7

INVENTORY MANAGEMENT

MGT2405, University of Toronto, Denny Hong-Mo Yeh

Inventory management is the branch of business management that covers the planning and control of the inventory. In the previous chapters, we have discussed priority and capacity planning and control. Priority planning determines what materials are needed and when they are needed in order to meet customers' demands. Capacity planning determines the amount of capacity required in each period to execute the priority plans. There are various ways to conduct priority and capacity planning; a "feasible" solution that satisfies a customer's requirement may not be good enough. We demand a "good" plan that satisfies customers while maintaining the lowest possible total cost.

Manufacturing Organization

Different inventory management approaches are required for different manufacturing organizations. The designs of manufacturing organizations for high-mix/low-volume products and low-mix/high-volume products are different. There are two forms of manufacturing organization: flow shop and job shop.

- *Flow Shop*

  In a flow shop, machines and operators perform stable, standard, usually uninterrupted materials management. The flow shop is appropriate for an extremely low-mix/high-volume product, where a single type of product is produced in the production line. Specialized equipment and labor are established to produce the product in large quantities. This is defined as *mass production*. Different products with very similar design can also be produced in a specialized production line with fixed routing and low or no setups. This is called *continuous production*. In continuous production, the productive equipment is organized and sequenced according to the steps involved in producing the products, and the material flow is continuous during the production process. Continuous production system produces continuous products such as steel and chemical. The products in the *repetitive production* have similar design and need low or no setup cost, the process is also continuous, yet the products are discrete. The repetitive production system produces different products with same process.

- *Job Shop*

In a job shop, equipments are organized by function. Each job, a certain amount of a product in production, follows a distinct routing through the shop. A routing comprises a number of operations. There are setups between operations. The process is not continuous, and material flows are sometimes interrupted. Each job contains a certain quantity of a product. Mold or fixture changes are required when the production line changes jobs. Machine utilization in a job shop is lower than that in a flow shop. Unless the quantity of a product is large enough to support a specialized facility, continuous production through a flow shop is impossible. This form of manufacturing is defined as *intermittent production.*

- *Throughput, WIP, and cycle time*

Throughput, work-in-process inventory, and cycle-time are related indices that are frequently used in flow shops. Throughput is the total volume of production through a facility per unit of time. Cycle time is the length of time that starts when a material enters a facility and ends when it exits. Therefore, work-in-process inventory equals the product of throughput and cycle time. Throughput is the output rate of a facility and is frequently used to measure the performance of a flow shop. In a job shop, since different products are processed through various routings, throughput and cycle times depend on the product mix and are not stable. The standard and actual cycle-times for each job and the planned and actual input/output and work-in-process inventory for each work center are used to monitor the performance of a job shop.

Inventory Classes

Materials flow from suppliers, through a manufacturing organization, to the customers. The progressive states of a material are classified as raw materials, semi-finished goods, finished goods, and work-in-process (WIP).

- *Raw Materials*

  Purchased items or extracted materials that are converted via the manufacturing process into components and/or products. Raw materials appear in the bottom level of BOM. They are stored in the warehouse and are non-phantom items.

- *Semi-finished Goods*

  Semi-finished goods are items that have been stored uncompleted, awaiting final operations that will adapt them to different uses or customer specifications. Semi-finished goods are made under the instruction of a shop order, using the components issued by a picking order, and stored in the warehouse when finished. They are the items between the top and bottom levels in a management BOM (rather than engineering BOM) and are non-phantoms. Semi-finished goods are not sold to the customers.

- *Finished Goods*

  A finished good is a product sold as a completed item or repair part, i.e., any item subject to a customer order or sales forecast. Finished goods are non-phantoms and are stored in the warehouse before they are shipped.

- *Work-In-Process (WIP)*

  Products in various stages of completion throughout the plant, including all material from raw material that has been released for initial processing up to completely processed material waiting for inspection and acceptance as finished goods. WIP inventory is temporarily stored on the shop floor and appears as a phantom in the BOM.

- *Maintenance, Repair, and Operational Supplies (MRO)*

  Items used in support of general operations and maintenance such as maintenance supplies, spare parts, and consumables used in the manufacturing process and supporting operations. These items are used in production but do not become part of the product.

