

CoTM 6203 Advanced Construction Material & Equipment Management

Lecture 5 - Integrated materials management

Introduction

- Every project needs materials inputs; there are a large variety of them as well as different types.
- These materials must be in the job site when needed, in the correct quantity or amount and with the required quality.
- Their management is a **fundamental part of project management** not only from the cost point of view but especially because **their unavailability in quantity and on time** can produce **delays** in the whole project, as well as **increasing costs with a loss of productivity**.

Introduction

- In this lecture, various issues related to **Material Management (MM)** have been highlighted.
- These include material procurement process in construction organization, different functions of *MM*, management of inventory, inventory-related costs, functions of inventory, classification of inventory systems, selective inventory control, and inventory models.
- It is envisaged that by following these principles, one may be able to manage the materials function effectively within the construction industry.

Introduction

- The construction process involves more than the actual placement of *concrete, steel, and other materials*.
- The technical complexity of many of today's construction projects requires the purchase of materials meeting *rigorous specifications*, often from remote vendors.
- Contractors often must go through a long review and approval process for these materials, which involves collecting and submitting technical data to the owner and/or architect/engineer for determination of a product's suitability for the project.
- Only after this review and approval can the actual purchase and installation take place.

Production processes

- Managing the operation means planning for and controlling the resources used in the process: **labor**, **capital**, and **material**.
- All are important, but the major way in which management plans and controls operations is through the **flow of materials**.
- The flow of materials in turn controls the **performance** of the **process**.
- If the right materials in the right quantities are not available at the right time, the process cannot produce what it should.
- If, **labor** and **machinery** will be poorly utilized, the profitability, and even the existence, of the company will be threatened.

Materials Management

- **MM** is defined as an integrated process for planning and controlling all necessary efforts to make certain that the quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a *reasonable cost*, and are *available* when needed. (CII Best Practices, Definitions, 2014).
- A *MM* system includes the major functions of **identifying** (project planning and material takeoff), **acquiring** (vendor inquiry and evaluation, purchasing, expediting, and transportation), **distributing** (field material control and warehousing), and **disposing** of materials needed for a construction project (CII, 1986b, 1988b).

Materials ...

- The concept of having one department responsible for the flow of materials, from supplier through production to consumer, thereby minimizing total costs and providing a better level of customer service, is known as **materials management**.
- Other names include *distribution planning* and *control*, *supply chain management*, and *logistics management*.

Reasons for poor *MM*

- some of the reasons for poor *MM* practices adopted by construction contractors:
 - Senior management of construction firms do not recognize the impact that *MM* has on the cost-effectiveness of their project operations.
 - Personnel performing related *MM* activities have not been properly selected and trained.
 - Computerized systems related to *MM* activities have not been properly selected, designed, or used to provide needed information for management and control.

Objectives of *MM*

- Four important objectives of MM are as follows (CII, 1988b):
 1. Ensure that materials meet the specifications and are on hand when and where they are required.
 2. Obtain the best value for purchased materials.
 3. Provide efficient, low-cost transport, security, and storage of materials at construction sites.
 4. Reduce any surplus to the lowest level possible.

Factors to be considered when preparing materials plan

- *MM* is an important component of the project schedule.
- This function starts early with the planning phase of the project.
- When developing the materials plan, the general contractor must consider various factors, such as project size, scope, and location; cash-flow requirements; schedule and *lead times* of critical purchases; the owner's philosophy; owner approvals; the number of project participants;

Factors ...

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MM theories

- Theoretically, there are two extreme *MM* theories:
 1. The ***Just-In-Time (JIT) theory***, which calls for delivering materials at the time of installation only. Thus, materials are not stored at the site.
 2. The ***Inventory Buffer (IB) theory***, which calls for all materials to be purchased, delivered, and stored on-site prior to installation.

Advantages and disadvantages of the theories

- The advantages of the *JIT theory* are *less handling, no storage, no frozen capital, and less vulnerability to theft, vandalism, obsolescence, shrinkage, and deterioration*—in other words, *fewer handling costs*.
- The disadvantages are *higher order costs* (more orders) and *higher shortage costs* (higher probability of not having materials on time).
- Conversely, the advantages of the *IB theory* are *lower order, and shortage costs* - The disadvantage is *higher holding costs*.

Strike a balance (trade-off)

- In real life, one must strike a balance somewhere between the two extreme theories in order to *obtain the least total cost*.
- This balance will vary from one project to another, depending on several factors, such as the *size of the project, the location of the project, the type and availability of materials, the locations of vendors, and weather*.
- While we never apply the “JIT” or “IB” approach purely but swing between them.
 - However, we lean more toward one of the two theories, depending on project location and circumstances.
- To illustrate this point, let us imagine two projects, one located in the middle of nowhere (*desert or countryside*); call it *project A*.

Strike a ...

- The other project is located in the **downtown** area of a major city; call it **project B**.
- A has **plenty of space** for organized storage and is located away from urban areas.
- Thus, it is **less vulnerable to theft and vandalism** but is far away from vendors and suppliers.
 - In this case, ordering most or all of the materials in advance as **IB theory** makes sense.
- In the case of B, which is located in the downtown area of a major city, storage space is scarce, and **theft and vandalism are more likely**.
 - At the same time, **plenty of vendors and suppliers** are located within a short radius and **can deliver on short notice and for little cost**.
 - In this case, we probably want *MM* by using an approach closer to the **JIT theory**.

Other factors

- Other factors influencing which theory should predominate are *the type and the availability of materials*.
- For instance, **ready-mix concrete** must be delivered on time in all cases because it cannot be stored.
- **Expensive equipment** may also need to be delivered on time for security reasons.
- Materials that are **susceptible to deterioration** are less likely to be stored for long periods of time.
- Also, **chemicals and explosives** have to be stored in a secure and safe manner and require special attention.

Other ...

- **Weather** (rain, snow, ice, wind, temperature, humidity) may be a factor that influences the **delivery and storage decision**.
 - The 1976 **Montreal Olympic Games** reminds us of what can happen with poor planning.
 - The precast posttensioned concrete beams were left on the ground (because of a **labor strike**), and water got into the tubes and froze before the cable had been threaded.
 - **Removal of the ice required expensive** drilling and contributed further to a loss of time (Neil, 1982).

Other ...

- Another interesting weather-related case was a large project in northern Canada. The location was remote from any urban area or even paved roads.
- Moving equipment and materials was possible only by air, which was expensive.
- Work was planned to take place only during the **warm months because of the harsh winter conditions**.
- An efficient plan was prepared to move **equipment and materials on sleds** during the winter.
- Some **icy roads and bridges** had to be prepared for this purpose, but the transportation cost was a **fraction of the alternative: *airlifting***.
- The equipment and materials were kept in shelters until the weather permitted the work to start.

Inventories

- Inventories are materials and supplies that a business or institution carries either for sale or to provide inputs or supplies to the production process.
- All businesses and institutions require inventories. Often they are a substantial part of total assets.
- As inventories are used, their value is converted into cash, which improves cash flow and return on investment.
- There is a cost for carrying inventories, which increases operating costs and decreases profits.

Inventory

- They are part of the planning process and provide a *buffer against* the differences in demand rates and production rates.
- *Production planning, implementation, control, and inventory management* work *hand-in-hand*.
- Inventories in manufacturing are used to support production or are the result of production.
- To get the most value out of resources, production processes must be so designed that they make products most efficiently.
- Once the processes exist, operations are managed so they produce goods most economically.

Determining Materials Needs

- Probably the first step regarding materials in a project is determining what is needed.
- This is normally done based on documents such as:
 - The project charter
 - The quantities takeoff
 - The Gozinto diagram for manufacturing
 - The *Work Breakdown Structure*
 - Working drawings

Determining ...

- The outcome of these procedures is a list called '*Bill of Materials*' (*BOM*).
 - It describes in a precise format all the components of a product, quantities involved, subassemblies, assemblies and sequence.
- This document is essential in all kinds of projects, and it is similar to the '*Bill of Quantities*' (*BOQ*) common in the construction industry and used for tendering.

The Gozinto Diagram for Manufacturing

- This is a diagram with a similar format of the *WBS*. It is also known as '*Assembly diagram*'.
- It consists in breaking down a product to analyze the relationships between the final product and its components and establishing an upward hierarchy, starting with parts and raw materials at the lowest level, following with subassemblies at an intermediate level, continuing with assembled sets in a semifinal level, and then to a subsequent level that corresponds to the finished product.
- It can be considered a project management tool, but in reality is a materials management technique used to prepare the *BOM*.

Inventory management

- The problem of inventory management is of maintaining an adequate supply of something to meet an expected demand pattern for a given financial investment.
- This could be raw materials, work in progress, finished products, or spares and other indirect materials.
- Inventory is one of the indicators of management effectiveness on the materials management front.
 - ***Inventory turnover ratio (annual demand/average inventory)*** is an index of business performance.

Inventory ...

- A soundly managed organization will have **higher inventory turnover ratio, and vice versa**.
- Inventory management deals with the determination of optimal policies and procedures for procurement of commodities.
- Since it is quite difficult to imagine a real work situation in which the required material will be made available at the point of use instantaneously, maintaining inventories becomes almost necessary.
- Thus, inventories could be described as '*necessary evil*'.

Inventory-Related Cost

- Inventory related cost has following broad cost components.
 - 1. Carrying inventories (holding cost)*
 - 2. Incurring shortages (stock-out cost)*
 - 3. Replenishing inventories (ordering cost)*
- The 3 types of costs are the most commonly incorporated costs in inventory analysis, though there may be other cost parameters relevant in such an analysis including **inflation** and **price discounts**.

Carrying Inventories (*Holding Cost*)

- This is the *opportunity cost* of blocking material in the non-productive form as inventories expressed as Birr/item held in stock/unit time.
- Some of the cost elements that comprise carrying cost are cost of *blocking capital (interest rate)*; *cost of insurances*; *storage cost*; and *risk costs*.
- It is generally expressed as a fraction of value of the goods stocked per year.
 - For example, if the fraction of carrying charge is 20% per year and a material worth Birr 1,000 is kept in inventory for one year, the unit carrying cost will be Birr 200/year.
- Items that are *perishable in nature*, the attributed carrying cost will be higher.

Risk costs

- The risks in carrying inventory are as follows:
 - a) *Obsolescence*. Loss of product value resulting from a model or style change or technological development.
 - b) *Damage*. Inventory damaged while being held or moved.
 - c) *Pilferage*. Goods lost, strayed, or stolen.
 - d) *Deterioration*. Inventory that rots or dissipates in storage or whose shelf life is limited.

