoothing often involves production without firm orders (and hence forecasts).

Push and Pull Examples

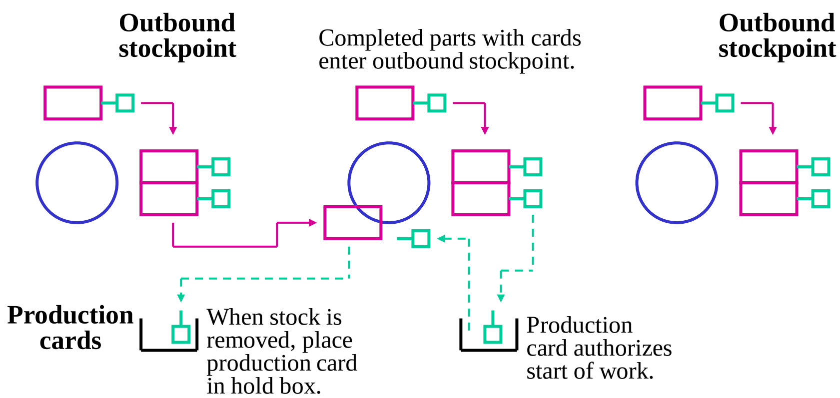
Are the following systems essentially push or essentially pull?

- Kinko's copy shop:
- Soda vending machine:
- "Pure" MRP system:
- Doctor's office:
- Supermarket (goods on shelves):
- Tandem line with finite interstation buffers:
- Runway at O'Hare during peak periods:
- Order entry server at Amazon.com:

Push and Pull Line Schematics



Pulling with Kanban



Advantages of Pull Systems

Low Unit Cost:

- low inventory
- reduced space
- little rework

High External Quality:

- high internal quality
- pressure for good quality
- promotion of good quality (e.g., defect detection)

Good Customer Service:

- short cycle times
- steady, predictable output stream

Flexibility:

- avoids committing jobs too early
- encourages floating capacity

The Magic of Pull

Pulling Everywhere?

> *You don't never make nothin' and* send *it no place. Somebody has to come get it.*
>
> – Hall 1983

No! It's the WIP Cap:

- Kanban – WIP cannot exceed number of cards
- "WIP explosions" are impossible

Pull Benefits Achieved by WIP Cap

Reduces Costs:

- prevents WIP explosions
- reduces average WIP
- reduces engineering changes

Improves Quality:

- pressure for higher quality
- improved defect detection
- improved communication

Improves Customer Service:

- reduces cycle time variability
- pressure to reduce sources of process variability
- promotes shorter lead times and better on-time performance

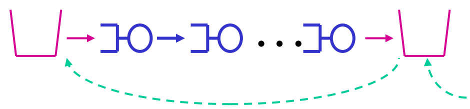
Maintains Flexibility:

- avoids early release (like air traffic control)
- less direct congestion
- less reliance on forecasts
- promotes floating capacity

CONWIP

Assumptions:

1. Single routing
2. WIP measured in units

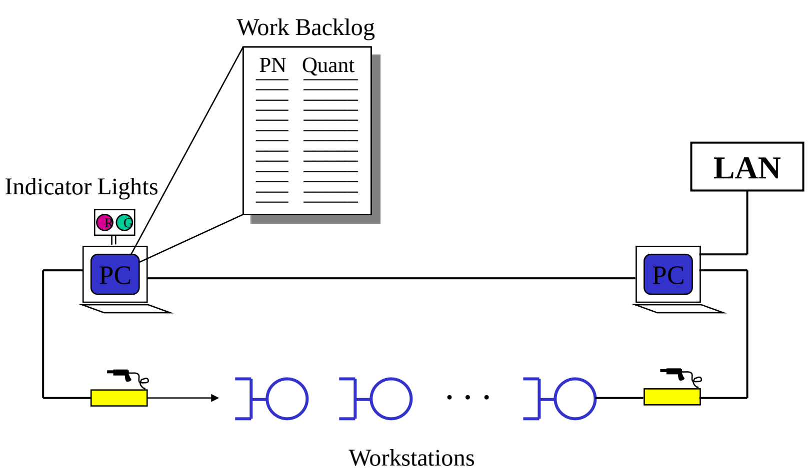


Mechanics: allow next job to enter line each time a job leaves (i.e., maintain a WIP level of *m* jobs in the line at all times).

