Chapter 4
Warehousing and Storage Equipment

Warehousing plays an important role in the perspective of supply chain management (SCM). In term of facilities, staff and equipment required, warehousing is somehow costly, whose performance will significantly and directly impact overall performance of SCM. Inadequate design of warehouse systems or poor management of warehouse systems will threaten the overall success of SCM. During the last couple of decades, some of the pressures on logistics—minimizing inventory, increasing customer service level and reducing cost and time—have inevitably changed supply chain structure and the position and role of warehousing within SCM.

Definitely, the traditional idea of warehouses as places to store material, components or finished goods has been outdated. Warehouses are possibly better improved to be distribution centres (DCs) to promote the movement of products. There are some exceptions like strategic stock holding, but commonly effective movement of products to the consumer/customer is the vital objective. In fact, as little inventory as possible has to be held to achieve this.

Warehouses come in different sizes and shapes, from facilities of some hundred square metres handling modest throughputs, to—regardless of the previous comments—large and continual throughputs (hundreds of pallets per hour).

On the other hand, the idea of throughput rather than storage, reduction of inventory and increased customer service has also seen the development of distribution centres that do not holding inventory—the minimum inventory/stockless depot, such like cross-docking operations and transhipment depots.

Another big problem troubling minds in recent years has been the technology level being use in the operations of warehouse. The range spans from conventional warehousing—shelving and racking with manual operations or forklift—to automated systems with AGVs, conveyors and on to robotic applications. It is not always clear-cut for the major reason of choosing a specific level of technology; reasons run from scope, marketing, financial and/or other factors, from firm's flexibility or image for future change to personal perception of the suitability of a specific information technology to a particular business.

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4.1 Strategic Issues

Warehouses, distribution centres and stores should operate as integral component factors within whole end-to-end supply chain management. Main decisions when establishing such facilities must be made through the overall strategies of logistics for cost and service. The following elements should be taken into account:

Market/Product Base Stability
The market expectations (long term) for growth and for item range will affect decisions on the location and size of a warehouse. These considerations also will significantly impact the perceived requirement for flexibility, which in turn may affect decision-making on the level of technology and type of warehouse.

Type of Products to Be Handled
Products handled may cover spare parts, raw material, finished goods, packaging material, or work in progress in a span of material types, weights, sizes, and other characteristics. The units to be controlled/handled can range from individual small products to packages, drums, sacks, palletized loads and on up to container of ISO. Special necessities for humidity and temperature may also have to be met, and these all will influence the level of technology and type of warehouse.

Type of Facility, Location and Size
As is not determined directly, the type of operation, size of a warehouse, the design capacity and its location will be influenced by its particular position and role in the SC. Customer base, need for inventory minimization, amount of inventory, time compression in the SC and the service levels should all be taken into account carefully before deciding the location, size and type of warehouse.

Inventory Location
In the perspective of SC, there is not only the issue of what products/goods to hold and how many, but also of the locations. Options may cover distribution centres (DCs) dedicated to particular parts of the product range or serving specific geographic areas, or regional level DCs that hold, for instance, the fast moving consumer goods (FMCG) product lines, with the slower lines held in a national distribution centre only. The choice is dependent on some elements as product range, customer base and service levels.

Level of Technology
The decision of level of technology can be affected by firm-wide strategic marketing policies, budget and financial considerations and the required levels of customer service. Other elements may cover requirements for flexible operation to fulfil crucial demand fluctuations, for example, perceived future stability, market growth and seasonal variations. The technology level implemented in any specific application should be achieved to most closely match the given objectives and requirements. It cannot be realized that similar technologies and automation can be right

in every situation/case. But it is possibly true that computer-based information and communication system is crucial in every application, irrespective of the level of technology.

Choice of Unit Load
The choice of load or unit loads—cage pallets, tote bins—will be made by the characteristics and nature of the goods moving along the chain of supply, and this very clearly covers an extremely broad range of goods, pack types, sizes and unit quantities. This can appear as a very ordinary/mundane element more subject to operations than to strategies. On the other hand, in the warehouse, it may influence the sizing and choice of storage systems, and choice of handling equipment systems. In simple words, it will influence transport operations in the order of vehicle unloading, loading and utilization.

4.1.1 Costs

In the early 1980s, the Institute of Logistics and Transport commissioned and published an annual survey of the distribution costs incurred by industry, analysed by the cost of transport, inventory, handling of the inventory and storage. Warehousing cost, as a percentage of sales turnover, appears to settle out at a figure of almost 2%. As a percentage of the complete cost of distribution, the warehousing factor ranges between almost 30% and 40%. By any measure, this shows a large expense to industry.

The operating costs of the single components in the warehousing visibly depend on such elements as the nature of the industry and warehousing operation.

The freight transport association (FTA) publishes broad guidelines on early basis, in which it focuses on the large variability of such costs, but suggests the dominant costs are employees, accounting for almost 50% of the total, with building costs being a further quarter.

Further detailed cost surveys for operations of a “conventional warehouse”—reach pallet racking and trucks with case picking at ground level—have indicated average annual costs of:

- Employees/Staff—more than 50% almost half of which is accounted for by the labour of order picking
- Building—25%
- Building services—15%
- Equipment—10–15%

From a cost perspective, the two main elements that emerge from these figures, on which managers should put specific focus, are design or management of order picking and space (building) utilization.