Example

- A company carries an average annual inventory of \$2,000,000. If it estimates the cost of capital is 10%, storage costs are 7%, and risk costs are 6%, what does it cost per year to **carry this inventory**?

Solution:

- Total cost of carrying inventory = $10\% + 7\% + 6\% = 23\%$
- Annual cost of carrying inventory = $0.23 \times \$2,000,000 = \$460,000$

Incurring Shortages (*Shortage Cost*)

- It is the *opportunity cost* of not having an item in stock when one is demanded.
 - **It may be due to lost sales or backlogging.**
 - In the case of backlogging (or back ordering), the order is not lost but is backlogged, to be cleared as soon as the item is available on the stock.
 - **In lost sales, the order is lost.**
- Both cases are characterized by demand, penalty cost, emergency replenishment, loss of goodwill, etc.
- This is generally expressed as Birr/order.

Replenishing Inventories (Ordering or Set-up Cost)

- This is the amount of money and efforts expended in procurement or acquisition of stock.
 - It is generally called **ordering cost**.
- This **cost is usually assumed to be independent of the quantity ordered**, because the fixed-cost component is generally more significant than the variable component.
 - Thus, it is expressed as Birr/order.

Functions of Inventory

- Inventory aims at absorbing the uncertainties of demand and supply by '*decoupling*' the demand and supply sub-systems.
- Thus, an organization may be carrying inventory for the following reasons:
 - Demand and lead-time uncertainties necessitate building of *safety stock (buffer stock)* so as to enable various sub-systems to operate somewhat in a decoupled manner.
 - The larger the uncertainty of demand and supply, the larger will have to be the amount of *buffer stock* to be carried for a prescribed service level.

Functions of ...

- Time lag in deliveries also necessitates building of inventories.
- If the replenishment lead times are positive, then stocks are needed for system operation.
- Cycle stocks may be maintained to get the economics of scale so that total system cost due to ordering, carrying inventory and backlogging is minimized.
- Technological requirements of batch processing also build up cycle stocks.
- Stocks may build up as pipeline inventory or work-in-progress inventory due to finiteness of production and transportation rates.

Functions of ...

- This includes materials actually being worked on or moving between work centres, or materials in transit to distribution centres and customers.
- When the demand is seasonal, it may become economical to build inventory during periods of low demand to ease the strain of peak period demand.
- Inventory may also be built up for other reasons such as quantity discounts being offered by suppliers, discount sales, anticipated increase in material price, and possibility of future non-availability.

Functions of ...

- Different functional managers of an organization may view inventory from different points, leading to conflicting objectives.
- This calls for an integrated systems approach to planning of inventories so that **conflicting objectives** can be scrutinized to enable the system to operate at minimum total inventory-related costs—both explicit costs such as purchase price as well as implicit costs such as carrying, shortage, transportation and inspection costs.

Inventory Policies (*IP*)

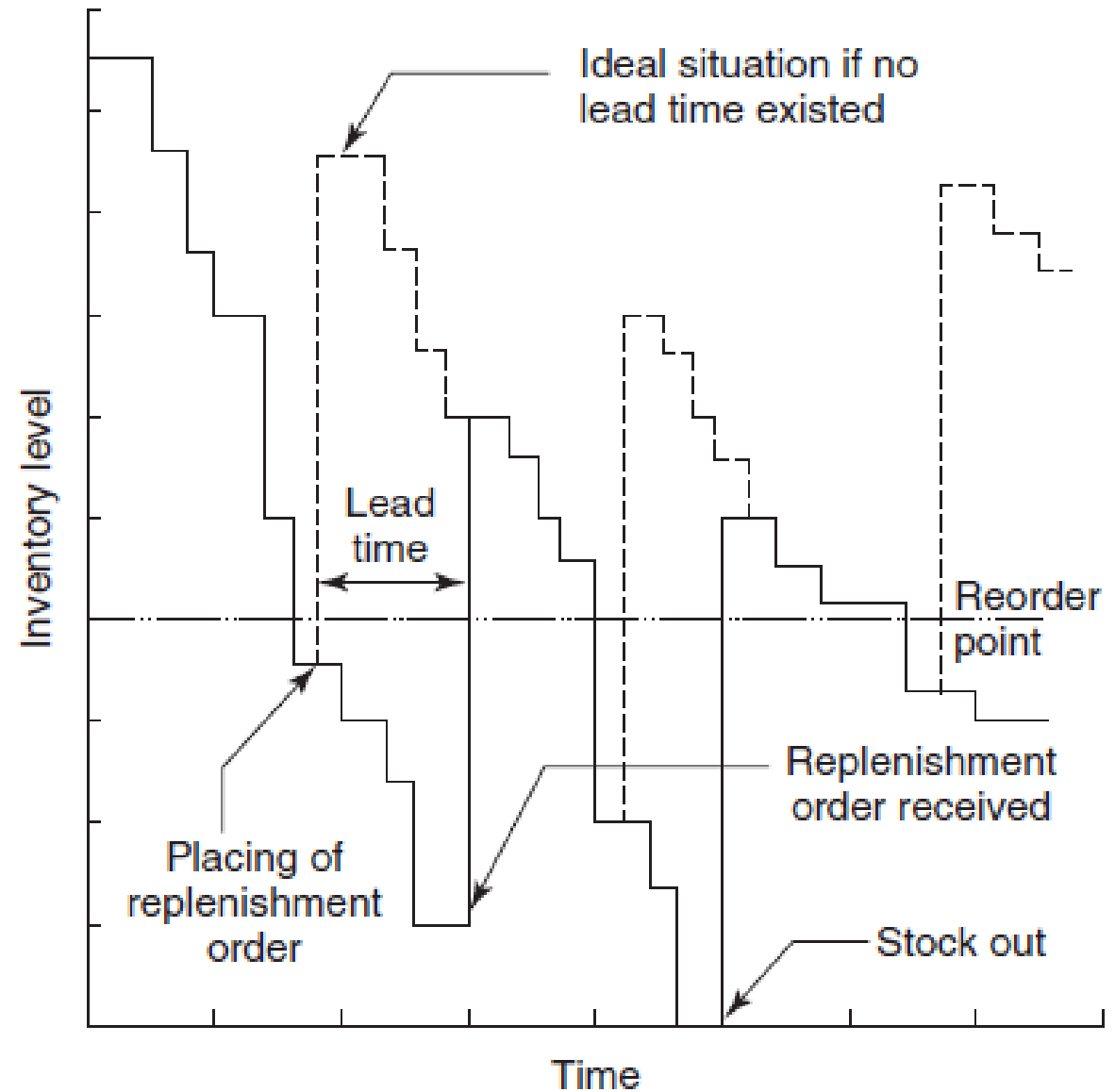
- a) Lot size reorder point policy
- b) Fixed order interval scheduling policy
- c) Optional replenishment policy
- d) Two-bin system

- In practice, there may be other policies that may be special cases of the policies mentioned or may be a combination of these policies.
- Some of the factors affecting the choice of an *IP* are—the nature of the problem; the usage value of an item; and situational parameters.
- It is desirable to first select an operating policy before determining optimal values of its parameters.

Lot size reorder point policy

- The inventory status is continuously reviewed and as soon as the inventory level falls to a prescribed value called '*reorder point*', a fresh replenishment order of fixed quantity known as *EOQ* is placed.
- This is one of the very classical types of *IP*.
- The decision variables for the design of policy are Lot size and reorder point.

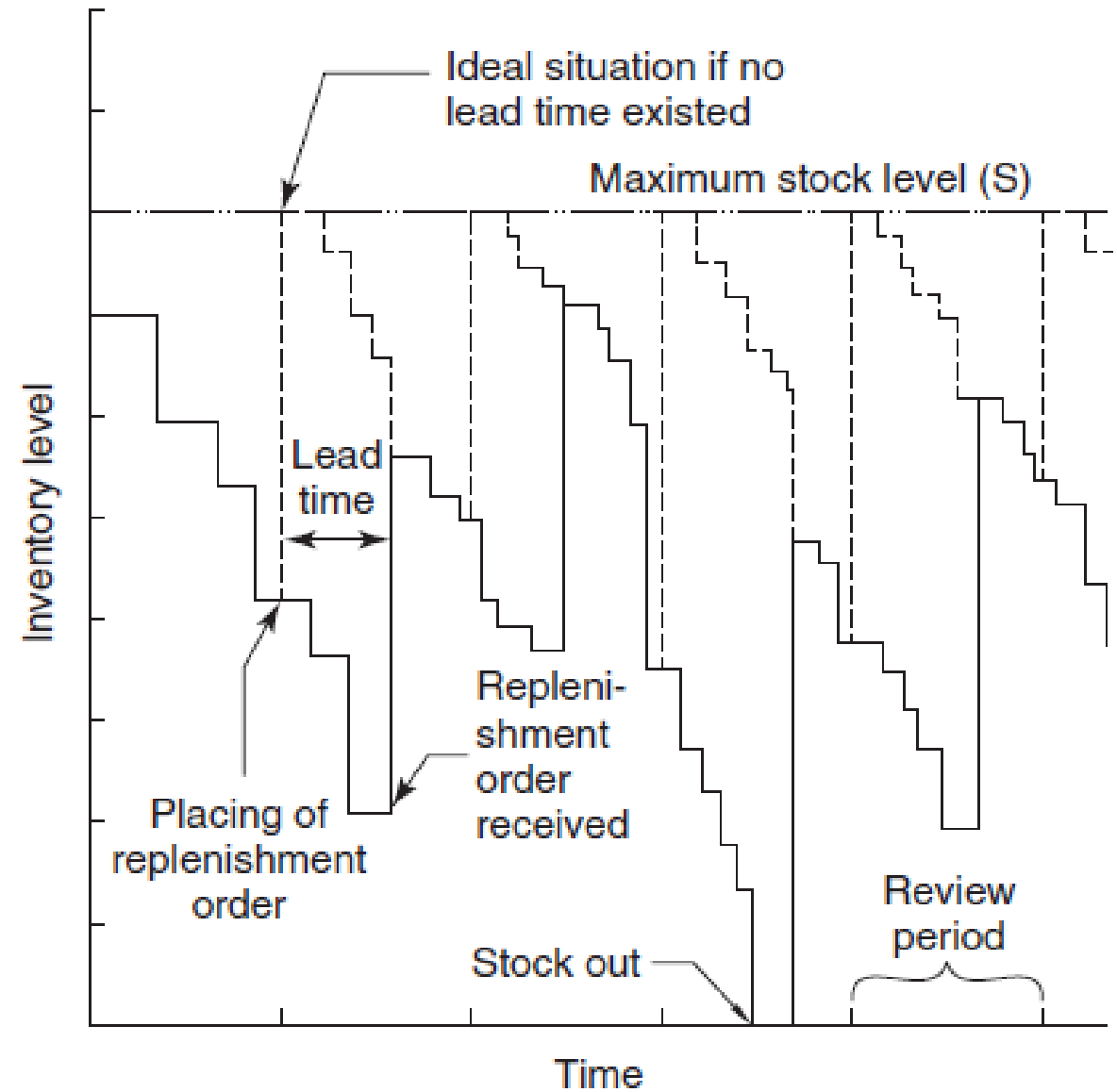
- The solid line in this figure represents the actual inventory held with a finite lead time, while the broken line shows the ideal situation if no lead time existed.