Inventory Functions

- *Safety Stock*

  An additional quantity of stock kept in inventory to protect against unexpected fluctuations in demands and/or supply. If demand is greater than forecast or supply is late, a stock shortage will occur. Safety stock is used to protect against these unpredictable events and prevent disruptions in manufacturing. Safety stock is also called buffer stock.

- *Lot-size Inventory*

  In order to take advantage of quantity price discounts, reduce shipping and setup costs, or address similar considerations, items are manufactured or purchased in quantities greater than needed immediately. Since it is more economical to produce or purchase less frequently and in larger quantity, inventory is established to cover needs in periods when items are not replenished. Lot-size inventory depletes gradually as customer orders come in and is replenished cyclically when suppliers' orders are received.

- *De-coupling Stock*

  Inventory between facilities that process materials at different rates. De-coupling stock de-couples facilities to prevent the disparity in production rates at different facilities from interfering with any one facility's production. This inventory increases the utilization of facilities.

- *Pipeline Inventory*

  Inventory to fill the transportation network and the distribution system including the flow through intermediate stocking points. This inventory exists because of the time needed to move goods from one location to another. Time factors involve order transmission, order processing, shipping, transportation, receiving, stocking, etc.

- *Transportation Inventory*

Transportation inventory is part of pipeline inventory. It is inventory in transit between locations. The average amount of inventory in transit is:

$$I = (A / 365) * D$$

Where I is the average annual inventory in transit, A is annual usage, and D is transit time in days. The transit inventory does not depend upon the shipment size but on the transit time and the annual usage. The only way to reduce the inventory in transit is to reduce the transit time.

- *Anticipation Inventory*

Additional inventory above basic pipeline inventory to cover projected trends of increasing sales, planned sales promotion programs, seasonal fluctuations, plant shut downs, and vacations. Anticipation inventory differs from safety stock in that it is a predictable amount.

- *Hedge Inventory*

Inventory held to protect against future fluctuations due to a dramatic change in prices, strikes, war, unsettled government, etc. These events are rare, but such occurrences could severely damage a company's initiatives. Risk and consequences are usually high, and top management approval is often required. Hedge inventory is similar to safety stock except that a hedge has a dimension of timing as well as amount. If the incident does not occur in the predicted time period, the hedge rolls over to the time period.

Safety, anticipation, and hedge inventories are compared in Table 1.

Table 1: Comparison of Safety, Anticipation, and Hedge Inventory

Inventory	Fluctuation	Time/Amount	Rolling Over
Safety	Unpredictable	Amount	No
Anticipation	Predictable	Time & Amount	No
Hedge	Semi-predictable	Time & Amount	Yes

Case Study: Comparison of Hedge and Safety Stock

Hedge inventory as well as safety stock is held to protect against future uncertainties. Both situations face unpredictable uncertainties, but a hedge considers timing as well as quantity. If we know the time when an event might happen, we can determine a hedge requirement adding onto the gross requirement for MRP to plan more planned order release (POR). An example of hedging process is shown in the MRP table in Table 2 and Table 3.

Table 2: MRP for Parent X (Hedge)

Part#=X	**Past**	OH=	370	LT=	2	SS=	0	AL=	0	Hedge Time Fence=		5
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Fcs Sale		130	160	120	260	130	120	185	115	130	140	150	130
Hedge							***60***	0					
GR		130	160	120	260	130	180	185	115	130	140	150	130
SR													
POH		240	80	-40	-260	-130	-180	-185	-115	-130	-140	-150	-130
PAB		240	80	0	0	0	0	0	0	0	0	0	0
NR		0	0	40	260	130	180	185	115	130	140	150	130
POR	0	40	260	130	180	185	115	130	140	150	130	0	0

Table 3: MRP for Component C

Part#=C	**Past**	OH=	20	LT=	2	SS=	0	AL=	0				
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR	0	40	260	130	180	185	115	130	140	150	130	0	0
SR		360											
POH		340	80	-50	-180	-185	-115	-130	-140	-150	-130	0	0
PAB		340	80	0	0	0	0	0	0	0	0	0	0
NR		0	0	50	180	185	115	130	140	150	130	0	0
POR	0	50	180	185	115	130	140	150	130	0	0	0	0

Suppose a product X is made from a component C. An extra quantity of 60 Xs might be required in period 6; this requirement is called a hedge. The timing or quantity of a hedge is changed when management has a new decision. The planned order for the hedge can only be released under the authorization of the management. If the planned order of a hedge is released, it is transformed to a scheduled receipt. When this uncertainty is covered by a safety stock, the overall inventory increases drastically, as shown in Table 4 and 5.