4.2 The Role of Warehouses

The primary and basic value of DCs and warehouses lies in facilitating the movement of products/goods from upstream (suppliers) out to downstream (customers). In terms of achieving this objective effectively, warehouses and DCs may have to hold inventory, but that is not their most important function. Some warehouses/DCs have a specific objective of storing/stocking products and raw materials against particular contingencies, which it is hoped will not occur, for instance, spare parts and disaster relief supplies.

The adoption of JIT systems and other related approaches to material supply, allied to computer-based information systems that give real-time information on stock locations and availability, has definitely challenged the requirement for holding stock and having warehouses at all.

There is no doubt that inventory levels have significantly come down over time. However, even with closer integration of logistics planning and manufacturing and new techniques of demand forecasting, in many ways within SCM there will remain a level of mismatches and also conflicts between demand and supply optimization.

There will also be the need to consolidate products/goods from different sources, for operations of break-bulk, for activities of value addition including postponement.

Hence, there are authentic and valid reasons for continuing to have DCS and warehouses for holding stock in the supply chain including:

- To facilitate economies of long production runs in manufacturing
- To give a buffer inventory between production runs in manufacturing
- To provide a buffer inventory to smooth variations between demand and supply
- To facilitate procurement savings through large buying
- To cover seasonal peaks and fluctuations, e.g. the EID-ul-fitar and Christmas
- To cover for breakdowns in production or planned production shutdowns

Remaining important reasons for operations of warehouses have included more operational tasks such as:

- Packaging/repackaging
- Order picking and assembly
- Postponement
- Kit marshalling for manufacturing and assembly

Latest developments in JIT systems and other related approaches to inventory and time minimization will continue to decrease inventory levels and also will change the "centre of gravity" of where stock/inventory is held, pushing it back up the SC. This, however, will not minimize/remove completely the need for stock and the facilities in which to hold it. The importance of DCs and warehouses has been shifted more towards improvement and focused on the following objectives:

- Fulfil the need of customer service standards
- Facilitate the flow of products to the consumer/customer

- Incorporate value-added activities, e.g. postponement as a means of minimizing the SKUs (stock keeping units), and also increasing the flexibility to fulfil customer needs and wants

4.3 Types of Distribution Centre and Warehouse

DCs and warehouses may operate at regional or national levels, determined by the structure of supply chain and customer service, and strategic decisions on levels of inventory. National or regional distribution centres can use traditional storage and handling systems or can be designed to be well equipped and automated. On a domestic level there can be “stockrooms” that serve a small number of retail shops within a close territory. These are stock holding facilities.

A basic difference exists between stockless depots and stockholding warehouses, and the latter have been receiving more attention in current years as making fast stock movement and inventory minimization. Usually there are two fundamental norms for a stockless depot: cross-docking and transhipment depots.

Cross-Docking
This is the trend to operate out of an empty building. Goods ordered by SKU from suppliers in quantities sufficient to fulfil the next day’s total customer orders are delivered to the site and unloaded. Goods then directly go to a sorting system which distributes the required quantities of each item/product to an allocated location of orders so that the orders build up, item by item, until the orders are fulfilled/completed. Completed orders are then loaded to outbound delivery vehicles parked along the dispatch face of the building. Dispatch vehicles leave to meet specified departure times to reach customer locations by given deadlines. The term “picked by line” is usually used to explain this type of operation.

Transhipment Depots
This is the trend to be located in such a way as to fulfil the specific areas of customer concentration. Customer orders are picked at a stock-holding depot—typically national distribution centre—loaded to road trailers in reverse drop sequence and dispatched to the transhipment depot overnight, where the trailer is dropped. The overnight tractor returns to the national distribution centres with the previous day’s empty trailer. In the morning, a local tractor unit picks up the overnight trailer, delivers the customer orders and returns the empty trailer to the transhipment depot. This system’s implication is that all order picking, down to individual customer level, is carried out at the national distribution centre, and there is no stock held at the transhipment depot, which need be only a small secure site without employees/personnel.

4.4 Operations of Warehouses

Among warehousing operations, there are many types of equipment and methods that can be used for handling and storing material and for order assembly, from which a system should be designed to fulfil the requirements of the SC within which it functions. However, there is a primary material flow that is general to most warehouse operations, while this can be modified in specific situations such as operations of cross-docking. Figure 4.1 shows the primary flow of material and the functions of a warehouse.

Figure 4.1 reflects the separation of reverse storage from order picking. The objective is to limit the distance that order picking personnel would otherwise have to travel to access the full range of stock items, particularly, in warehouses holding high stock volumes.

By limiting the stock held in the area of picking, travel distances for picking are minimized. Separation helps to minimize the interferences between building material movements and order picking. However, the risk is that due to concentrating all the picking activity into a small geographical location, congestion will ultimately occur. Hence there is a quid pro quo (balance/trade-off) between reducing distance of travel and avoiding congestion in the area of picking. Clearly, if the total inventory for a stock product is small, it will not be suitable to hold it in a separate place.