Modeling:

- MRP looks like an open queueing network
- CONWIP looks like a closed queueing network
- Kanban looks like a closed queueing network with blocking

CONWIP Controller



CONWIP Efficiency Example

Equipment Data:

- 5 machines in tandem, all with capacity of one part/hr ($u=TH \cdot t_e=TH$)
- exponential (moderate variability) process times

CONWIP System: $TH(w) = \frac{w}{w+W_0-1} r_b = \frac{w}{w+4}$ ***PWC formula***

Pure Push System: $w(TH) = 5\frac{u}{1-u} = 5\frac{TH}{1-TH}$ ***5 M/M/1 queues***

CONWIP Efficiency Example (cont.)

How much WIP is required for push to match TH attained by CONWIP system with WIP=*w*?

CONWIP Robustness Example

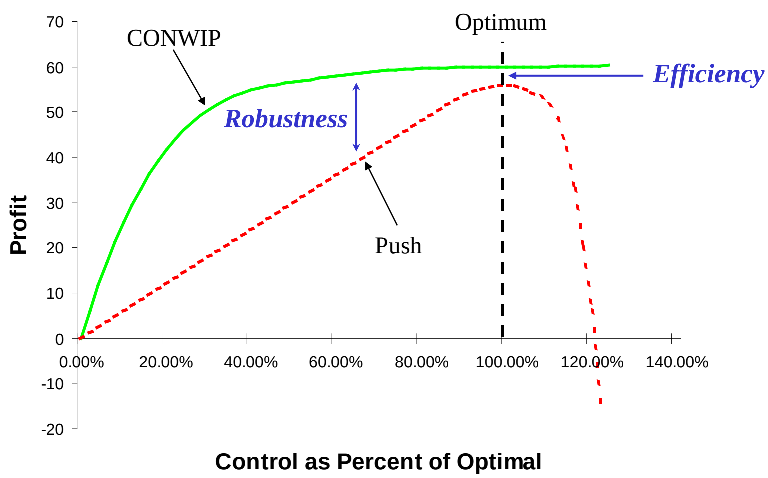
Profit Function: $\text{Profit} = pTH - hw$

CONWIP: $\text{Profit(w)} = p\left(\frac{w}{w+4}\right) - hw$ ***need to find "optimal" WIP level***

Push: $\text{Profit(TH)} = pTH - h\left(\frac{5\,TH}{1-TH}\right)$ ***need to find "optimal" TH level (i.e., release rate)***

Key Question: ***what happens when we don't choose optimum values (as we never will)?***

CONWIP vs. Pure Push Comparisons



Modeling CONWIP with Mean-Value Analysis

Notation:

$u_j(w)$ = utilization of station j in CONWIP line with WIP level w

$CT_j(w)$ = cycle time at station j in CONWIP line with WIP level w

$CT(w) = \sum_{j=1}^{n} CT_j(w)$ = cycle time of CONWIP line with WIP level w

$TH(w)$ = throughput of CONWIP line with WIP level w

$WIP_j(w)$ = average WIP level at station j in CONWIP line with WIP level w

Basic Approach: Compute performance measures for increasing *w* assuming job arriving to line "sees" other jobs distributed according to average behavior with *w-1* jobs.

Mean-Value Analysis Formulas

Starting with $WIP_j(0)=0$ and TH(0)=0, compute for w=1,2,…

$$CT_j(w) = \frac{t_e^2(j)}{2}[c_e^2(j)-1]TH(w-1) + [WIP_j(w-1)+1]t_e(j)$$

$$CT(w) = \sum_{j=1}^{n} CT_j(w)$$

$$TH(w) = \frac{w}{CT(w)}$$

$$WIP_j(w) = TH(w)CT_j(w)$$

Exercise 5

1. Consider a production line with three single-machine stations in series. Each has processing times with mean two hours and standard deviation of two hours. (Note that this makes it identical to the line represented in the practical worst case of Chapter 7.)
   a. Suppose we run this line as a push system and release jobs into it at a rate of 0.45 per hour with arrival variability given by $c_a = 1$. What is the average WIP in the line?
   b. Compute the throughput of this line if it is run as a CONWIP line with a WIP level equal to your answer in (*a*). Is the throughput higher or lower than 0.45? Explain this result.
2. Consider the same production line as in Problem 1. Suppose the marginal profit is $50 per piece and the cost of WIP is $0.25 per piece per hour.
   a. What is the profit from the push system if we set TH = 0.4?
   b. What is the profit from the pull system if we set WIP = 12? How does this compare to the answer of (*a*) and what does it imply about the relative profitability of push and pull systems?
   c. Increase TH in (*a*) by 20 percent to 0.48, and compute the profit for the push system. Increase WIP in (*b*) by 25 percent to 15, and compute the profit for the pull system.