Table 4: MRP for Parent X (Safety Stock)

Part#=X	**Past**	OH=	370	LT=	2	SS=	***60***	AL=	0	Hedge Time Fence=			5
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Fcs Sale		130	160	120	260	130	120	185	115	130	140	150	130
Hedge							0						
GR		130	160	120	260	130	120	185	115	130	140	150	130
SR													
POH		240	80	-40	-200	-70	-60	-125	-55	-70	-80	-90	-70
PAB		240	80	60	60	60	60	60	60	60	60	60	60
NR		0	0	100	260	130	120	185	115	130	140	150	130
POR	0	100	260	130	120	185	115	130	140	150	130	0	0

Table 5: MRP for Component C

Part#=C	**Past**	OH=	20	LT=	2	SS=	0	AL=	0				
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR	0	100	260	130	120	185	115	130	140	150	130	0	0
SR		360											
POH		280	20	-110	-120	-185	-115	-130	-140	-150	-130	0	0
PAB		280	20	0	0	0	0	0	0	0	0	0	0
NR		0	0	110	120	185	115	130	140	150	130	0	0
POR	0	110	120	185	115	130	140	150	130	0	0	0	0

Conflict of Objectives

All enterprises are pursuing high customer service level, high operating efficiency, and low inventory cost. However, these objectives are conflict.

- *Customer Service*

  Customer service is the ability of a company to deliver a product to the customer at the time the customer specifies. It is a measure of inventory management effectiveness. The customer can be a purchaser, a distributor, another plant in the organization, or the next workstation. Ways to measure customer service include percentage of orders shipped on schedule, percentage of line items shipped on schedule, and order-days out of stock. Inventory (safety stock) helps to improve customer service by protecting against uncertainties in production, but at the price of incurring higher inventory cost.

- *Operating Efficiency*

Operating efficiency is the ratio of the actual output of a work center, department, or plant to the planned or standard output. Inventory (de-coupling stock) allows operations with different production rates to operate separately and more economically. Inventory (anticipation inventory) can also level the production by building more in the valley periods for sale in the peak period. By doing this, the costs of changing production levels are avoided. Changing production level involves costs such as overtime, hiring and firing, training, subcontracting, etc. Inventory (lot-size inventory) allows longer production runs, which bring lower setup costs, ordering costs, and quantity discounts.

- *Inventory Cost*

The enhancement of customer service and operating efficiency is by no means free. Inventories have tangible and intangible costs. Item costs (direct material, direct labor, overhead, transportation, custom duty, and insurance), carrying costs, ordering costs, shortage costs, and capacity costs are all tangible inventory costs. Inventories cover the manufacturing problems; the manufacturing problems cause more inventories and deteriorate the manufacturing system. This is an intangible inventory cost.

Inventory Costs related to Lot Sizing

- *Ordering Cost*

Ordering costs are the costs associated with placing an order with the factory or a supplier. The ordering cost does not depend on the quantity ordered. It is a composite of all costs related to placing purchase orders or preparing shop orders, including

1. Paperwork,
2. Work station setups,
3. Inspection, scrap, and rework associated with setups,
4. Record keeping for work-in-process.

- *Carrying Cost*

Carrying cost is the total of costs related to maintaining the inventory, including

1. Capital cost invested in inventory, or foregone earnings of alternate investment,
2. Storage costs for space, equipment, and people,
3. Taxes and insurance on inventory,
4. Obsolescence caused by market, design, or competitors' product changes,
5. Deterioration from long-term storage and handling,
6. Record keeping for inventory.

ABC Classification Method

As there are enormous materials in the warehouse, we cannot manage all the materials in the same way. Important parts should be paid more attention to, and those cheaper and less important materials should be managed in a simple way or not managed. Materials are classified into three classes. In planning, order releasing, receiving, storing, counting, and costing, we use sophisticated and precise approach for class A materials, and simpler approach for class C materials.

- *Stock Keeping Unit (SKU)*

An item may be stocked at many warehouses. An item at a particular geographic location is called an SKU. For example, one item stocked at two plants and four distribution centers would represent six SKUs. In determining the classification of a material, all the SKUs have to be included.

