CHAPTER 57
Storage and Warehousing

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1. INTRODUCTION

Storage and warehousing operations are a critical part of maintaining a profitable business. With over 300,000 large warehouses and 2.5 million employees in the United States, the cost of American warehousing is over 5% of the gross national product. In the past few years, the field of warehousing has begun to receive the attention it deserves. However, the warehouse management has been asked to increase customer service, reduce inventories, increase productivity, handle a large number of stock-keeping units, and improve space utilization. Warehouse management has realized that these conflicting objectives require a much more professional approach than previously adopted. It is critical that today's warehouse management follow this approach to achieve the results expected by today's upper management.

1.1. Warehousing Defined

The functions performed by a warehouse are:

1. Receiving the goods from a source
2. Storing the goods

3. Picking the goods when they are required
4. Shipping the goods to the appropriate customer

Oftentimes, a distinction is made between a finished-goods warehouse and a raw-materials storeroom. The fact is, however, that the functions performed in a finished-goods warehouse—receive, store, pick, and ship—are identical to the functions performed in a raw-materials storeroom. Consequently, both are warehouses. The only true distinctions between the two are the source from which the goods are received and the user to whom the goods are shipped. A raw-materials storeroom receives goods from an outside source, stores the goods, picks the goods, and ships the goods to an inside user. A finished-goods warehouse receives goods from an inside source, stores the goods, picks the goods, and ships the goods to an outside user. Likewise, an in-process inventory warehouse receives goods from an inside source, stores the goods, picks the goods, and ships the goods to an inside user, while a distribution warehouse receives goods from an outside source, stores the goods, picks the goods, and ships to an outside user. The differences among these various warehouses are restricted to the perspectives of the sources, management, and users of the warehouses. If the primary functions of an activity are receive, store, pick, and ship, the activity is a warehouse, regardless of its position in a company's logistics. The tools and techniques presented in this chapter can be successfully used to plan and manage that activity.

1.2. The Value of Warehousing in Today's Economy

It is important to ponder the question "Does warehousing add value to a product?" The traditional school of thought has concluded that no, warehousing does not add value to a product; warehousing is strictly a cost-adding activity that is a necessary evil. In firms that follow this school of thought, warehousing costs are typically classified as indirect costs. Often these cost categories are spread over the direct costs of the firm in such a way that the cost of warehousing is not distinguishable.

2. STORAGE AND WAREHOUSING

To convince yourself of the value of warehousing, consider the value of the refrigerator in the home. The refrigerator is essentially a warehouse. You purchase food at the supermarket, deliver the food to the refrigerator, store it in the refrigerator, pick the food from the refrigerator as needed, and ship the food to some location where it will be processed or consumed. What is the value of the refrigerator? What is the value of having milk where needed, when needed? If the answer is not yet clear, consider the costs that would be incurred if you did not own a refrigerator. What are the costs of not having milk for cereal at breakfast in the morning? Some of the costs are hunger from not eating, indigestion from eating dry cereal, the inconvenience of having to go to the supermarket before breakfast, and the actual expense of going to the supermarket before breakfast.

The true value of warehousing lies in having the right product in the right place at the right time. Thus, warehousing provides the time-and-place utility necessary for a company to prosper.

Without a complete and accurate understanding of the value of warehousing, companies have failed to give warehousing the same scientific scrutiny as the other aspects of their business. For a profession as important as warehousing, this is not acceptable. A more scientific approach must be taken to the warehouse of today.

3. SCIENTIFIC APPROACH TO WAREHOUSE PLANNING

Warehouse planning is more than pouring a concrete slab and installing some rack and tilting up some walls. Warehouse planning is not a static, one-time activity. The changing, dynamic environment within which warehouses are planned quickly renders existing plans obsolete. Therefore, warehouse planning must be a continuous activity in which the existing plan is constantly being scrutinized and molded to meet anticipated future requirements. For a warehouse to accomplish its objectives, warehouse managers must consider the variable warehouse resources and mold them into an effective plan. A successful warehouse maximizes the effective use of the warehouse resources while satisfying customer requirements.

3.1. Requirements for Successful Warehousing

To be successful into the 21st century, warehouse planning must be accomplished within the framework of a clear, long-term, consistent vision of where the warehousing operations are headed. The following strategies should form the basis of this vision.

1. *Professionalism:* Warehousing will be viewed as a critical supply chain enabler and a competitive strength, not as an inert facility.
2. *Customer awareness:* Serving the customer is only the foundation; satisfying them is vital to their continuing to patronize your organization.