The functions of warehouse are the following:

Fig. 4.1 Warehouse functions and flow of material

Goods Inwards

This covers the physical unloading of incoming goods, recording of receipts, checking and making decisions on where these goods should to be put away. It also can cover such activities as repackaging, temporary quarantine storage of goods (awaiting clearance, due to quality reasons) and checks of quality control.

Reverse Storage

Reverse storage is the biggest space user in warehouses; this space holds the build-up of warehouse inventory in recognizable locations. Products are moved to storage (reverse) from goods inwards, and the locations/place communicated to the warehouse information system (WIS).

Replenishment

Replenishment is the movement of products/goods in greater than order quantities, for instance, a full pallet at a time, from reverse storage to order picking, to ensure that locations of order picking do not become empty. Keeping stock availability for order picking is crucial for attaining higher levels of order fill.

Secondary Sortation

For small order sizes, it is usually more suitable to batch a number of orders together and also treat them as "one" to pick. In this situation, the picked batch will have to be sorted down as single/individual orders, i.e. secondary sortation before shipping goods.

Sortation

In some situations the usage of IT means that the ultimate destinations of an important and crucial proportion of the products/goods coming into a warehouse are known. Latest developments have therefore used this facility to make goods coming into a warehouse to be sorted into particular order of customer immediately on arrival, often using high-speed sortation conveyors. The products then directly go to collation of order. This method has been used for a couple of years in operations of cross-docking for grocery items by key super markets.

Order Picking

Products are selected from stock of order picking in the required quantities and at the required time to fulfil the orders of customers. Usually picking involves operations of break-bulk, when products are received from suppliers in say, whole pallet quantities, but there are orders by customers in less than quantities of a pallet. On the other hand, if specific goods are required in sufficiently larger quantities, for instance, a whole pallet load, the order is directly picked from reverse storage. The picking order is crucial for achieving higher customer service; it also conventionally takes a high proportion of the total warehouse personnel complement and is costly. The picking systems and operations, good design and management are consequently important and critical to effective performance of warehouse.

Collate

This involves packing into dispatch outer cartons, operations of labelling and shrink and stretch wrapping for load stability and protection.

Dispatch
Collated, picked and packaged products are assembled for loading to outbound trucks, and onward dispatched to the next node in the SC—intermediate DCs, then to the next transport leg such as air, sea or dispatched directly to the customer/consumer.

The above-mentioned functions show the basic activities found in the operations of warehouse. Additionally, there may be a broad range of subsidiary activities like sub assembly, packaging material stores, packing areas, equipment maintenance shop, amenities and offices and truck battery charging area, and in some circumstances services to support particular product environments, such as frozen products stores.

4.5 Objectives of Good Warehouse Design and Management

There is an oft-quoted definition which used to be quoted to compress the final point of material handling, covering the goals of all SC operations in different ways, including warehousing:

"Getting the right products in the right quantities, at the right time and right place, in the right form, safely and at the minimum overall cost of system". From a couple of facets, this "old hat", has been around for decades, while it is hard to fault that as a statement of what goal distribution is trying to achieve.

Setting out a statement of best practices for the system design and management of warehouse, however, is more open; different authorities have expressed this in distinctive ways. A couple of decades ago, one researcher created a list of almost 30 principles. In an overall context of minifying overall cost of system, a briefer summary of the major and fundamental principle, providing the essential quality of customer service in order of accuracy, completeness of order fulfilment, timeliness, is displayed in the sections given below:

4.5.1 Use of Building Space

Warehouse space is a crucial proportion of total warehouse space, and costs should be utilized properly and effectively. For making full use of warehouse space, the following should be considerations:

- Eliminating obsolete stock and reducing total stock holding
- Careful selection of appropriate handling and storage systems
- Effective usage of space—building height, mezzanine floors
- Using random location systems for stock

However, it is crucial that there should be clear access to stocked products, and in warehouse design, one of the important "trade-offs" is to achieve maximum utilization of space while maintaining unrestricted stock access. With careful analysis of stock, where the emphasis should be put in any specific circumstances or for specific parts of the goods range will be suggested.

4.5.2 Choice of Unit Load

A unit load is an assembly of single/individual packages or products, often of a like kind, to make composite movement convenient, whether mechanized/manual. For instance, pallets in a range of goods, whether wooden pallets (still very common), post pallets, tote containers, roll cage pallets, steel or plastic cage pallets and ISO containers. The advantages of effective utilization cover moving maximum quantities of products every journey, and thus reducing the number of movements, the ability to use standard storage and handling equipment, protection and security of stock, best use of space for storage, and facilitating the interface between transport operations and warehousing, including the unloading and loading of trucks.

4.5.3 Utilization of Resources

The warehouse design and management should enable efficient and effective use of resources, covering the monitoring of equipment utilization and availability.