- *Application of Pareto's Law*

Inventory control is exercised by controlling individual stock keeping units. Pareto's Law observes that a small number of items often dominate the results achieved. In inventory control, it is found that the relationship between the percentage of the number of items and the percentage of the annual dollar usage follows a pattern. We can classify items into three classes based on their observed dollar usage:

1. Class A: About 10% to 20% of the items account for about 50% to 80% of the dollar usage,
2. Class B: About 20% to 30% of the items account for about 15% to 20% of the dollar usage,
3. Class C: About 50% to 70% of the items account for about 5% to 10% of the dollar

usage.

Steps in ABC classification include:

1. Determine the annual usage for each item,
2. Calculate the annual dollar usage for each item,
3. Sort the items according to their annual dollar usage,
4. Calculate the accumulated annual dollar usage, percentage of the accumulated annual usage, and the accumulated percentage of the items,
5. Group the items into A, B, and C classes based on the percentage of annual usage.

- *Control Approaches*

"C" class items account for only a small percentage of total dollar usage but are vital to the entire production process. A shortage of a single C class material could result in interruption of the operations in a plant. Simple control approaches that call for large quantities and high safety stocks are used to ensure that there is an adequate amount of C class materials anytime. A two-bin system is an approach for inventory management of C class items.

"A" class items are extremely important and deserve the tightest control and the most frequent reviews. Tight control includes absolutely accurate records, regular reviews by management, frequent reviews of demand forecasts, and close follow-up and expediting to reduce the lead times. TPOP (for independent items), MRP (for dependent items), and close following up of purchase and shop orders are types of inventory planning and control used for A class items.

Normal controls with good record keeping are applied to B class items. Both MRP and ROP are commonly applied in planning and controlling B class items.

Simple Inventory Replenishment Methods

Not every item should use a sophisticated approach such as MRP to plan and control purchase or manufacturing orders. For low-value C class items, such as nuts and bolts, simple methods should be used to replenish the inventory.

- *Two-bin system*

A type of fixed order system in which inventory is carried in two bins. The second bin represents the order point (the inventory level at or below which an order is released), and is not touched until the first bin is used up. A replenishment order is placed when the first bin is empty. When the material is received, the second bin is refilled and the excess is put into the first bin. At this time, stock is again drawn from the first bin until it is exhausted.

There are variations on the two-bin system. In one variation, there need not be exactly two bins. For example, the first "bin" may include five boxes, and the second bin, three boxes of materials. In other versions, there may be no bins. For example, tags are frequently used in a bookstore to replenish the inventories. A tag is placed in a book that is in a stack in a position equivalent to the order point. When that book is sold, the tag automatically informs the clerk to reorder the books.

- *Visual Review System*

A simple inventory control system where the inventory reordering is based on actual visual inspection of the amount of inventory on-hand. Visual review system periodically checks stocks of items against rough inventory levels where reordering is thought to be necessary, or order points. If this level is reached, replenishing orders are placed.

The visual review system also has variations. The inventories are not necessarily reviewed where they are physically located. In one variation, a card is attached to each case of materials. When a case's materials are exhausted, the card is placed on a board in the office. The number of cards on the board indicates the consumption of the materials. A red line drawn on the board represents the order point. When the cards touch the red line, a replenishment order is released.

- *Min-max System*

A type of order point replenishment system where the "min" is the order point, and the "max" is the "order-up-to" inventory level. The order quantity is variable and is the result of max minus available and on-order inventory. An order is placed when the available and on-order is at or below the min. The min and max levels are usually arbitrarily determined through experience.

Reorder Point System and EOQ

- *EOQ Theory*

The EOQ formula was created by Ford W. Harris in 1915. Although it was developed long before MRP logic was invented, it can easily be incorporated into an MRP system. In stable demand cases, EOQ is still frequently used. The assumptions on which EOQ is based are

1. Demand is continuous, relatively stable, and known,
2. Ordering cost and inventory carrying cost are constant and known,
3. The replacement occurs all at once.