Fixed order interval scheduling policy

- The time between the consecutive replenishment orders is constant.
- A *maximum stock level (S)* is prescribed and the inventory status is reviewed periodically with a *fixed interval (T)*.
- At each review an order of size O is placed, which takes the stock on hand plus an order equal to the *maximum stock level*.
- The order quantity could vary from period to period.

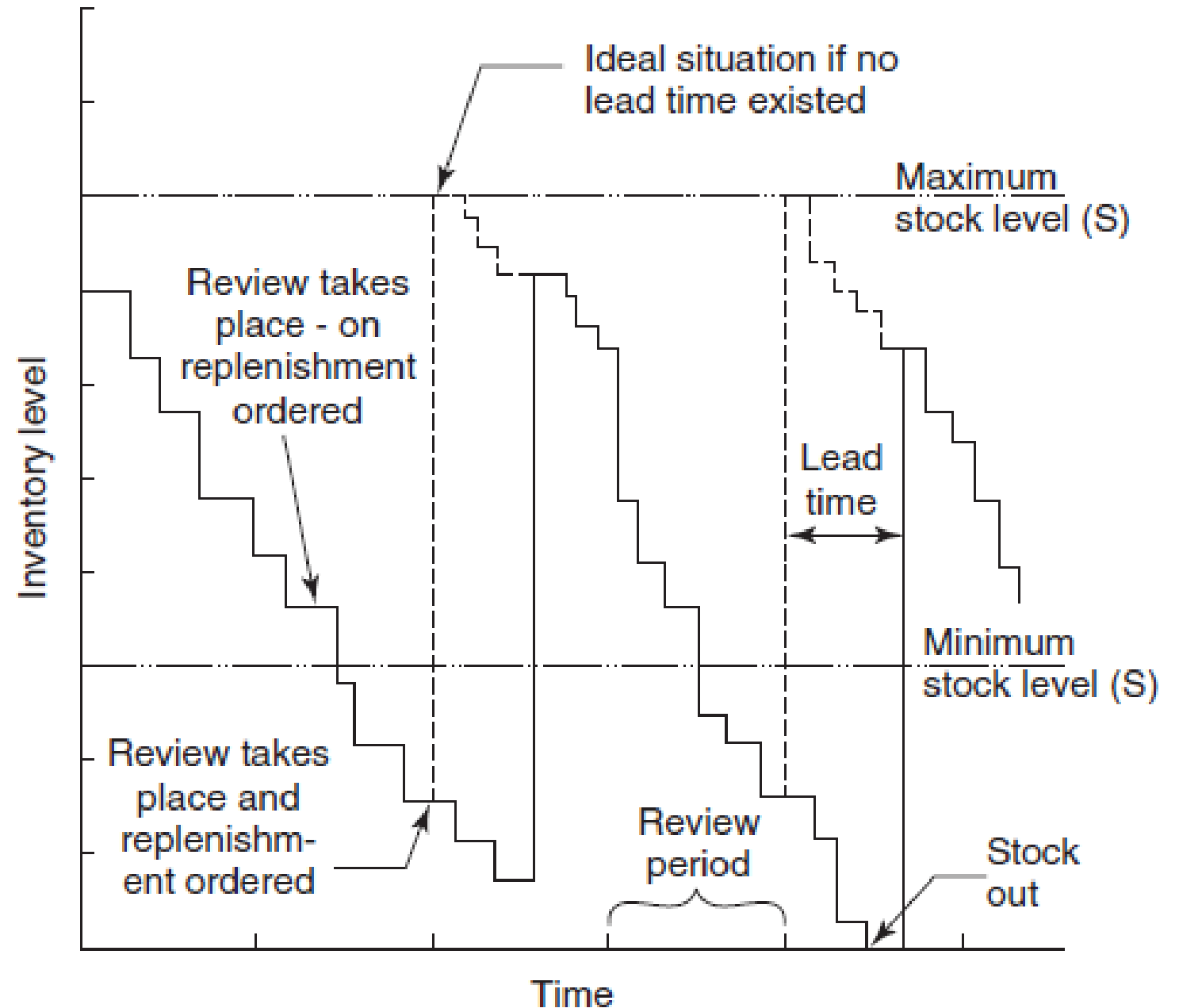
- In this policy, when the level of stock on hand is high at review, a smaller-size replenishment order is placed.
- The decision variables for the design of policy are S , the maximum stock level, and T , the review period



Optional replenishment policy

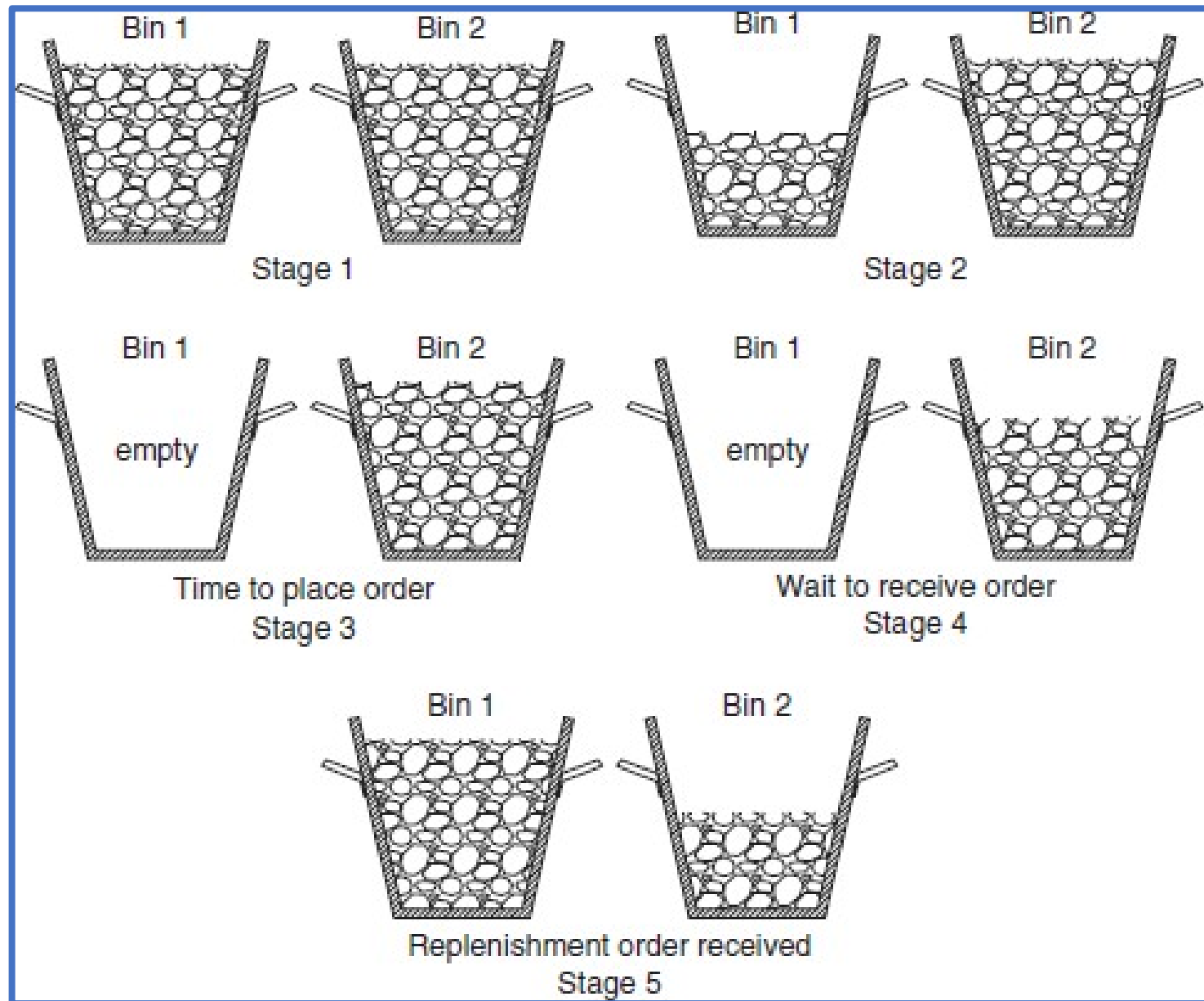
- This policy is also known as *(s, S) policy*. The status of stock is periodically reviewed and *maximum stock level (S)* and *minimum stock level (s)* are prescribed.
- At the time of review, if the stock on hand is less than or equal to s , an order of size Q is placed so that *stock on hand plus the order equals the maximum stock level S*.
- If stock on hand at review is higher than s , no order is placed and the situation is reviewed at the next review period.

The decision variables for the design of policy are S , s and T .



Two-bin system

- This system is simple to operate and easy to understand.
- There are two bins kept full of items.
- Item from the first bin are used first.
- The moment the first bin is exhausted, an order is placed for items and the second bin acts as buffer or safety cushion.



Selective Inventory Control (*IC*)

- As there is a large variety of items stocked by a project site, applying scientific *IC* for all these items is **neither feasible nor desirable**.
- Since applying *IC* across all items may render the **cost of *IC* more than its benefits**, it may prove to be counter-productive → ***IC* has to be exercised selectively**.
- Depending upon the value criticality and usage frequency of an item, we may have to decide on an appropriate type of *IP*.
- Selective *IC*, thus, plays a crucial role so that we can apply our limited control efforts more judiciously to the more significant group of items.
- In selective control, items are grouped in a few discrete categories depending upon **value, criticality** and **usage frequency**.

Some commonly adopted inventory-control policies

Name of the policy	Expansion	Basis of classification	Remarks
VED	Vital, essential and desirable	It is based on the criticality of the item, which are classified in three categories.	Classification depends on the consequences of material stock-out when demanded.
FSN	Fast, slow and normal	It is based on consumption rate of the inventory.	It is helpful in controlling obsolescence.
HML	High, medium and low	It is based on unit price of material.	It is mainly used to control the inventory of purchased material.
XYZ	Value of balance stocks very high	It is used for classifying materials in storage.	Its main use is in review of inventory.
SDE	Scarce, difficult and easy to obtain	It is based on the level of difficulty in the procurement of inventory.	It is useful in lead-time analysis and decision related to the procurement of purchasing strategies.
GOLF	Government, ordinary, local and foreign	It is based on the inventory.	It is useful for decision related to the procurement strategy.
HML	High, medium and low price	It is based on the prices of materials.	It is useful for delegating the purchasing responsibilities.