   Compare the difference to the difference computed in (*b*). What does it imply about the relative robustness of push and pull systems?
3. Consider the same production system and profit function as in Problem 2.
   a. Compute the optimal throughput level operating as a push system and the optimal WIP level operating as a CONWIP system. What is the difference in the resulting profit levels?
   b. Suppose the process times actually have a mean and standard deviation of 2.2 hours, but the throughput used for the push system and the WIP level used for the pull system are computed as if the process times had a mean and standard deviation of 2 hours (i.e., were equal to the levels computed in (*a*)). Now what is the profit level in the push and pull systems, and how do they compare? Repeat this calculation for a system in which processing times have a mean and standard deviation of 2.4 hours. What happens to the gap between the profit in the push and pull systems?
4. In the practical worst case, it is assumed that the line is balanced (that is, $t_e(j) = t$ for all j) and that processing times are exponential (that is, $c_e(j) = 1$ for all j). Show that under these conditions, the MVA formulas for CT(w) and TH(w) reduce to the corresponding formulas for the practical worst case

$$\mathrm{CT}(w) = T_0 + \frac{w-1}{r_b}$$

$$\mathrm{TH}(w) = \frac{w}{W_0 + w - 1} r_b$$

   Hint: Note that because the line is balanced, $T_0 = nt$ and $r_b = 1/t$, where n is the number of stations in the line.

- What is a Supply Chain?

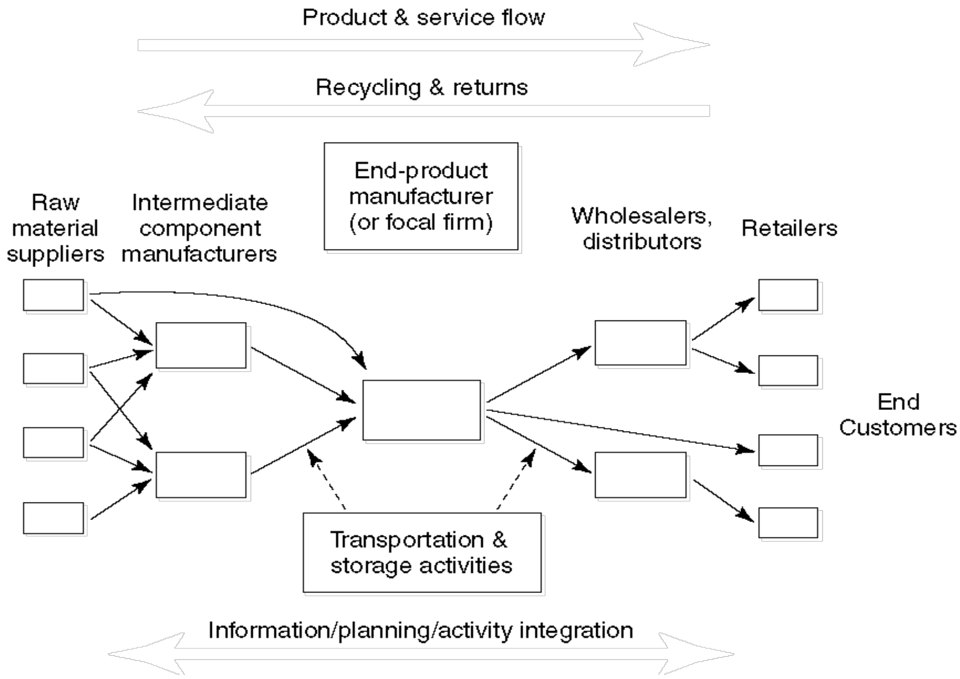
A supply chain consists of the flow of products and services from:

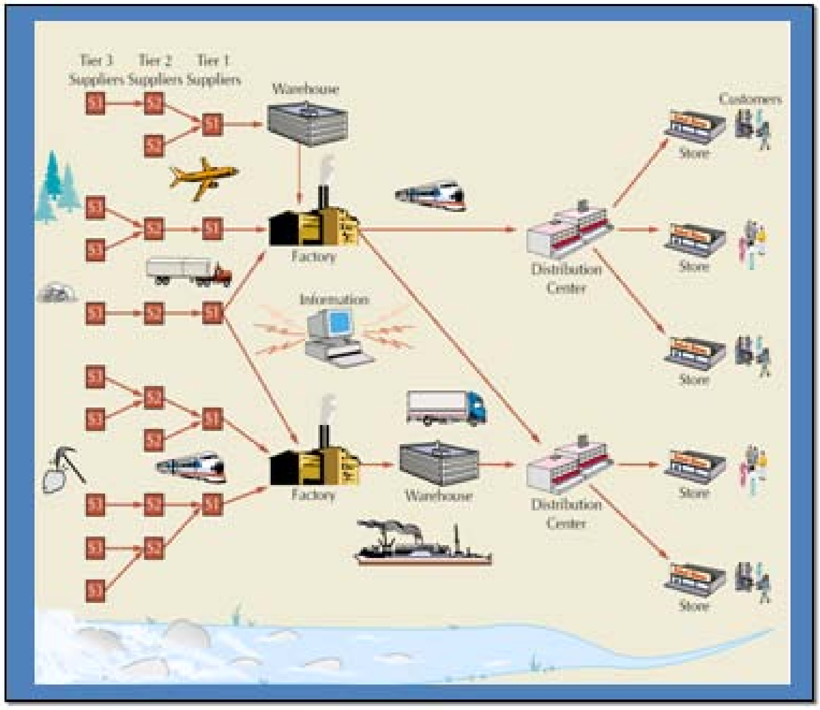
- Raw materials manufacturers
- Component and intermediate manufacturers
- Final product manufacturers
- Wholesalers and distributors and
- Retailers

Connected by transportation and storage activities, and

Integrated through information, planning, and integration activities

Many large firms are moving away from in-house Vertically Integrated structures to Supply Chain Management




Tier 3 Suppliers
Tier 2 Suppliers
Tier 1 Suppliers
Warehouse
Customers
Store
Factory
Distribution Center
Information
Store
Store
Factory
Warehouse
Distribution Center
Store
Store

- History:

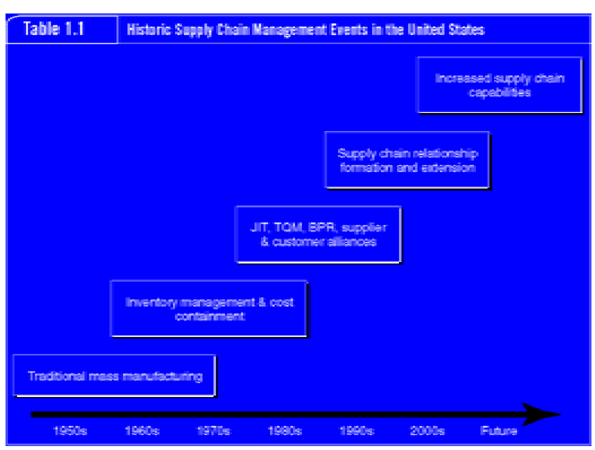


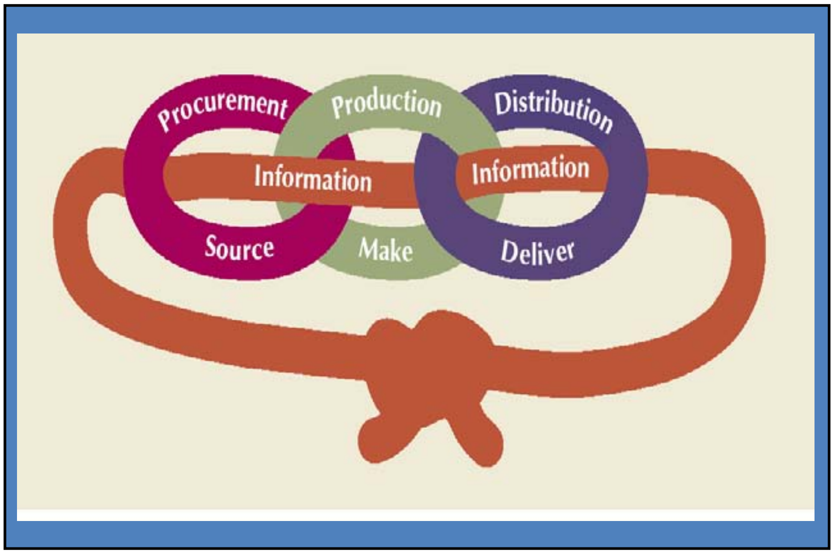
Table 1.1
Historic Supply Chain Management Events in the United States
Increased supply chain capabilities
Supply chain relationship formation and extension
JIT, TQM, BPR, supplier & customer alliances
Inventory management & cost containment
Traditional mass manufacturing
1950s
1960s
1970s
1980s
1990s
2000s
Future