Let S be ordering cost, C be unit item cost, I be carrying cost rate in percentage per year, U be the annual usage, SS be the safety stock, and Q be the order quantity. The total inventory cost is

$$T = S \cdot \frac{U}{Q} + (\frac{Q}{2} + SS) \cdot I \cdot C$$

To obtain the optimal solution for Q, the first derivative of T must be equal to zero.

$$\frac{dT}{dQ} = -\frac{SU}{Q^2} + \frac{IC}{2} = 0$$

$$\therefore Q = \sqrt{\frac{2SU}{IC}}$$

- *Safety Stock*

If demand in the lead-time can be described by a normal distribution, the safety stock at a certain customer service level can be determined by following steps:

1. Calculate the mean absolute deviation (MAD) of demands during the lead-time,

MAD = Sum of absolute deviations / Number of observations

2. Determine the safety factor for the required service level. Table 6 shows the safety factors and the service levels.

Table 6: Safety Factors

Service Level (%)	Safety Factor
50	0.00
75	0.84
80	1.05
85	1.30
90	1.60
94	1.95
95	2.05
96	2.19
97	2.35
98	2.56
99	2.91
99.5	3.20
99.99	5.00

3. Safety stock is calculated by multiplying MAD by the required safety factor.

Safety Stock = MAD * Safety Factor

- *Order Point*

Order point is the inventory level below which inventory must be replenished. If the total inventory on hand and on order falls to or below that point, action must be taken to replenish the inventory. The order point is calculated by the following formula:

$$OP = (U/365)*LT + SS$$

In the above equation, OP is the order point, U is the annual usage in unit, LT is the lead-time in day, and SS is the safety stock.

Lot-Sizing Techniques

In the following discussion, we use an example to describe various lot-sizing techniques. In this example, the ordering cost is 10 and the holding cost per part per period is 0.007.

- *Lot-For-Lot (LFL)*

A lot-sizing technique that generates planned orders in quantities equal to the net requirements in each period. In MRP logic, planned order releases are equal to net requirements for LFL lot sizing rule. An example for LFL is shown in Table 7. The total cost for this schedule is 107.8.

Table 7: LFL Lot-Sizing

Part#=X	Past	OH=	370	LT=	2	SS=	80	AL=	0			
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	160	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	-80	-50	-40	-105	-35	-50	-60	-70	-50
PAB		240	80	80	80	80	80	80	80	80	80	80	80
NR		0	0	120	160	130	120	185	115	130	140	150	130
PORC		0	0	120	160	130	120	185	115	130	140	150	130
POR	0	120	160	130	120	185	115	130	140	150	130	0	0

- *Fixed Order Quantity (FOQ)*

A lot-sizing technique that will always cause planned or actual orders to be generated for a predetermined fixed quantity, or multiples, if net requirements for the period exceed the fixed order quantity. The order quantity is decided arbitrarily. An example is shown in Table 8. The total cost is 61.33. The ordering frequency is much lower than that in LFL.

Table 8: FOQ Lot-Sizing

Part#=X	Past	OH=	370	LT=	2	SS=	80	AL=	0	FOQ=	600		
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	160	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	400	270	150	-35	450	320	180	30	500
PAB		240	80	560	400	270	150	565	450	320	180	630	500
NR		0	0	120	0	0	0	115	0	0	0	50	0

PORC		0	0	600	0	0	0	600	0	0	0	600	0
POR	0	600	0	0	0	600	0	0	0	600	0	0	0

- *Economic Order Quantity (EOQ)*

This is a fixed order quantity rule with order quantity equal to EOQ. Annual usage is determined by the average of the twelve week gross requirements times 52. Item unit cost is 1.5, and the holding cost rate is 25%. The inventory carrying cost is equivalent to those in the previous examples. An example is shown in Table 9; the calculation of EOQ is shown in Table 10. The total cost is 64.06.

Table 9: EOQ Lot-Sizing

Part#=X	Past	OH=	370	LT=	2	SS=	80	AL=	0	EOQ=	621		
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	160	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	421	291	171	-14	492	362	222	72	563
PAB		240	80	581	421	291	171	607	492	362	222	693	563
NR		0	0	120	0	0	0	94	0	0	0	8	0
PORC		0	0	621	0	0	0	621	0	0	0	621	0
POR	0	621	0	0	0	621	0	0	0	621	0	0	0

Table 10: The Calculation of EOQ

Average Usage per Period=				139.2		Ordering Cost=		10
Annual Usage =				7237		Item Unit Cost=		1.5
EOQ=				621		Annual Holding Cost Rate=		0.25

- *Periodic Review System (PRS)*

A periodic reordering system where the time interval between orders is fixed, but the size of the order is variable. An order is placed every n time periods. The time interval is determined arbitrarily. This approach as well as the next approach (POQ) is also known as fixed reorder cycle inventory models. Table 11 is an example of PRS. The size of the order is the total GR in the ordering time intervals. The total cost is 57.27.