4.5.4 Minimum Movement

Movement of goods/products uses resources and, except in the case of an automated system, involves operating personnel time. The layout of warehouse and the positioning of the warehouse operations inside the building obviously influence the amount of goods movement, so does the location of stock within the systems of storage. Approaches to reduce goods movement are the following:

- To reduce travel time, locating FMCG/high turnover products close to dispatch area
- Providing handling equipment to reduce manual movement and effort;
- Computer-based planning of warehouse goods movement routes to shrink travel time
- Separation of reverse stock and order picking to concentrate picking activity into the smallest feasible area while avoiding bottleneck/congestion
- Movement planning to increase utilization of handling equipment and personnel and avoid travelling without payloads, for example, dual cycling, in which both return movements and outward movements of product handling equipment are utilized for carrying products

4.5.5 Control System and Information System

A fast, effective, flexible and accurate information and communication system should be established in the warehouse installation. The functionality should cover the capability of:

- Logging stock movements and maintaining balances
- Monitoring productivity, the availability and utilization of resources like storage and handling equipment
- Controlling stock location
- Tracking the goods movement through the effective system, ideally instantaneous communication between management system and operators
- Planning optimum goods movement routes, additionally order picking
- Sorting order requirements into suitable order picking tasks

4.5.6 Product Integrity

The systems of warehousing and handling should be so designed and managed that product can be maintained in an appropriate state for the consumers/customers. This involves systems in place to reduce loss and damage, and to satisfy stock rotation, and any legal constraints on storage environment like limits of temperature.

4.5.7 Working Safety and Conditions

Conventionally, the numbers of warehouse takes have made the function monotonous and arduous. In recent years, this becomes an area of growing importance. Some current innovations in trucks design (forklift), for instance, is particularly aimed at reducing risk of repetitive strain injury and improving operator environment. Lighting levels, humidity and hygiene also have an impact on operator environment and consequently on performance of operators in the long run.

There is no doubt that due to the lifting and manual handling of goods involved, safety has prime importance in warehousing operations. In fact, with the levels of automation and mechanization in some advanced installations, safety plays a vital role. This is further highlighted by the amount of related legislation.

4.5.8 Environmental Issues

The awareness of environmental issues is increasing day by day, and it is one major reason that more and more has to be taken into account in the system of warehouse design and management. Examples are the regulations affecting packaging, the additional responsibility and cost that have been forced/imposed on suppliers.

4.5.9 Information and Communication

In essence, warehousing is a simple operation, but it can go spectacularly wrong. The general reasons for performance failure are related with inadequate communication and information systems.

From the author's point of view, a good communication system, information and monitoring system inside the warehouse, and also communication out to the broader supply chain, are a sine qua non (essentials) of effective and efficient warehouse management. Without such an appropriate system, in fact, without experienced personnel and well-designed facilities, overall maximization of performance of the warehouse will not be accomplished.

4.5.10 Packaging and Unit Loads

4.5.10.1 Packaging

The definitions of packaging cover "the art, science and technology of preparing products for dispatch and sale". Safe delivery of goods is an integral part of a SC, and the use of packaging and design influence not just handling and storage, but also other functions like marketing, manufacturing and determination of the most suitable type of unit load to be in use. The following are the functions of packaging:

- To preserve an item from chemical, mechanical and physical deterioration, contamination or damage
- To contain the goods
- To communicate safety instructions, instructions for item use and other information
- To facilitate ease of unitizing, ease of handling, and, in some cases, to act as a dispenser and measure
- To act as a marketing aid through presentation and appearance

Packaging requires being compatible with the processes through which it will pass, such as packaging and filling machinery. The design must also take potential reuse and for the disposal of the package after use into account. Forms of packaging include the following:

- Primary package in direct contact with the product, to contain, protect and seal, e.g. tube, sachet or envelope
- Secondary package, considering one or many primary packages, to offer physical protection
- Transport pack or outer packaging

During moving and handling through the SC, packaging will be subject to potential deterioration, damage including the following:

- Environmental elements such as water, temperature changes, odours and other contamination
- Mechanical shock, vibration, compression, abrasion or impact
- Pilferage
- Other potential reasons of damage, including fungi, infestation, bacteria and vermin

4.5.10.2 Unit Loads

The concept or idea of unit loads puts goods onto suitable/appropriate standard modules for storage and handling, loading, unloading and movement. It facilitates the use of standard equipment irrespective of the goods being handled, meanwhile achieving goods security, economy and protection in the use of space, and minimization of the amount of handling needed for a given quantity of material.

Most physical distribution is structured round the concept of the unit load, and the choice of unit load is basically to facilitate the economies and effectiveness of a SC. The following are examples of unit loads:

- Wooden pallets made to standard sizes, although there are many and different standards, which can be the reason for some issues and problems with cross border movement. For instance, the dominant pallet in the United Kingdom is the ISO (1200 mm × 1000 mm), in Europe is the Europal (1200 mm × 800 mm). Except for the size of pallet, other variables cover pallet construction: 2-way or 4-way fork entry, non-reversible or reversible, closed boarded or open boarded. The pallet (wood) is possibly the most generally used type of unit load.
- Small containers like tote bins, made of galvanized plastic, and used for small parts handling and storage.
- The pallets (roll cage), which contain bases fitted with dolly cage sides and wheels. These have been widely used in wholesale grocery distribution systems.
- Box pallets and cage, usually of metal construction, fitted with corner posts to contain the items, and often stackable by means of bell ends fitted on the bottom of the corner posts.