ABC Analysis

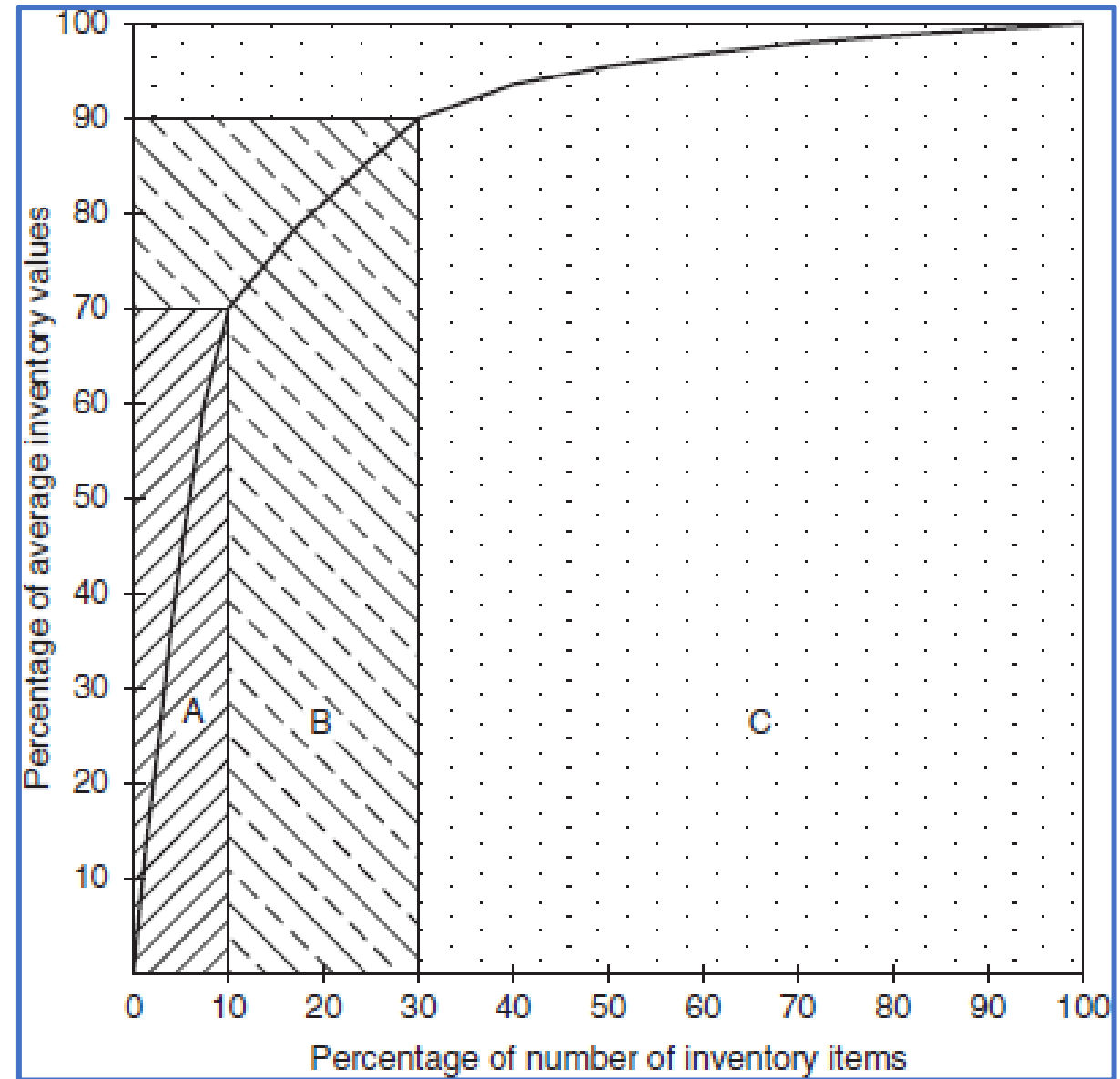
- This is based on *Pareto's Law*, which says that in any large group there are '**significant few**' and '**insignificant many**'.
- For example, only 20% of the items may be accounting for **80% of the total material cost procured** by a construction organization.
 - Here, the 20% constitute the '**significant few**' that require utmost attention.
- To prepare an *ABC-type curve*, we may follow a simple procedure:
 1. Different materials required for the project are identified and their **estimated quantities worked out**. The quantity estimate could be on the basis of **either annual consumption or the project's total requirement**.
 2. The **unit rates of materials** are estimated.

ABC ...

3. The **usage values** for each of the materials = the **estimated quantities** X **unit rates**. These values are converted into **percentage** of total annual usage cost or total project cost, as the case may be.
4. The **percentage usage cost** for each of the materials is arranged in the **descending order** of their ranking, starting with the first rank, i.e., highest to lowest usage value. The **cumulative percentage usage** value is also calculated.
5. A curve is plotted, and points on the curve at which there are **perceptible sudden changes of slopes are identified**. In the absence of such sharp points, cut-off points corresponding to the top 10% and the next 20% or so are marked as a **general indicator of A, B and C type of materials**.

6. According to an empirical approach, 'A' class items account for about 70%, 'B', 20%, and 'C', 10% of the *usage value*.

- In terms of **numbers**, 'A' class items constitute about 10%, 'B' about 20%, and 'C' about 70% of total items.
- These percentages are indicative only and can vary depending on a number of factors.



Classification of materials vs *IP*

- Upon classification of materials into *A, B and C types*, suitable *IPs* can be decided.
- **Item type 'A'** The salient features are:
 - Accurate forecast of quantities needed
 - Involvement of senior level for purchasing
 - Ordering is on requirement basis
 - Enquiries for procurement need to be sent to a large number of suppliers
 - **Strict degree of control is required**, preferably monitoring on a **weekly** basis
 - Low safety stock is needed

Classification ...

- *Item type 'B'* The salient features are:
 - Approximate forecast of quantities needed
 - Requires involvement of middle level for purchasing
 - Ordering is on *EOQ basis*
 - Enquiries for procurement need to be sent to 3-5 reliable suppliers
 - Moderate degree of control required, preferably monitoring on a *monthly basis*
 - Moderate safety stock needed

Classification ...

- *Item type 'C' The salient features are:*
 - No need of forecasting; even rough quantity estimate is sufficient
 - Junior-level staff is authorized to order purchase
 - Bulk ordering is preferred
 - Quotations from even 2-3 reliable suppliers are sufficient
 - A relatively relaxed degree of control is sufficient, and monitoring can be done on a **quarterly basis**
 - Adequate safety stock can be maintained

VED Analysis

- This analysis attempts to classify items into 3 categories depending on the **consequences of material stock-out when demanded**.
- The cost of shortage may vary according to the seriousness of such a situation.
- Thus, the items are classified into *V (vital), E (essential) and D (desirable)*.
- **Vital** items are the most *critical having extremely high opportunity cost* of shortage and must be **available in stock when demanded**.
- **Essential** items are **quite critical** with substantial cost associated with shortage and should be **available in stock by and large**.
- **Desirable** group of items do not have very serious consequences if not available when demanded, but these **can be stocked items**.

Two-way classification: VED & ABC

- The **percentage risk** of shortage with the ***V Group*** of items has to be **kept quite small**, thus calling for a **high level of service**.
- With ***E*** category we can take a **relatively higher risk** of shortage, and for ***D*** category, even higher.
- Since even a *C-class* item may be *V* or an *A-class* item may be *D*. Thus, we should carry out a ***two-way classification*** of items grouping them in 9 distinct groups as ***A-V, A-E, A-D, B-V, B-E, B-D, C-V, C-E and C-D***.
- We can then determine the aimed service level for each of these 9 categories and plan for inventories accordingly.

Impact of *VED* Classification

- **V Group** comprises those items for the want of which the production will come to a stop—for example, power in the factory.
- **E Group** features those items for whose non-availability the stock-out cost is very high.
- **D Group** contains items whose non-availability causes no immediate loss of production; the stock cost involved is very less and their absence may only cause minor disruption in the production for a short time.

Steps used for *VED* classifying materials

1. Factors such as stock-out case, lead time, nature of items, and sources of supply are identified and considered for *VED* analysis.
2. Assign points or weightages to the factors according to the importance they have to the company.
3. Divide each factor into 3 degrees and allocate points to each degree.
4. Prepare categorization plan to provide basis for classification of items.

Steps ...

- For example, items scoring between 100 and 160 can be classified under D items; items between 161 and 230 can be classified under E items; and items between 231 and 300 can be classified under V items.
5. Specify the degree and allocate weightages to all the factors.
 6. Evaluate and find the final score for every item, and specify the type of item.

FSN Analysis

- Not all items are required with the same frequency.
- Some materials are required quite regularly, some are required very occasionally, and yet some others may have become **obsolete and might not have been demanded for years together.**
- **FSN analysis groups them as *Fast-moving*, *Slow-moving* and *Non-moving (dead stock)*, respectively.**
- *IPs* and models for the 3 categories have to be different.
- Most inventory models in literature are valid for the ***F* items exhibiting a regular movement (consumption) pattern.**

FSN ...

- Many spare parts come under the *S* category, which have to be managed on a different basis.
- For *N dead stock*, we have to determine optimal *stock disposal rules* rather than *inventory provisioning rules*.
- Categorization of materials into these 3 types on value and critical usage enables us to adopt the *right type of IP* to suit a particular situation.

***FSN* detail**

- ‘*F*’ items are those items that are fast-moving—i.e., in a given period of time, say, a month or a year, they have been issued a number of times. However, ‘*fast-moving*’ does not necessarily mean that these items are consumed in large quantities.
- ‘*S*’ items are those items that are slow-moving—in the sense that in the given period of time they have been issued in a very limited number.
- ‘*N*’ or non-moving items are those that are not at all issued for a considerable period of time.

FSN detail

- Thus, the **stores department**, which is concerned with the moving of items, would prefer to classify items in the categories *F-S-N*, **so that they can manage, operate and plan stores activity accordingly**.
 - For example, for efficient operations it would be necessary that fast-moving items are stored **as near as possible to the point of issue**, for these to be issued with minimum of handling.
 - Also, such items must be **stored at the floor level**, avoiding higher heights.
- Thus, if the items are slow-moving or issued once in a while in a given period of time, they can be stored in the interior of the stores and even at greater heights because handling of these items becomes rare.