- Importance of Supply Chain Management:

Who benefits most? Firms with:

- Large inventories
- Large number of suppliers
- Complex products
- Customers with large purchasing budgets

- To gain efficiencies from procurement, distribution and logistics
- To make outsourcing more efficient
- To reduce transportation costs of inventories
- To meet competitive pressures from shorter development times, more new products, and demand for more customization
- To meet the challenge of globalization and longer supply chains
- To meet the new challenges from e-commerce
- To manage the complexities of supply chains
- To manage the inventories needed across the supply chain



- The Foundations of Supply Chain Management

Supply Management	Supplier management, supplier evaluation, supplier certification, strategic partnerships
Operations	Demand management, MRP, ERP, inventory visibility, JIT (AKA lean production & Toyota Production System), TQM (AKA Six Sigma)
Distribution	Transportation management, customer relationship management, distribution network, perfect order fulfillment, global supply chains, service response logistics
Integration	Process integration, performance measurement

Purchasing Trends:

- ***Long term relationships***
- ***Supplier management-*** improve performance through
  - **Supplier evaluation** (determining supplier capabilities)
  - **Supplier certification** (third party or internal certification to assure product quality and service requirements)
- ***Strategic partnerships-*** successful and trusting relationships with top-performing suppliers

Operations Trends:

- **Demand management-** match demand to available capacity
- Linking buyers & suppliers via ***MRP*** and ***ERP*** systems
- Use ***JIT*** to improve the *"**pull**"* of materials to reduce inventory levels
- Employ ***TQM*** to improve quality compliance among suppliers

Distribution Trends:

- **Transportation management-** tradeoff decisions between cost & timing of delivery/customer service via trucks, rail, water & air
- **Customer relationship management-** strategies to ensure deliveries, resolve complaints, improve communications, & determine service requirements
- **Network design-** creating ***distribution network*s** based on tradeoff decisions between cost & sophistication of distribution system

Integration Trends:

- **Supply Chain Process Integration-** when supply chain participants work for common goals. Requires intrafirm functional integration. Based on efforts to change attitudes & adversarial relationships
- **Supply Chain Performance Measurement-** Crucial for firms to know if procedures are working

- Why is supply chain management difficult?

- Different organizations in the supply chain may have different, conflicting objectives
  - Manufacturers: long run production, high quality, high productivity, low production cost
  - Distributors: low inventory, reduced transportation costs, quick replenishment capability
  - Customers: shorter order lead time, high in-stock inventory, large variety of products, low prices
- Supply chains are dynamic - they evolve and change over time

- Key issues in supply chain management include:

- Distribution network configuration:
  - How many warehouses do we need?
  - Where should these warehouses be located?
  - What should the production levels be at each of our plants?
  - What should the transportation flows be between plants and warehouses?

– Inventory control:
  - Why are we holding inventory? Uncertainty in customer demand? Uncertainty in the supply process? Some other reason?
  - If the problem is uncertainty, how can we reduce it?
  - How good is our forecasting method?

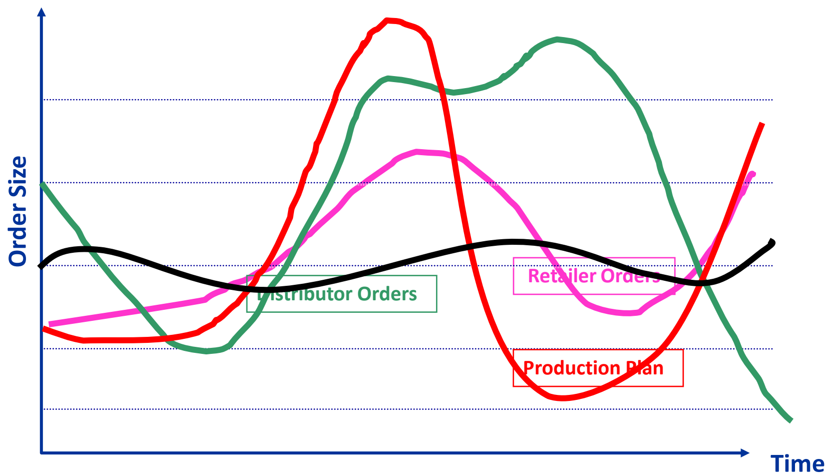
– Distribution strategies:
  - Direct shipping to customers?
  - Classical distribution in which inventory is held in warehouses and then shipped as needed?
  - Cross-docking in which transshipment points are used to take stock from suppliers' deliveries and immediately distribute to point of usage?