- International standards organization freight containers are made in a range of standard external sizes that can stack and fit together for loading onto sea and land transport and for holding at container terminals. Standard handling, unloading or loading, and stowing can therefore be used, which support and help to minimize turn-around times of transport and offer secure transit. Different designs of containers, within the standard external dimensions, enable their use for bulk solids, refrigerated goods, general cargo and bulk liquids.
- Intermediate bulk containers (IBCs) show the link between unit load and bulk handling, and are designed for payloads of 1–2 tons. They are used for solid particulate goods like building products, chemicals, and some are specifically designed for liquid items. Usually these are rigid IBCs made of plastic, collapsible intermediate bulk containers made of canvas for ease of return, folding, and one-trip and low-cost intermediate bulk containers made of fireboard. IBCS are used inside of the plant transport and storage, and they cut out the need for conventionally sized sacks. Usually they are designed for bottom emptying, top filling and are handled by standard forklift. They can often be block stacked.

4.5.11 Storage Systems and Equipment

The function of storage in the warehouse design is a main consideration if for no other reason than that it frequently occupies more space than any other activity. Hence, it accounts for an important and significant part of the costs of building. Operational storage systems impact on product protection, integrity, access to stock, the discipline of correct stock rotation and location, the ease or otherwise of stock management.

The material type to warehouse differs enormously—different weights, sizes, brittleness, hazard characteristics and shapes. A main advantage of unit loads such as pallets is that they allow the use of handling equipment, and standard storage systems. On the other hand, variations in order picking and throughput patterns make it suitable to have types of storage systems with different operational characteristics, so that systems can be selected that the most nearly match the requirements of the broader system within which they are to operate.

Suggested clearances, horizontal and vertical, to enable safe access for items moved into and out of equipment of storage and other guidance for the use of storage and design equipment can be found in a series of codes of practice published by the storage equipment manufacturers association (SEMA).

The major elements affecting choosing a storage system are given below:

- The effective use of building volume—vertical and horizontal
- The characteristics and nature of the unit loads and items held
- Good access to stock
- Maintenance of stock integrity and condition
- Compatibility with requirements of information system
- Staff/personnel safety
- Overall system costs

Comparing the different storage systems' costs, it is not just the costs of storage equipment that must be considered. Other cost elements that can be mainly affected by the choice of system are:

- Fire protection
- Personnel
- Space—building, land and building services
- Handling equipment
- Information management systems

One method to categorizing storage systems could be:

- Loose product storage, e.g. fabrications, casting held loose on the floor
- Bulk storage for solids, such as bunkers, silos, and stockpiles
- Non-standard unit loads
- Small product storage for individual products or small unit loads

4.5.12 Stock Location

In stock management perspective, the location of stock within a warehouse is crucial. For instance, the overall position of stock within specific places/areas in the store can influence the total amount of movement needed to get goods into and out of stock. It also can significantly affect the efficiency with which order selection and picking operations can be done by influencing the distance that order pickers have to travel to get to required stock.

It is crucial to place certain stock products at lower levels for ease of handling and operator lifting. For instance, very large and heavy products should be near to the level of the picking trolley platform to reduce operator lifting. The product lines of fast moving stock have to be accessed frequently and should be placed at best possible operator arm movement levels.

4.5.13 Random and Fixed Stock Location

Whether single product lines are held in dedicated places or randomly in any available storage place would influence the effective storage capacity of a given installation.

In a fixed location system, any exact place can only be used for its labelled product line. Therefore, the installation should be designated with sufficient capacity to hold the maximum stock of every single item line.

With random location, when any empty place can be used for any item line as needed, the size of installation may be minimized, since the possibility of each item being in stock at maximum stock level at the same time is virtually nil. In this situation, the future capacity storage may be estimated according to the sum of the average level of stock for all item lines, inflated by a factor, say 10%, to account for variation above the average.

In any installation of storage, the usage of storage places will be less than 100% since the movement of goods builds empty places that can never be refilled immediately. This effect is also taken into account when estimating the storage locations required in a random place warehouse.

Random place is usually used for storage of reverse products, which tend to take up the biggest areas in a store, and fixed place for order picking stock, which allows the use of storage by specific classification, such as popularity—fast moving item lines placed to reduce the picker's moving distances.

As with other characteristics of warehouse management, the ability to record fast every place, and identify which places are empty and therefore available for use, is a vigorous requirement for the effective management of the storage installation. In this implication is a requirement for effective place identification systems for stock places.

4.6 Palletized Storage

4.6.1 Block Stacking

There is no use of any storage equipment in block stacking. Loaded pallets are directly located on the ground/floor and built up one pallet on top of another to a maximum stable height. Rows of stacked pallets are set out side by side (see Fig. 4.2). Usual clearance in a block stack is almost 100 mm between pallets in every single row. When stock is removed for use, the only free access is to pallets at the front and on top of each row.

The loads of pallets must be able to carry the placed over pallets, and the top of every load must be flat enough to offer a steady/stable base for the next layer. If these requirements cannot be met, post pallets and pallet converters may be used, which carry the placed over/superimposed load directly to the next pallet in the stack via corner posts, and no weight is placed directly onto the "payload".

Any one row should comprise only pallets of similar or same items, to avoid double handling, and must be fully deflated/emptied before being refilled in order to avoid trapping old stock at the backs of rows.