FSN ...

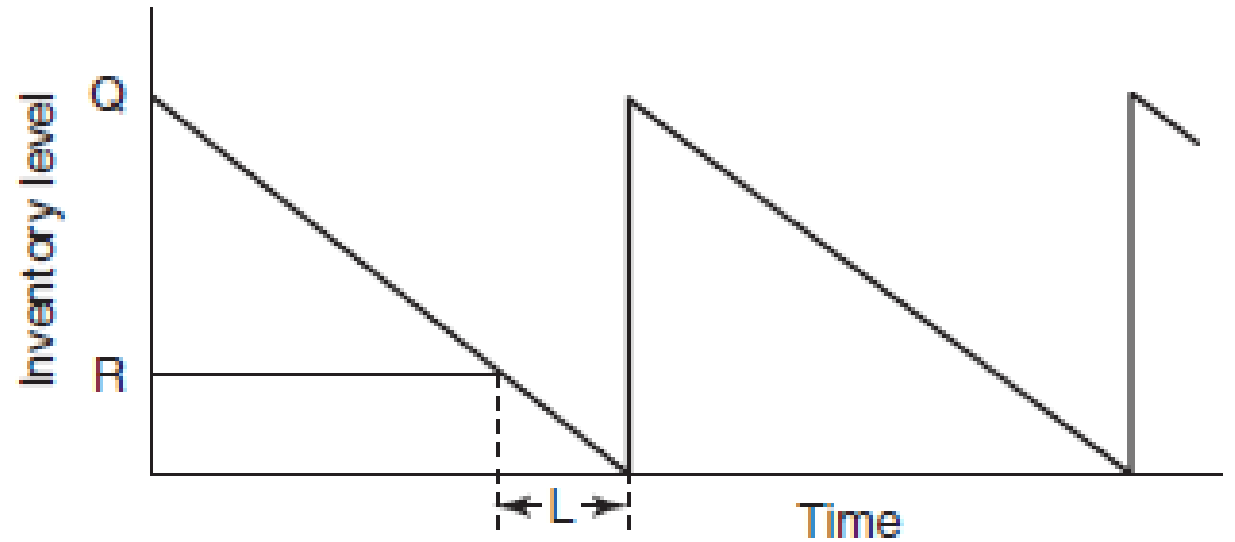
- It is necessary for the stores in-charge to know about non-moving items for various reasons mentioned below:
 1. Non-moving items mean unnecessary blockage of money which affect **the rate of returns of the company**.
 2. Non-moving items also **occupy valuable space in the stores without any usefulness** and, therefore, it becomes necessary to identify these items and find reasons for their non-moving status. If justified, recommendation may be made to top management for their **speedy disposal** so that company operations are performed efficiently.

Inventory Models

- There are a number of computer-based analytical inventory models available (such as *Economic Order Quantity [EOQ]* model), most of which are able to *generate economic purchase orders, shipping orders, delivery notes and invoices*.
- Most models claim to improve management control by reducing inventory-holding costs without loss of customer service.
- The basic philosophy behind these models is to use a **trade-off analysis by comparing the cost of inventory holding vs. the cost of ordering**.

EOQ Model

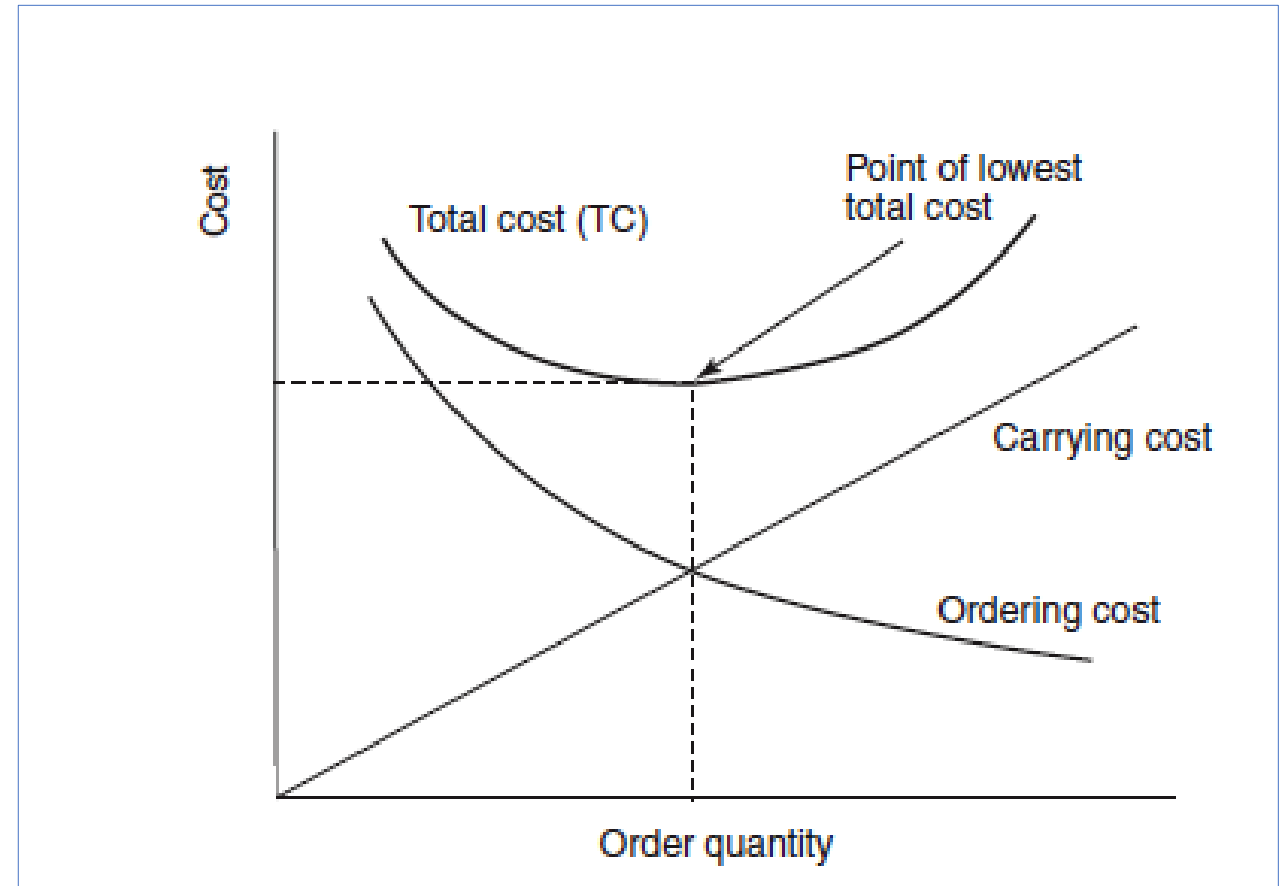
- The *EOQ* model provides answers on **how much to order**.
- The **reorder point R** and the quantity to be ordered, Q , are shown in the figure, as is the *lead time L* .
- The ordered quantity derived from this model is known as **EOQ**.



Optimum Quantity

- It is usually less expensive to purchase (and transport) or produce a bunch of material at once than to order it in small quantities.
 - If orders for large quantities are specified, there will be fewer orders placed.
 - For purchasing, this means that quantity discounts and transportation efficiencies may be realized.
 - The other side of the coin, however, is that larger lot sizes result in more inventory, and inventory is expensive to hold.
 - *EOQ* model attempts to specify a balance between these opposing costs.

- It is clear that there is a decrease in cost associated with increase in order quantity, while there is increase in cost with increase of inventory.
- **Total cost $TC = \text{Ordering cost} + \text{Carrying cost}$**
- The following notations are used to develop the **EOQ model**:
 - D = Demand rate; unit/year
 - A = Ordering cost; Birr/order
 - C = Unit cost; Birr/unit of item
 - I = Inventory-carrying charges per year
 - H = Annual cost of carrying inventory/unit item
 - Q = Order quantity; number of units per lot



- It is assumed that demand is at a uniform rate. Thus, the average inventory required throughout the year would be :

$$\frac{(0+Q)}{2} = \frac{Q}{2}$$

- The total number of orders placed would be :

$$\frac{Q}{D}$$

- Order cost per year = Number of orders placed per year
× Cost per order

$$\text{Carrying cost per year} = \frac{C \times I \times Q}{2} = \frac{H \times Q}{2}$$

Using the notations mentioned above, we can write the expression of TC as:

For optimum Q , one needs to find the particular value of Q which will *minimize total cost*. This can be done by *differentiation*, and one gets:

Some facts from the model

- Some of the observations that are clear from the above expressions are:
 1. The more the demand per year, the larger the order quantity.
 2. The higher the order cost, the larger the order quantity.
 3. The more expensive the item, the smaller the order quantity.
 4. The higher the carrying cost, the smaller is the order quantity.

Assumptions in *EOQ* model

- The derivation of *EOQ* is based on a number of assumptions such as:
 - Demand is deterministic and continuous at a constant rate.
 - The process continues infinitely.
 - No constraints are imposed on quantities ordered, storage capacity, budget, *etc.*
 - Replenishment is instantaneous (the entire order quantity is received all at one time as soon as the order is released).
 - All costs are time-invariant.

Assumptions ...

- There are no shortages of items.
- The quantity discounts are not available.
- There is negligible or deterministic lead time.
- The above assumptions mean that there is no uncertainty and one is able to predict the demand and the constancy of cost parameters such as item cost, carrying rate, or ordering cost.
- In real life, however, all these assumptions may not hold good.

EOQ with varying lead time

- In case the lead time is varying, one has to keep safety stock or *buffer stock*.
- Normally, the service level that is expected will decide the safety stock.
- If one keeps a very small quantity as safety stock, there is a *danger that stock-out may occur*.
- On the other hand, large safety or buffer stock may result in *large inventory-carrying cost*.

Relations to be noted with lead time

For optimum Q , one needs to find the particular value of Q which will *minimize total cost*. This can be done by differentiation, and one gets:

- The higher the lead time, the more will be the safety stock, and vice versa. In general, the safety stock varies with the square root of lead time (assuming all other factors as constant). For example, if the lead time for an item is reduced by a factor of 4, then the safety stock will be reduced by a factor of 2.

Effect of Uncertainty in Demand

- Generally, demand is never uniform all throughout the year.
- In case, the demand has a mean D_m and standard deviation σ_d , the *reorder point* is expressed as given below:

- *Where, Z is standard normal variate for a given service level. In order to find the value of Z , one can use normal distribution table.*

Values of Z for different service levels

- *The service level is the probability of having material in stock when construction project.*

Service level	90%	92%	94%	95%	96%	98%	99%
Z	1.29	1.41	1.56	1.65	1.75	2.05	2.33

Classification of project material inputs

- Considering the large variety of conceivable projects, there is an enormous diversity of possible inputs. However, they can be classified into five main categories.