Table 11: PRS Lot-Sizing

Part#=X	Past	OH=	370	LT=	2	SS=	80	AL=	0	POS=	3		
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**

GR		130	160	120	160	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	210	80	-40	195	80	-50	230	80	-50
PAB		240	80	370	210	80	380	195	80	370	230	80	80
NR		0	0	120	0	0	120	0	0	120	0	0	130
PORC		0	0	410	0	0	420	0	0	420	0	0	130
POR	0	410	0	0	420	0	0	420	0	0	130	0	0

- *Periodic Order Quantity (POQ)*

A lot-sizing technique under which the lot size is equal to the net requirements for a given number of periods as decided by EOQ. This is a PRS where the time interval is determined by EOQ. Table 12 is an example. The total cost is 50.37. The time interval is calculated in Table 13.

Table 12: POQ Lot-Sizing

Part#=X	Past	OH=	370	LT=	2	SS=	80	AL=	0	POQ=	4		
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	160	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	330	200	80	-105	350	220	80	-70	80
PAB		240	80	490	330	200	80	465	350	220	80	210	80
NR		0	0	120	0	0	0	185	0	0	0	150	0
PORC		0	0	530	0	0	0	570	0	0	0	280	0
POR	0	530	0	0	0	570	0	0	0	280	0	0	0

Table 13: Calculation of Time Period

Average Usage per Period=			139.2	Ordering Cost=		10
Annual Usage =			7237	Item Unit Cost=		1.5
EOQ=			621	Annual Holding Cost Rate=		0.25
POQ=EOQ/Usage Per Period=			4			

- *Least Unit Cost (LUC)*

A dynamic lot-sizing technique that chooses the lot size with the lowest unit cost by adding ordering cost and inventory carrying cost for each trial lot size and dividing by the number of units in lot size. The unit cost is calculated from the period next to a period with a planned order receipt, until the lowest unit is found. In Table 14, a lot size covering the GR from period 3 to period 6 is of the least unit cost, as shown in Table 15. The total cost of this example is 48.99.

Table 14: LUC Lot-Sizing

Part#=X	**Past**	OH=	370	LT=	2	SS=	80	AL=	0				
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	160	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	515	385	265	80	-35	500	360	210	80
PAB		240	80	675	515	385	265	80	630	500	360	210	80
NR		0	0	120	0	0	0	0	115	0	0	0	0
PORCP		0	0	715	0	0	0	0	665	0	0	0	0
POR	0	715	0	0	0	0	665	0	0	0	0	0	0

Table 15: Determining Lot Size with LUC

Period		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	160	130	120	185	115	130	140	150	130
Acc. Fcst.				120	280	410	530	715	830	960	1100	1250	1380
hold time				0	1	2	3	4	5	6	7	8	9
Hold cost				0	1.154	1.875	2.596	5.337	4.147	5.625	7.067	8.654	8.438
Acc. hold cost				0	1.154	3.029	5.625	10.96	15.11	20.73	27.8	36.45	44.89
total cost				10	11.15	13.03	15.63	20.96	25.11	30.73	37.8	46.45	54.89
unit cost				0.083	0.04	0.032	0.029	0.029	0.03	0.032	0.034	0.037	0.04
Acc. Fcst.				120	280	410	530	715	830	960	1100	1250	1380
Lot Size=	715		Least Unit Cost=			0.029							

- *Least Total Cost (LTC)*

A dynamic lot-sizing technique that calculates the order quantity by comparing the setup (or ordering) cost and the carrying cost for various lot sizes, and selects the lot where these costs are most nearly equal. Least total cost occurs where the accumulated carrying cost equals a setup cost. An example is shown in Table 16. The accumulated holding cost of GR from period 3 to period 7 (11.68) is closest to the setup cost (10), so a lot size of 715 is determined, as shown in table 17. The total cost for this example is 48.99.