The front to back depth of any row must not exceed 6 pallets in from the truck access aisle, for safe driving, which means blocks of 12 deep, back to back. In fact, designs can well incorporate rows of distinctive depths to products' accommodation with distinctive levels of stock.

Block stacking is appropriate for that part of the range of products where there are few item lines, each with high level of stock, and where strict first-in-first-out movement of stock is not required. The benefits are efficient utilization of space, flexibility to change the design of the blocks, fast and timely access to inventory for rapid throughput.

Fig. 4.2 Block stacking

Remember that almost every working warehouse usually has some unoccupied places—for block stacking, where any row must be emptied before being refilled, usually some 30% of the single pallet positions. When planning and designing for random place block storage installation with capacity of "P" pallets, the capacity of holding for 1000 pallets is needed, then 1000/0.7 = 1429 approximate places should be provided.

4.6.2 Drive Through Racking and Drive-In

Although this is a racked storage system, it is operationally the same as block storage. In every row, there should be only one product line, and the effective usage of pallet positions is almost 70%. The weight of the pallets is supported the structure of racking, so this is suitable for very high inventory/stock product lines, where strictly first-in-first-out movement is not required, but where the pallet loads are not strong enough or of regular enough shape to carry over/superimposed loads.

Since the pallets are reinforced/sustained by the structure, the installation height is not limited by pallet stability or strength.

The rack is made up of vertical support frames, tied on the top, with cantilever pallet support beams at distinctive heights. The forklift enters the racking between the vertical supports to access the pallets sitting on the cantilever beams. If access is all from one end, the racking is called *drive-in*, and if pallets are fed in one end and removed from the other, it is called *drive-through*.

Access for the fork-lift within the racking is tight because the cantilever supports have to be narrower than the width-size of the pallets, which have to be moved out and in of the racking in a raised position. But this tends to limit the movement (out and in racking) of pallets in terms of speed, and driver strain can be one factor.

Since pallets are supported along each side, the condition of pallets is significantly important, and due to the narrow truck access, the floor and the racking have to be built with close-fitting tolerances to reduce the risk of the trucks colliding with the racking.

Fig. 4.3 Drive-in racking

The maximum height suggested is 10–11 m, with the front to back narrow depth of six pallets in from the forklift access aisle (Figs. 4.3).

This type of racking is a recent development. Similar to drive-in racking, it gives higher-density storage and can also be built to any height up to the maximum lift height of the lift trucks retrieving or accessing it. In the racking, the pallets can be stored very well up to almost four deep on both sides of the access aisle.

Each level in every vertical row of the racking is fixed with inclined rails along which trolleys may move, the incline sloping down to the front of the racking. The trolleys "nest" when vacant. The incoming pallets are lowered over to the trolleys, pushed up the incline and into the racking by fork truck till the lane is completely full. As a retiring/outgoing pallet is withdrawn, the pallet behind moves down to replace it, until the lane is completely vacant and can be refilled.

The primary operational differences between drive-in or block stacking and push back racking is the increased selectivity achieved (Fig. 4.4). There should be no mix of item lines in lanes, but mixed product can be among the lanes in any one row.

4.6.3 Adjustable Pallet Racking

It is probably that adjustable pallet racking is the type of pallet racking that is used the most frequently, which gives free and easy access to every pallet held. It can be created to match the height-lift of any fork truck.

This racking consists of horizontal beams and upright end frames on which the pallets are placed, and heights of beams are adjustable to suit the pallet height loads being stored. According to the academic theory to enhance the utilization of beam heights, vertical space can be altered if pallet load heights change. But, practically, this usually does not happen.

Other than on pallets, unit loads may be stored using "adjustable pallet racking" and there is a broad range of accessories like channel and drum supports for post pallets to facilitate this.

Fig. 4.4 Push back racking

The traditional method of laying out "adjustable pallet racking" is to have a deep single row on each end of the installation, with back-to-back rows in between. This offers each truck aisle access to two racking rows, reducing the number of aisles needed. Guidelines for the vertical and horizontal spacing of the racking component to make safe access to pallets are offered in "storage equipment manufacturers associations" code of practice.

The "adjustable pallet racking" is one versatile, flexible storage system, that offers excellent access to stocks. It is very simple in idea or concept, easily laid out, and damaged parts are easily changed. It may be appropriate for slow-moving stock and fast-moving stock, and for item lines with low levels or high levels of palletized stock holding. Typical utilizations for positions of pallets in random location "adjustable pallet racking" can lie in the range of 90–95%, depending partially on the effectiveness of the warehouse management system (WMS) handling the information of location.

On the other hand, "adjustable pallet racking" does not make good use of a building. In a typical installation using fork-reach, each aisle (say 2.8 m) is broader than the back-to-back pallets in the racking (2.1 m, with international standard organization pallets positioned 1000 mm deep into the racking). Therefore, before allowing for any other requirement of space, such as aisles of transverse, the space utilization

Fig. 4.5 Adjustable pallet racking

of the building is well below 50%, and this is significantly critical in the context of the costs of a building.