1. Bulk materials, such as sand, water, bricks, cement, ready mix concrete, *etc.*,

2. Off-the shelf materials, such as electrical cables and switches, bolts, screws, piping, piping accessories, pallets, spare parts, hand tools, *etc.*,

Classification ...

3. **Fabricated elements**, such as assembled parts and subparts, air conditioning units, vessels, steel beams, panels, control equipment, kitchen appliances, air compressors, laboratory equipment, Formica sheets, *etc.*,
4. **Specially fabricated equipment (custom made)**, such as elevators, hydraulic turbines, sluice gates for dams, assembled parts for cracking towers, large refrigeration equipment, desalting plants, large engines for ships, transformers, electronic devices, fabrication lines, robots, electric switchboards, *etc.*,
5. **Construction equipment** either purchased or rented such as backhoes, pile drivers, grid rollers, trucks, pneumatic drills, cranes, derricks, forklifts, *etc.*

Inspection

- Make sure to inspect the material and equipment in the seller's premises, to be sure that the material matches all technical requirements and conditions as specified in the contractual documents, as well as its compliance with the shop drawings sent by the seller, and approved by the owner or his representative.
- Such checking is not limited to visual inspection for proper finishing, possible damages and completeness, for instance using a **video borescope** to inspect internal parts, but especially involves tests to make sure that certain parameters are observed.

Construction project *SCM* features

- Since construction production management is project oriented, the connections between contractors and subcontractors or suppliers are usually short-term relationships.
- However, without good SCM in construction project management there will be excessive costs, inefficient information flow, and inefficient communication between project stakeholders.

Construction project ...

- Many contractors have had to adopt multiple quantity take-off and estimating solutions to deal with technological advances.
- The use of *BIM* tools and techniques for quantity take-offs, estimating, and budgeting is rapidly expanding.
- It is important to note that metrics from previous projects such as actual cost, productivity, and labor hours are essential components for preparing estimates.

Integrated materials management

- Today, the concepts of *lean production* stress the need to supply customers with **what** they want, **when** they want it, and to **keep inventories at a minimum**.
- These objectives put further **stress on the relationship among production, marketing, and finance**.
- One important way to resolve these conflicting objectives is to provide close coordination of the **supply, production, and distribution functions**.

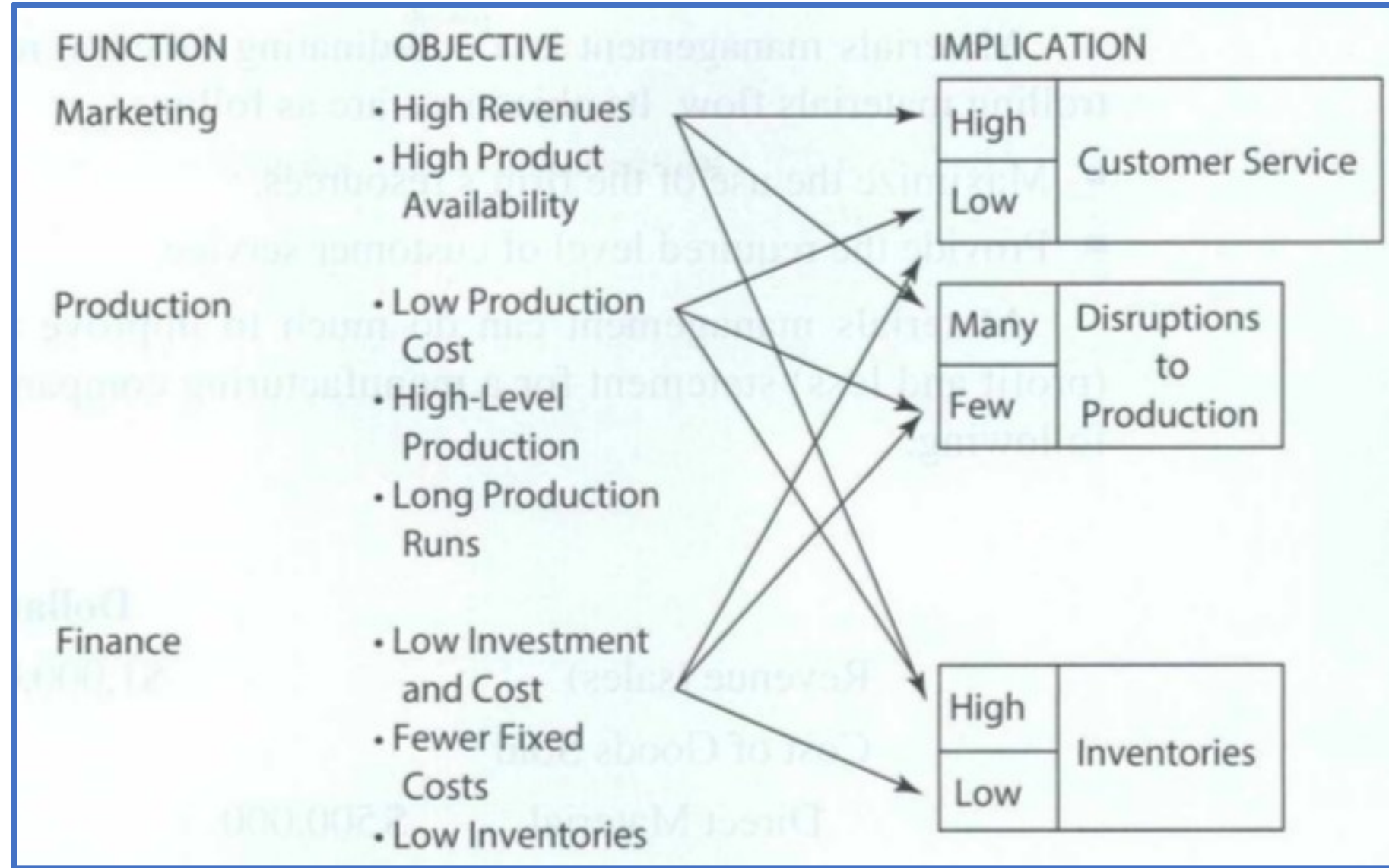
Integrated ...

- The problem is to **balance conflicting objectives to minimize the total of all the costs** involved and **maximize customer service** consistent with the goals of the organization.
 - This **requires some type of integrated materials management** or logistics organization that is responsible for supply, production, and distribution.
- Rather than having the planning and control of these functions spread among marketing, production, and distribution, they should occur in a **single area of responsibility**.

- To get the most profit, a company must have at least 4 main objectives:

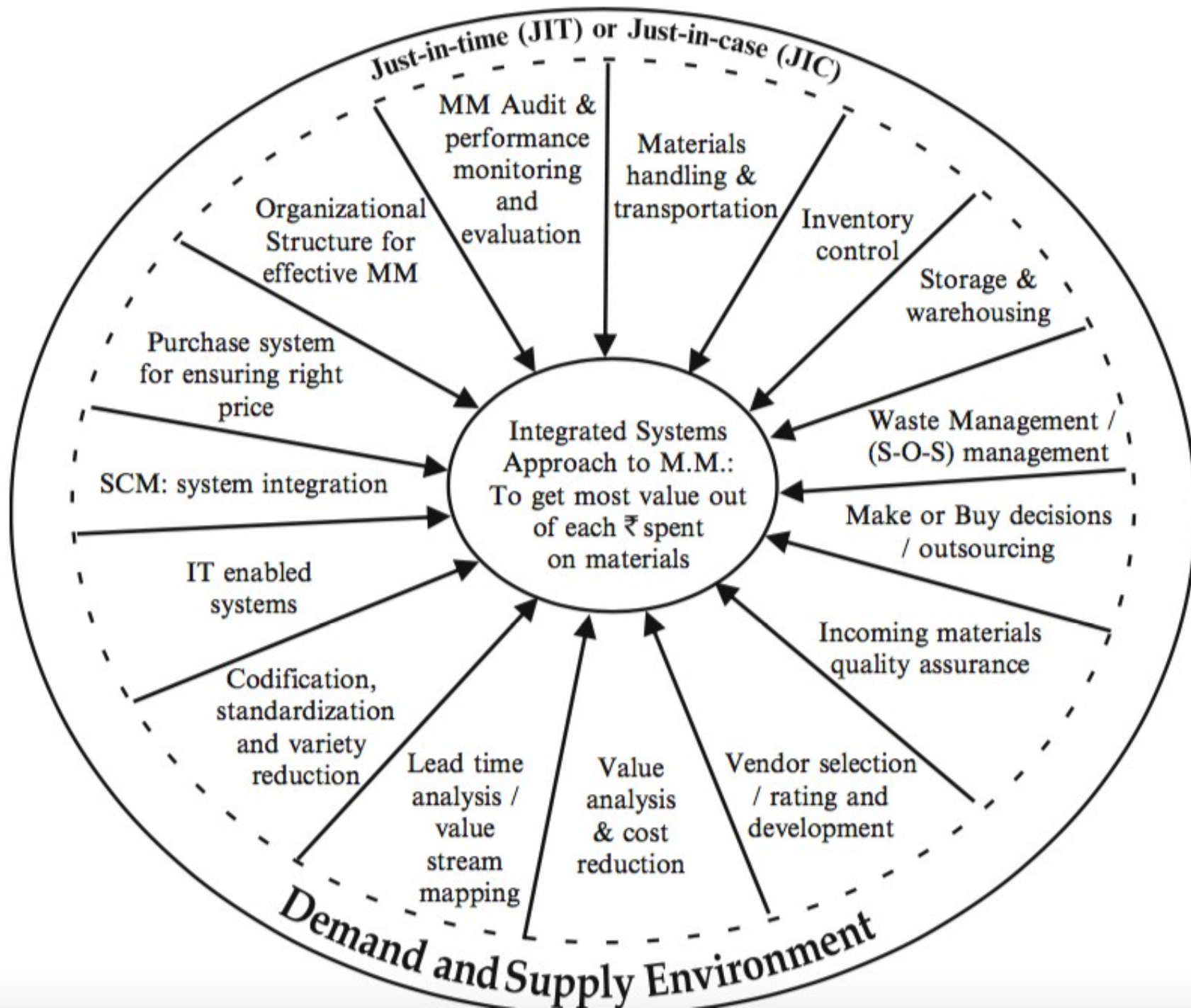
1. Provide best customer service
2. Provide lowest production costs
3. Provide lowest inventory investment
4. Provide lowest distribution costs

- One important way to resolve these conflicting objectives is to provide close coordination of the supply, production, and distribution functions.