Table 16: LTC Lot-Sizing

Part#=X	**Past**	OH=	370	LT=	2	SS=	80	AL=	0				
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	160	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	515	385	265	80	-35	500	360	210	80
PAB		240	80	675	515	385	265	80	630	500	360	210	80

NR		0	0	715	0	0	0	0	665	0	0	0	0
PORC		0	0	715	0	0	0	0	665	0	0	0	0
POR	0	715	0	0	0	0	665	0	0	0	0	0	0

Table 17: Determining Lot Size with LTC

Period		1	2	3	4	5	6	7	8	9	10	11	12
GR		130	160	120	160	130	120	185	115	130	140	150	130
Acc. Fcst.				120	280	410	530	715	830	960	1100	1250	1380
hold time				0	1	2	3	4	5	6	7	8	9
hold cost				0	1.154	1.875	2.596	5.337	4.147	5.625	7.067	8.654	8.438
Acc. hold cost				0	1.154	3.029	5.625	10.96	15.11	20.73	27.8	36.45	44.89
Ordering cost				10	10	10	10	10	10	10	10	10	10
Abs. deviation				10	8.846	6.971	4.375	0.962	5.108	10.73	17.8	26.45	34.89
Acc. Fcst.				120	280	410	530	715	830	960	1100	1250	1380
Lot Size=	715		Minimal absolute deviation=				0.962						

The above examples show that LUC and LTC have the same result. But it is not always so. LUC and LTC may have different results. Suppose the gross requirement in period 4 is 260. The results of LUC and LTC are listed in Table 18 to 21.

Table 18: LUC Lot-Sizing

Part#=X	**Past**	OH=	370	LT=	2	SS=	80	AL=	0				
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	260	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	330	200	80	-105	350	220	80	-70	80
PAB		240	80	590	330	200	80	465	350	220	80	210	80
NR		0	0	120	0	0	0	185	0	0	0	150	0
PORC		0	0	630	0	0	0	570	0	0	0	280	0
POR	0	630	0	0	0	570	0	0	0	280	0	0	0

Table 19: Determining Lot Size with LUC

Period		1	2	3	4	5	6	7	8	9	10	11	12
GR		130	160	120	260	130	120	185	115	130	140	150	130
Acc. Fcst.				120	380	510	630	815	930	1060	1200	1350	1480
hold time				0	1	2	3	4	5	6	7	8	9
hold cost				0	1.875	1.875	2.596	5.337	4.147	5.625	7.067	8.654	8.438
Acc. hold cost				0	1.875	3.75	6.346	11.68	15.83	21.45	28.52	37.18	45.61
total cost				10	11.88	13.75	16.35	21.68	25.83	31.45	38.52	47.18	55.61
unit cost				0.083	0.031	0.027	0.026	0.027	0.028	0.03	0.032	0.035	0.038
Acc. Fcst.				120	380	510	630	815	930	1060	1200	1350	1480
Lot Size=	630		Least Unit Cost=			0.026							

Table 20: LTC Lot-Sizing

Part#=X	Past	OH=	370	LT=	2	SS=	80	AL=	0				
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	260	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	515	385	265	80	-35	500	360	210	80
PAB		240	80	775	515	385	265	80	630	500	360	210	80
NR		0	0	120	0	0	0	0	115	0	0	0	0
PORC		0	0	815	0	0	0	0	665	0	0	0	0
POR	0	815	0	0	0	0	665	0	0	0	0	0	0

Table 21: Determining Lot Size with LTC

Period		1	2	3	4	5	6	7	8	9	10	11	12
GR		130	160	120	260	130	120	185	115	130	140	150	130
Acc. Fcst.				120	380	510	630	815	930	1060	1200	1350	1480
hold time				0	1	2	3	4	5	6	7	8	9
hold cost				0	1.875	1.875	2.596	5.337	4.147	5.625	7.067	8.654	8.438
Acc. hold cost				0	1.875	3.75	6.346	11.68	15.83	21.45	28.52	37.18	45.61
Ordering cost				10	10	10	10	10	10	10	10	10	10
Abs. deviation				10	8.125	6.25	3.654	1.683	5.829	11.45	18.52	27.18	35.61
Acc. Fcst.				120	380	510	630	815	930	1060	1200	1350	1480
Lot Size=	815		Minimal absolute deviation=				1.683						

- *Part Period Balancing (PPB)*

One *part-period* of an item means one unit of that item is carried in inventory for one period. *Economic part-period* (EPP) is the quantity of an item which, if carried in inventory for one period, would result in a carrying cost equal to setup cost. Therefore,

$$EPP = \text{Ordering Cost} / \text{Unit Carrying Cost}$$

PPB is a dynamic lot-sizing technique that uses the same logic as LTC method. An example of PPB is shown in Table 22 and 23. The result is the same as in LTC.