– Supply chain integration and strategic partnering:
  - Should information be shared with supply chain partners?
  - What information should be shared?
  - With what partners should information be shared?
  - What are the benefits to be gained?

- Product design
  - Should products be redesigned to reduce logistics costs?
  - Should products be redesigned to reduce lead times?
  - Would delayed differentiation be helpful?
- Information technology and decision-support systems
  - What data should be shared (transferred)
  - How should the data be analyzed and used?
  - What infrastructure is needed between supply chain members?
  - Should e-commerce play a role?
- Customer value
  - How is customer value created by the supply chain?
  - What determines customer value? How do we measure it?
  - How is information technology used to enhance customer value in the supply chain?

bullwhip effect:

- Ordering/producing in large lots can also increase the safety stock of suppliers and its corresponding carrying cost. It can also create what's called the *bullwhip effect*.
- The *bullwhip effect* is the phenomenon of orders and inventories getting progressively larger (more variable) moving backwards through the supply chain. This is illustrated graphically on the next slide.



Methods for coping with the *bullwhip effect:*

- **Reducing uncertainty.** This can be accomplished by centralizing demand information.
- **Reducing variability.** This can be accomplished by using a technique made popular by *WalMart* and then *Home Depot* called *everyday low pricing* (EDLP). EDLP eliminates promotions as well as the shifts in demand that accompany them.
- **Reducing lead time.** Order times can be reduced by using EDI (electronic data interchange).
- **Strategic partnerships.** The use of strategic partnerships can change how information is shared and how inventory is managed within the supply chain

- Global Supply Chain

- To compete globally requires an effective supply chain
- Information technology is an "enabler" of global trade
- Nations form trading groups
- No tariffs or duties

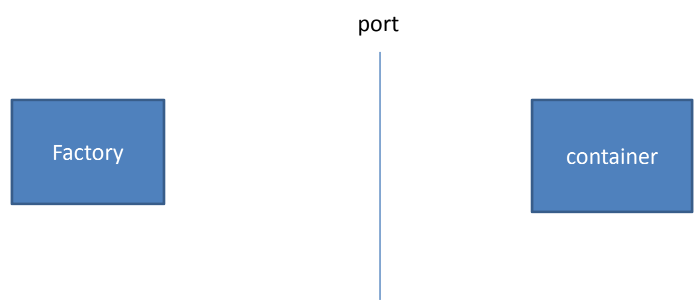
-Obstacles to Global Chain Transactions:

- Increased documentation for invoices, cargo insurance, letters of credit, ocean bills of lading or air waybills, and inspections
- Ever changing regulations that vary from country to country that govern the import and export of goods
- Trade groups, tariffs, duties, and landing costs
- Limited shipping modes
- Differences in communication technology and availability

- Different business practices as well as language barriers
- Government codes and reporting requirements that vary from country to country
- Numerous players, including forwarding agents, custom house brokers, financial institutions, insurance providers, multiple transportation carriers, and government agencies
- Since 9/11, numerous security regulations and requirements

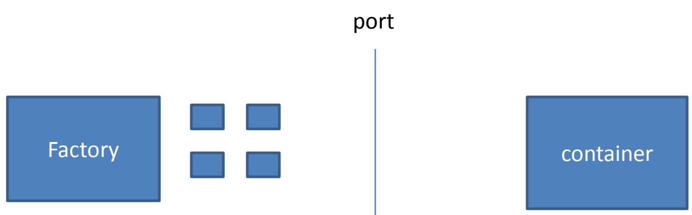
- Example of SCM in Sabic:

- Transportation



- This moving takes 30 days

- They used supply change management to solve this problem , the found



- It is taking now 2 days only

Competition is no longer between companies ; it is between supply chains

END