Conflicting objectives

Proposed framework for integrated systems approach to Materials Management (MM)



Diversity of the construction industry (CI)

- A challenge for construction logistics is that while the processes described above can be argued to be generic, the application of these processes in construction is extremely varied.
- Construction sites vary from the small-scale building of private houses to major areas of urban regeneration with multiple activities taking place in a city location at the same time.
- The nature of the *CI* means that organizations of many different sizes and levels of sophistication will often be involved in a project.
- The coordination aspect of logistics management is complicated and can be hard to achieve.

Factors that influence logistics activities

- When considering the logistics costs associated with a product a number of key factors about the characteristics need to be considered.
- The particular characteristics of any given product will have an impact upon the distribution system for that product.
- Product characteristics that will influence the distribution system can be classified in 3 categories: *volume to weight ratio*, *value to weight ratio* and *special* characteristics.

Factors that influence ...

- Given the range of materials and products used in construction, it is clear that there is **tremendous variety** in terms of these **ratios** and the **special** characteristics and **storage, handling** and **transport** requirements.
- It is also important to recognize that global issues also impact on construction logistics.
 - For example the many political, regulatory and cultural differences that need to be taken into account when shipping materials internationally.

Volume to weight ratio

- Both the **volume** and **weight** characteristics of a product are likely to have a significant impact upon transport costs.
- Distribution systems tend to deal with products with **low volume to weight ratios** more *efficiently* than products with *high ratios* (products with low ratios include dense products such as **steel** and hard woods, whilst high-ratio products include many items such as **insulation materials**).
- This is because products with a **low volume to weight ratio tend to fully utilize the carrying capacity of a road freight vehicle**, handling equipment and storage space.

Value to weight ratio

- The higher the value of the product, the **greater the potential for absorbing the logistics costs** (i.e. the smaller the proportion of the final cost of the product accounted for by logistics).
- By using the ***value to weight ratio***, it is possible to consider the distribution costs associated with a product in terms of the value per unit weight of that product.
- Products with low value to weight ratios (such as sand, ore, coal and gravel) tend to be associated with higher transport costs (as a proportion of total delivered cost) than products with high ratios (for example, electronic equipment and computers).

Value to weight ...

- However, conversely, the storage costs for products with high value to weight ratios are greater than those for products with low ratios; this is explained by the level of capital tied up in the stock and the need for expensive, secure warehousing.

Special characteristics

- There are a number of other characteristics of a product that affect the selection of an appropriate transport, storage and handling system.
- The **fragility** of a product will determine the packaging requirements to safeguard the product during transportation and handling.
- The perishability of a product will affect the conditions under which it must be moved and stored and the speed at which it must travel through the SC.
- Certain products possess **hazardous** characteristics and must therefore be moved, handled and stored in isolation from other products and within stringent regulations.
- The nature of construction logistics means that there are many products that exhibit special characteristics, leading to complicated and challenging logistics management requirements.

Storage cost

- Storage costs are made up of three key elements:
 - The physical costs of stockholding (i.e. The cost of building, equipping and operating warehouses) including labour costs
 - The opportunity cost of holding stock (i.e. The cost of having money tied up in stock) or the cost of borrowing money
 - The costs of '*goods loss*' during storage: this can result from damage to the stock, theft and changes in taste that make the *goods unusable* (or means they cannot be sold).

Storage ...

- Products can be stored at several points in the SC: the point of extraction/harvest, the manufacturing/processing point, the distribution centre and at the retail outlet.
- Each point of stockholding requires handling of the product – and the more times the product is handled the greater the total logistics costs (as handling requires both equipment and labour).

Storage ...

- As well as raising issues about who will be responsible for storage, this also has implications for the point in the SC at which storage costs will arise and who will bear these costs (and the impact that money tied up in stock will have upon cash flow).
- The size of the storage facilities in the SC will also affect the transport arrangements.
 - For example, a retail outlet with a relatively small on-site stock level (e.g. just what is displayed on the shelf – a few days' supply) will require more frequent, evenly spread deliveries than an outlet with a large storage capacity (e.g. with an attached warehouse).

Inventory Monitoring and Control

- Inventory may be defined as '*usable but idle resource*'.
- If resource is some **physical and tangible object such as materials**, then it is generally termed as **stock**.
- Thus, stock and inventory are synonymous terms, though inventory has wider implications.
- It is very important to have a check on the inventory level.
- Scientific inventory management is an extremely important problem area in the *MM* function.
- Materials account for more than half the total cost of any business, and organizations maintain a huge amount of stocks, though much of this could be reduced by following scientific principles.

Inventory ...

- Inventory management is highly amenable to control.
- Across industries, there is a substantial potential for cost reduction through inventory control.
- Inventory being a symptom of poor performance, one can reduce inventories through proper design of procurement policies by reduction in the uncertainty of lead times by variety reduction and in many other ways.

Site planning to reduce loss and waste

- It is essential to allocate specific monies in the tender for the costs of managing materials – no matter which of the preliminaries it is hidden in or included in. Monies need to be included in a tender bid to provide:
 - Hard standing areas for site access and materials storage areas
 - Facilities to cover and protect components from the weather
 - Timber pallets or crates in which to store materials such as formwork, scaffold fittings and drainage fittings

Site planning ...

- A storage compound with dedicated material storage areas for the storage of window frames, lintels, pipes and sheeting *etc.*
- Lifters or loaders to handle materials onto scaffolds and loading platforms
- Tarpaulin sheets to cover plasterboard and other sheet material
- Racked storage for specialist timber products, trunking and pipework.

Bad site practice observations

- Here are a series of site images indicating both good and bad site practice in relation to materials management.
- The project case studies all include aspects of materials control and site layout planning situations.
- Every site situation is different and there isn't one magical solution to them all.
- As the site progresses from foundation work to roofing and external works, different materials are brought on site for each construction stage.
- The site layout plan should therefore be flexible enough to accommodate this ever-changing situation.



“The Good”



"The Bad"



"The Ugly"

Snapshot – high-quality housing project

- There is no excuse for the degree of untidiness on the site.
- Areas under scaffolds should be maintained clear of waste material as each scaffold platform is raised.
- On speculative housing projects extensive use is made of labour-only subcontractors. The main contractor should ensure that they are responsible for the material losses that they create.
- A “*name-and-shame*” approach should be taken, and they should be contra-charged for cleaning up their mess at the end of each stage of work.

Materials mismanagement on a high quality residential project. Surely the subcontractors cannot be held responsible for all this mess!



Snapshot – surplus materials and over-ordering

- The over-ordering of materials during a contract generates extensive costs for the contractor.
- The images display surplus bricks, plastic piping, insulation and timber within the compound area.
- Packs of sheet insulation, expensive earthenware pipes and aluminium or galvanized metal external cladding materials await disposal.
- Not only has the contractor been charged for delivering the goods to site – but he now has to pay for them to be disposed of.

A disorganized storage compound - situations of this type occur towards the completion of a project, often resulting from the over-ordering of materials



Surplus materials lying around the site at the contract completion - surpluses again created by over-ordering of materials during the contract



Good site practice for materials management

- Good practice observations are indicated here, together with a comprehensive section on the use of waste skips to separate the collection of waste materials on site.
- On larger projects, specialist waste disposal firms are often engaged to manage waste on site.
- Monthly waste analysis reports are prepared on the amount of waste disposed of each month.
- The aim is to achieve a maximum of 5% waste to be returned to landfill.

Worked examples

Example 1

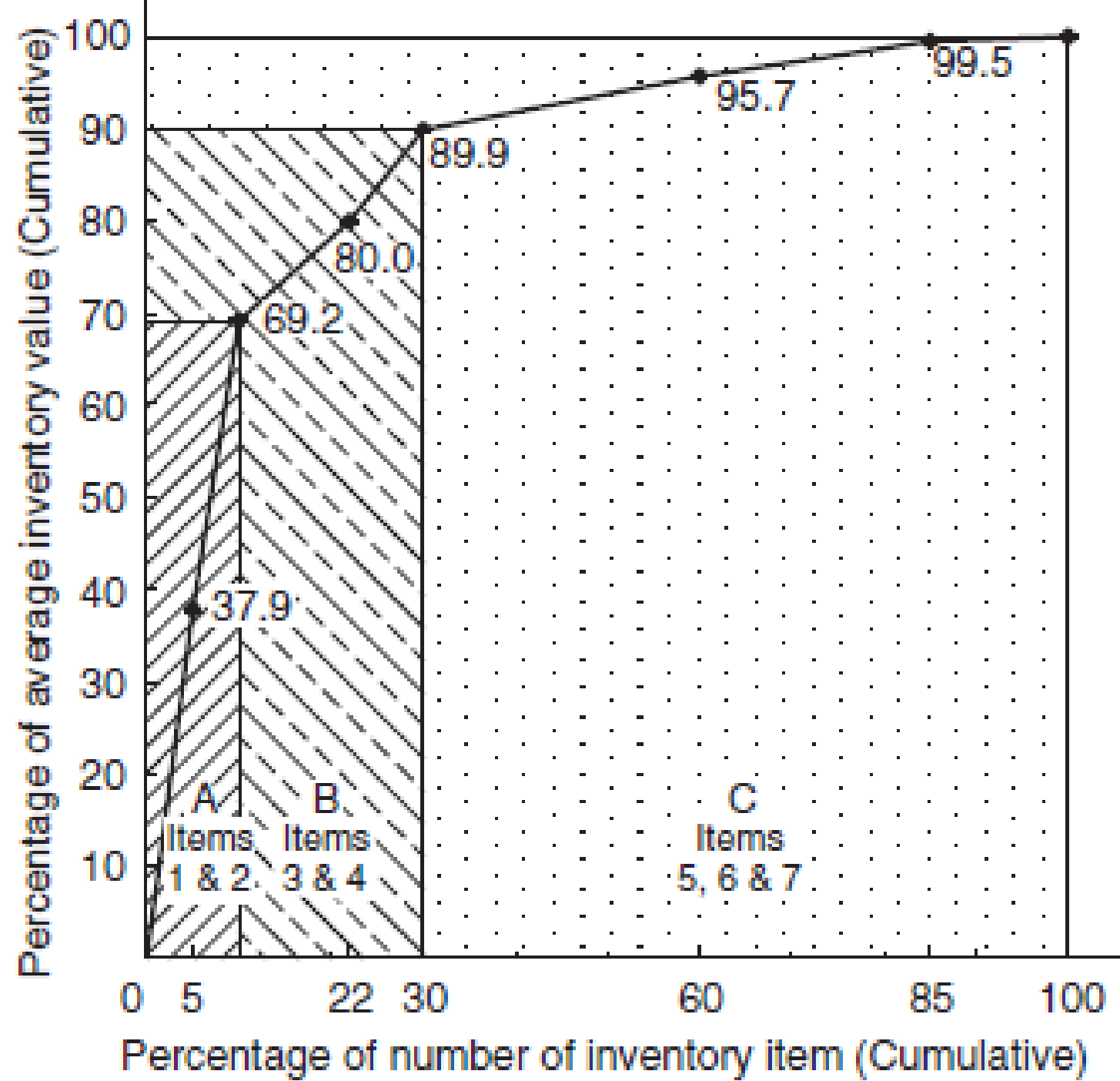
- A shop dealing in construction goods has 7 different items in its inventory. The average number of units of each of these items held in the store along with their unit costs is given in Table 1. The shopkeeper has decided to employ *ABC* inventory system. Classify the items in *A*, *B* and *C* categories.