Table 22: PPB Lot Sizing

Part#=X	Past	OH=	370	LT=	2	SS=	80	AL=	0			
Period	**Due**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GR		130	160	120	160	130	120	185	115	130	140	150	130
SR			0										
POH		240	80	-40	515	385	265	80	-35	500	360	210	80
PAB		240	80	675	515	385	265	80	630	500	360	210	80
NR		0	0	715	0	0	0	0	665	0	0	0	0
PORC		0	0	715	0	0	0	0	665	0	0	0	0
POR	0	715	0	0	0	0	665	0	0	0	0	0	0

Table 23: Calculation of EPP

Period		1	2	3	4	5	6	7	8	9	10	11	12
GR		130	160	120	160	130	120	185	115	130	140	150	130
hold time				0	1	2	3	4	5	6	7	8	9
Part-Periods				0	160	260	360	740	575	780	980	1200	1170
Acc. Part-Periods				0	160	420	780	1520	2095	2875	3855	5055	6225
EPP	1387			1387	1387	1387	1387	1387	1387	1387	1387	1387	1387
Abs. deviation				1387	1227	966.7	606.7	133.3	708.3	1488	2468	3668	4838
Acc. Fcst.				120	280	410	530	715	830	960	1100	1250	1380
Lot Size=	715		Minimal absolute deviation=				133.3						

An adjustment procedure called "look ahead/look back" is frequently added to the PPB technique to improve the schedule. Look-forward/look-back features adjust the schedule by including the requirement next to or excluding the requirement prior to the period covered by current lot size. This technique is used to prevent stock covering peak requirements from being carried for long periods of time and to keep orders from being brought in too early in periods with very low requirements. When the look ahead/look back feature is used, a lot quantity is calculated and the next or the previous periods' demands are evaluated to determine whether it would be economical to include them in the current lot before the quantity is firmed up.

The total costs for the above lot-sizing rules are compared as in Table 24.

Table 24: Comparison of Lot-Sizing Rules

Lot Sizing Rule	Total Cost
LFL	107.80
FOQ	61.33
EOQ	64.06
PRS	57.27
POQ	50.37
LUC	48.99
LTC	48.99
PPB	48.99

The characteristics of various lot-sizing rules are compared in Table 25.

Table 25: Characteristics of Lot-Sizing Rules

LS tech \ Compare	Lot Size	Order Interval
FOQ, EOQ	Fixed	Variable
PRS, POQ	Variable	Fixed
LUC, LTC, PPB	Variable	Variable

Cushions

The environment of operations planning and control is uncertain. The best way to solve the uncertainty problem is to eliminate the uncertainty, i.e., to make the environment more stable through the efforts such as increasing the similarity of product and process design, shortening the setup time, decreasing the lot sizes, decreasing the manufacturing lead-times, smoothing the supply channels, etc. Before the uncertainties are removed, we have to face them. The consideration of safety is crucial to reduce the influences of manufacturing environment's uncertainties. Three safety considerations are frequently applied.

- Safety Stock

The safety stock is used to cover the random uncertainties caused by unknown factors. When the source of an uncertainty is known, such as suppliers' late delivery, approaches other than safety stock should be used to resolve it. Masking the source of the problem causing an uncertainty with safety stock will prevent the actual cause of the problem from being addressed.

- Safety Time

If a supplier's delivery tends to be late, increasing the lead-time will not be an effective method of smoothing production. Suppliers tend to ignore orders with long lead-times in favor of urgent orders placed by other buyers. Longer lead-times may therefore result in more serious late deliveries. Safety time in the MRP logic moves both the planned order receipt and the planned order release to an earlier period. To the suppliers, the lead times remain the same, but the due dates are earlier than when are actually needed.

- Safety Capacity

In priority planning, sometimes scheduled quantities require available capacity that exceeds current productive capacity (see chapter five). Safety capacity provides protection from planned activities, such as resource contention and preventive maintenance, and unplanned activities, such as additional requirement, resource breakdown, poor quality, rework, or lateness.