With high rack stacker trucks equipped with sliding pallet or rotating pallet handling mechanisms, there is no need to turn in an aisle to retrieve/access pallet places, and "adjustable pallet racking" stacker trucks may typically operate in aisles (1.8 m or less). High rack stacker trucks may also lift higher than reach trucks; these two effects maximize the use of space. On the other side, there are penalties of cost in providing the required floor flatness and strength for working in high but narrow aisles, and the trucks are more expensive than reach trucks (Fig. 4.5).

4.6.4 Double Deep Racking

Double deep racking may be used if little loss of totally free access to inventory may be accepted. While not nearly as severe as push back or drive-in storage, block utilization of space can be improved by using double deep racking. This supports pallets on pairs of beams as in "adjustable pallet racking", and also improves and enhances utilization of space by eliminating an alternate access aisle, using a double reach forklift that can access not only one but two pallets deep into the racking. The idea is shown in Fig. 4.6.

The price of this space saving is the requirement for double deep reach trucks to access the stock, more costly than ordinary reach trucks, and some loss of selectivity since pallets are now stacked two deep into the racking, i.e. loss of absolute first-in-first-out inventory rotation. The position of pallet expected to be of the order of 85%. A practical requirement is that the level of bottom of pallets in the racking has to be backing on a raised beam to permit the legs of a double reach truck to properly fit under the structure of racking when accessing the pallet furthest in from the aisle. In individual deep "adjustable pallet racking" the bottom pallet may directly sit on the floor.

Fig. 4.6 Double deep racking

4.6.5 Powered Mobile Racking

The powered mobile racking is significantly effective single deep "adjustable pallet racking", with the racking, excluding the outer rows or end rows, mounted on electrically powered base frames, which move on rails set into the floor as illustrated in Fig. 4.7. Commonly only one forklift access aisle is offered, and the rack sections are shifted to open up access as needed to any particular pallet place—floor loadings are high. Operationally it almost has the same characteristics as "adjustable pallet racking", but is somehow slower in use, and the position of pallet utilization is likely to be the same as "adjustable pallet racking" at 90–95%. Safety trips are fitted to both sides of every mobile base frame to cut power of any obstruction in the event of hazardous or other situations.

Usually, this kind of system takes up a big part in floor and equipment costs, and it tends to be slower in operation. But it offers dense storage, and is appropriate for the large number of item lines forming the "Pareto tail" of an item range, where single item lines have low stock and throughput. Also, it finds use in applications of cold-store where costs of space are significantly high, where variations of temperature are minimized by cutting the air space in the area of storage.

4.6.6 Pallet Live Storage

The systems of live storage are made up of inclined gravity roll conveyors, laid out side by side and on a number of vertical levels. The pallets are fed in at the high end and removed as required at the lower. Such a system imposes "first-in-first-out". The pallets (only accessible) are at the outfeed end, so any one lane only should hold pallets of the similar/same item line.

In these installations, the conveyor's incline is significantly critical, and is perhaps best obtained by trial and error, by testing the pallets that will be using the

Fig. 4.7 Powered mobile racking

system. The devices of braking and end stops are fitted to control the pallets' movements towards the discharge end.

The system of live pallet storage is appropriate for fast-moving item lines. They may offer effective order picking regimes, which automatically refill vacant places, as well as also offer physical separation between replenishment operations and picking.

The pallet live storage is significantly expensive, and utilization of pallet position is not always high—say 70%. The type of pallet and condition is significantly critical, and in some applications slave pallets may have to be used (Fig. 4.8).

4.6.7 High Bay and Other Storage Installations

High bay warehouses, with racking accessed through automated-control stacker cranes can be created with double deep racking or single deep racking. Typically stacker cranes require 1.5 m to 1.6 m aisles for installation and standard pallet handling can be 40–45 m high. They are, therefore, inclined to make good utilization of place.

Operationally, they are similar to "double deep installation" or "adjustable pallet racking", with almost similar pallet position utilization figures, but they may be designed for high rates of throughput, with operation of 24 h. Remaining computerized handling and storage systems cover block stacking accessed through computer controlled in the air/overhead cranes, and storage of racked with pallets accessed through robot trolleys.

Fig. 4.8 Pallet live storage

Table 4.1 Comparison of palletized systems of storage

Factors	Block	DD	APR	Live	VNA	Push-back	Mobile	Drive-in	High-bay
Use of floor area	5	3	1	5	3	5	5	5	4
Use of building	5–2	3	2	5	3	5	5+	5	5
Volume ability to go high[a]	1	4	4	4	5	4	4	4	5+
Speed of throughput	4	4	5	5	5	3	1	3	5
Access to stock	1	4	5	2	5	2	5	1	5
Suitability for picking	2	4	5	5	4	1	1	1	1
Stock rotation (FIFO)	1	4	5	5	5	3	5	1	5
Product damage	1	4	4	4	4	4	4	3	5
Easy to manage	3	4	5	5	5	3	5	3	5
Fire protection	5	3	4	3	3	2	1	3	2
Rack cost	5+	3	4	1	3	1	1	3	3

[a]Depends on height of building, *APR* adjustable pallet racking, *DD* double deep racking, *VNA* very narrow aisle racking, *FIFO* first in first out, Live = pallet live storage, Mobile = powered mobile racking

4.6.8 Palletized Storage

One method to compare systems of storage is the use of a matrix to "rank" the significance and importance of the different characteristics. This can be completed through grading on a scale of say 5 = Good to 1 = Poor. One researcher's example is shown as Table 4.1.