Table 1 Data for [Example 1](#)

Item	Average number of units	Average cost per unit in inventory (in Birr)
1	10,000	121.50
2	10,000	100.00
3	24,000	14.50
4	16,000	19.75
5	60,000	3.10
6	50,000	2.45
7	30,000	0.50

Solutions

Item	Units	% of total	Cumulative % of total item	Unit cost (Birr)	Total cost (10 ⁶ Birr)	% of total cost	Cum. % of total cost
1	10,000	5.00	5	121.50	1.215	37.9	37.9
2	10,000	5.00	10	100.00	1.00	31.2	69.2
3	24,000	12.00	22	14.50	0.348	10.9	80.0
4	16,000	8.00	30	19.75	0.316	9.9	89.9
5	60,000	30.00	60	3.10	0.186	5.8	95.7
6	50,000	25.00	85	2.45	0.1225	3.8	99.5
7	30,000	15.00	100	0.50	0.015	0.5	100.0
Total	200,000	100.00			3.2025	100.00	



- A graph as in Figure is drawn between cumulative percentage of cost and cumulative percentage of numbers.
- From the graph, it is clear that about 70% cost is consumed in 10% of the inventory items.
- These are for items 1 and 2. Thus, items 1 and 2 are *Class 'A'* items.
- Similarly, items 3 and 4 have a cost share of about 20% (89.9%– 69.2%) and an inventory share of 20%.
- Thus, items 3 and 4 are *Class 'B'* items.
- Finally, we can see that items 5, 6 and 7 belong to *Class 'C'* as their cost share is about 10% (100%–

Example 2

- A construction company stores various items (see Table 2) in the central stores. The average annual consumption and cost per unit of items stored are given. Classify the items using *ABC* analysis.

Table 2 Data for [Example 2](#)

Name of the item	Average annual consumption (No.)	Average cost per unit (Birr)
a	5,000	45.00
b	1,000	90.00
c	2,000	225.00
d	4,000	11.25
e	50	300.00
f	6,000	62.50
g	2,000	67.50
h	4,000	18.75
i	50	375.00
j	250	105.00
k	200	187.50
l	50	150.00

Solutions

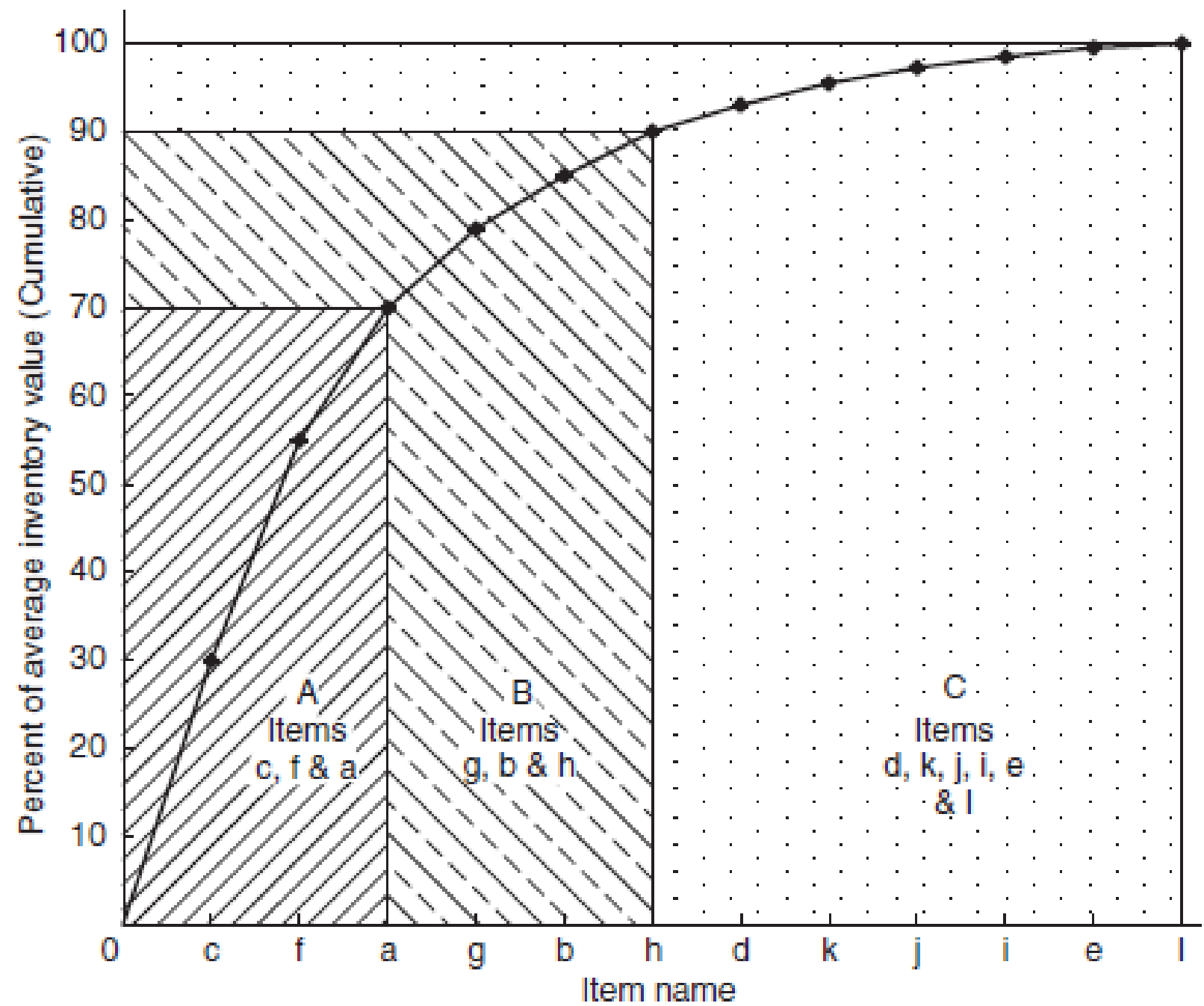
Table S2.1 Computation details for average annual cost of consumption

Name of the item	Average annual consumption (No.)	Average cost per unit	Average annual cost of consumption	Ranking
a	5,000	45.00	225,000	3
b	1,000	90.00	90,000	5
c	2,000	225.00	450,000	1
d	4,000	11.25	45,000	7
e	50	300.00	15,000	11
f	6,000	62.50	375,000	2
g	2,000	67.50	135,000	4
h	4,000	18.75	75,000	6
i	50	375.00	22,500	10
j	250	105.00	22,500	9
k	200	187.50	37,500	8
l	50	150.00	7,500	12

- The computations of average annual cost consumption of different items have been performed in Table S2.1 .
- The ranking based on the average annual cost of consumption has also been performed.
- Now, we prepare Table S2.2 in the descending order of average annual cost of consumption. The average annual cost in percentage of total annual cost is computed.
- The cumulative value of this percentage is also computed.
- From the graph, it is clear that about 70% cost is consumed by items *c*, *f* & *a*.
- Thus, items *c*, *f* & *a* are *Class 'A'* items.
- Similarly, items *g*, *b* & *h* have a cost share of about 20%. Thus, items *g*, *b* & *h* are *Class 'B'* items.
- Finally, we can see that items *d*, *k*, *j*, *i*, *e* & *l* belong to *Class 'C'* as their cost share is about 10%.

Table S2.2 Computation details for A,B,C classification

Rank in descending order of cost	Name of the item	Average annual cost	Annual cost (percentage)	Cumulative cost (%)	Category
1	c	450,000	30	30	A
2	f	375,000	25	55	A
3	a	225,000	15	70	A
4	g	135,000	9	79	B
5	b	90,000	6	85	B
6	h	75,000	5	90	B
7	d	45,000	3	93	C
8	k	37,500	2.5	95.5	C
9	j	26,250	1.75	97.25	C
10	i	18,750	1.25	98.5	C
11	e	15,000	1	99.5	C
12	l	7,500	0.5	100	C



Example 3

- A construction material trading company receives a total of 200 ton as annual demand for steel reinforcement. The annual cost of carrying per-unit ton of reinforcement is Birr 2,000 and the cost to place an order is Birr 25,000. What is the economic order quantity?

Solutions

$$EOQ = \sqrt{\frac{2 \times \text{Order cost} \times \text{Demand}}{\text{Inventory carrying cost}}}$$

$$EOQ = \sqrt{\frac{2 \times 25,000 \times 200}{2000}}$$

Thus, economic order quantity 570.7 ton per order.

Example 4

- A construction company purchases 10,000 bags of cement annually. Each bag of cement costs Birr 200 and the cost incurred in procuring each lot is Birr 100. The cost of carrying is 25%. What is the most economic order quantity? What is the average inventory level?

Solutions

Given

- Unit item cost (C) = Birr 200
- Ordering cost (A) = Birr 100 per order
- Annual usage (D) = 10,000 units
- Carrying rate (I) = 25%

$$\begin{aligned} \text{EOQ} &= \sqrt{\frac{2 \times A \times D}{I \times C}} \\ &= \sqrt{\frac{2 \times 100 \times 10000}{0.25 \times 200}} \\ &= \sqrt{(40000)} \\ &= 200 \text{ units} \end{aligned}$$

Hence, the order quantity will be 200 units and on an average, $200/2 = 100$ units in inventory will be carried.

Example 5

- For Example 3, if the lead time of procuring cement is two weeks, determine the reorder point.

Solutions

- The lead time given is two weeks. So, the weekly usage is $10,000 \text{ units} / 52 \text{ weeks} = 192 \text{ units}$.
- The reorder point will be $= 192 \text{ units} \times 2 \text{ weeks} = 384 \text{ units}$.
- That is, place an order for cement whenever the stock reaches the level of 384 units.
- The order quantity will be 200 units.