4.6.9 Small Product Storage Systems

With palletized storage systems, there is a different range and types of systems for holding small products. In some cases, operationally these are almost similar to their pallet holding "big brothers".

With storage of small product it usually occurs that many systems are integrated into one installation. For instance, cabinet and drawer units can be built into a shelving installation. As a result, the idea of modularity and standard size of equipment is significantly important for systems of small item storage.

4.6.10 Shelving: Long and Short Span

Generally, shelving consists of modular parts that allow installation of different heights, shelf depths and vertical shelf spacing. Typically the standard span width is almost 1 m; however, long span shelving is available that facilitates holding products of stock. Subdividers may be used to give more places but smaller where this is suitable for the stock being held.

Shelving can be accessed in many methods—from mezzanine levels, ground levels, free path or fixed path lifting equipment such as picking cranes and forklifts. A variant on this idea is cantilever shelving that is sustained/supported from sides and backs, and provides complete access from the front and flexibility for holding products of different sizes.

4.6.11 Tote Bins

Tote bins are created in a range of raw material such as polypropylene, fibreboard, wire mesh and galvanized steel. They are created in modular sizes that are submultiples of standard dimensions, and this facilitates stacking and nesting, and the use of many sizes of tote bins within one installation.

A very useful device of supporting tote bins—in place of static storage places—for ease of movement (e.g. movement from store to manufacturing assembly operation) is the Louvre panel. It gives easy removal and attachment of totes, and also gives other attachments like spigots for holding products such as belts, and gaskets.

4.6.12 Drawer Units

Drawer units may be incorporated or free-standing into shelving stores or modules counters. Sub-separators are used that enable specifically good use of drawer space, and there is a range of many other fittings suitable for such products as machined products and electronic components. The drawer offers good access to inventory/stock and gives a secure and clean environment.

4.6.13 Dynamic Systems: Live and Mobile Storage

For palletized inventory, there is very small item mobile storage with shelves mounted on moving platforms, which run along floor-mounted nails. Alternative palletized systems are not usually powered, but are moved manually by turning a large wheel at the end of every shelving section (Fig. 4.9).

Broad usage of this system is in insurance companies and banks for holding documents required not very frequently.

Small cartons and items may also be held in systems of live storage, sometimes referred to as flow racking, with the goods placed on inclined roller conveyors, fed in at the high end and taken out as needed at the lower end (Fig. 4.10).

4.6.14 Mechanized Systems: Carousels

On shelves carousels hold materials, moved and supported by chains, which are electric-motor-driven to bring particular item lines as needed to an operator. The aim is to reduce the movement of operator when accessing stock, so carousels find application in small products order picking. The carousel units may offer speedy rates of accession to inventory, and are secure.

Carousels have two different types, vertical and horizontal carousels.

In the horizontal carousel, inventory is held in shelved baskets suspended from a motor-driven overhead chain conveyor loop, and for every stock accession the chain is driven backwards or forwards to bring the needed materials/components to the operator through the shortest distance (Fig. 4.11).

Fig. 4.9 Mobile parts storage

Fig. 4.10 Small parts live storage

Fig. 4.11 Horizontal carousel

In the vertical carousel, inventory is held on shelves suspended between two motor-driven vertical chain loops. The shelves are moved down or up, taking the shortest distance/route to bring inventory products as needed to the operator. The one major benefit of the vertical carousel is "it can be built on the roof (roof height) of a building, and enjoy full use of building space" (Fig. 4.12).

For carousel units, usually it is not practical to replenish inventory at the same time as stock is being withdrawn, so a working pattern has to be established for these two aspects of the operation.

Another mechanized storage system of small products is the miniload. A computerized crane operates in a central aisle to retrieve products/materials and put them into the medium storage tote containers or shelving set out on either side of a central crane aisle (Fig. 4.13).

4.6.15 Other Types of Storage

Material like linoleum and carpets, and engineering material like rod, tube and bar are not appropriate for the standard types of storage system, which has been discussed before, and these items require special handling and storage.

Fig. 4.12 Vertical carousel

Fig. 4.13 Miniload

Cantilever racking—supporting bars set at many levels from back frames—is usually used in applications of engineering for long rigid products such as tube and bar stock. This kind of storage is usually accessed by four-directional reach trucks, overhead cranes or side loaders in order to reduce the aisle widths required for access. For products such as heavy sections of sheet or plate, vertical "toast-rack" storage type is very commonly used.

Other long loads that need some support along the length, such as carpet rolls, can be stocked in pigeonhole racking, accessed by forklift fitted with long carpet booms that are inserted into the centre of the roll to position and lift it.

Discussion Questions

1. Explain the strategic issues affecting warehousing.
2. What is the main role of warehouses?
3. Briefly explain the types of warehouses.
4. Discuss warehouse operations in detail with examples.
5. What are the principles and objectives of good warehouse design and management?

6. What is the difference between fixed stock and random stock location? Discuss with examples.
7. Explain and discuss the “palletized storage systems” with examples.

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