3. *Measurement:* Warehouse standards will be established, performance will be measured against these standards, and timely actions will be taken to overcome any deviations.
4. *Operations planning:* Systems and procedures will be put into effect that allow the warehouse manager to plan the operations proactively rather than reactively respond to external circumstances.
5. *Supply chain network:* Warehouses will not be viewed as independent operations but as an element of the overall, well-planned supply chain.
6. *Third party/outsourcing:* More intelligent use of third-party logistics (3PL) is the norm so that organizations can focus on core competencies.
7. *Pace:* The reduction of lead times, shorter product lives, and increased inventory turnover result in an increase in the pace of the warehouse.
8. *Variety:* More different SKUs and more special customer requirements result in an increase in the variety of tasks performed in the warehouse.
9. *Adaptability:* Due to the increase in warehouse pace and variety, all warehouse systems, equipment, and people will be able to handle products that vary in size and weight.
10. *Uncertainty:* All uncertainty will be minimized; discipline will be increased.
11. *Integration:* Integration needs to be understood as not only a method of improvement within, or even between, processes but rather as a method of improvement of the whole process.
12. *Inventory accuracy:* Inventory above 99% is the norm with real-time warehouse management systems, bar coding, and electronic order processing. Annual physical inventories are eliminated and cycle counting is fully embraced.
13. *Space utilization:* Space utilization will be enhanced through dynamic slotting or the placement of product in a facility for the purpose of optimizing material handling and space efficiencies.
14. *Housekeeping:* There is efficiency in order in the warehouse. The certainty that the work areas are safe, free of congestion, and properly organized enables personnel to move through a day's work with just the work on which to concentrate.
15. *Orderpicking:* The criticality of orderpicking will be understood, and procedures and layouts will be designated to maximize orderpicking efficiency.
16. *Business process continuous improvement (BPCI):* The power of the people will be unleashed via a methodical process of continuous improvement.
17. *Continuous flow:* There will be a clear focus on pulling product through the logistics system and not building huge inventories.
18. *Warehouse management systems:* Real-time, bar code-based, RF communication Warehouse management systems (WMS) will be required to meet today's requirements.
19. *Change:* Organizations that will usher in the new century successfully will be the organizations that proactively embrace change.
20. *Leadership:* There must be a balance between the control aspects of management and harnessing the energy of change to create peak-to-peak performance of leadership.

3.2. Warehouse Objectives

The resources of a warehouse are space, equipment, and personnel. The cost of space includes not only the cost of building or leasing space but also the cost of maintaining the space. Typically, the cost of space in a warehouse is $0.20 to $0.30 per cubic foot per year for taxes, insurance, maintenance, and energy. A company that is ineffectively using its available cubic space is incurring excessive operating costs.

The equipment resources of a warehouse include data-processing equipment, dock equipment, unit load equipment, material-handling equipment, and storage equipment, all of which combine to represent a sizable capital investment in the warehouse. In order to obtain an acceptable rate of return on this investment, the proper equipment must be selected and it must be properly used.

Oftentimes, the personnel resource of the warehouse is the most neglected resource, even though the cost of this resource is usually the greatest. Approximately 50% of the costs of a typical warehouse are labor related. Reducing the amount of labor, pursuing higher labor productivity, good labor relations, and worker satisfaction, will significantly reduce warehouse operating cost.

Customer requirements are simply the demand to have the right product in good condition at the right place at the right time. Therefore, the product must be accessible and protected. If a warehouse cannot meet these requirements adequately, then the warehouse does not add value to the product and, in fact, very likely subtracts value from the product.

Therefore, the following objectives must be met for a warehouse to be successful:

1. Maximize effective use of space.
2. Maximize effective use of equipment.
3. Maximize effective use of labor.
4. Maximize accessibility of all items.
5. Maximize protection of all items.

The two distinct types of continuous warehouse planning needed to result in an efficient and effective warehouse operation are contingency planning and strategic master planning.

3.3. Contingency Planning

Contingency planning is a *defensive* tool used to guard against a predictable future change in warehouse requirements whose timing is extremely difficult, if not impossible, to anticipate. In other words, a contingency plan answers the question "What do I do *if* some unexpected event or condition arises?" Contingency plans are needed to guard against the following short-term situations:

1. Equipment downtime
2. Labor problems
3. Surges of activity
4. Material supply disruptions
5. Other emergencies

Contingency planning is not crisis management or putting out fires, which entail developing solutions to problems *after* the problems occur. Proper contingency planning develops the action plan to the fullest extent possible *before* the problem occurs. Consequently, proper contingency planning can significantly reduce the lead time required to correct or accommodate the unexpected event. One does not wait until after a fire starts in the warehouse to install a sprinkler system; instead, one installs the sprinkler system long before as a contingency against a fire whose timing is unpredictable. Likewise, formal contingency plans can protect the warehouse for other conceivable circumstances with unpredictable timing.

To develop contingency plans for a warehouse, use the following procedures:

1. Make a list of the conceivable "bad things" that can happen to or within the operation.
2. Rank the bad things with the events having the greatest probability of occurrence, and/or the most adverse consequences if they do occur, at the top of the list.
3. Starting with the highest-ranked bad thing, carefully determine, in as much detail as possible, the proper steps and actions that should take place to resolve, eliminate, and deal with the consequences to the warehouse operations of the bad thing if and when it occurs.
4. Review these steps and actions with the key warehouse people and refine them based on the inputs received.
5. Publish the resulting contingency plans in print and drill those persons responsible for executing the plans at the time of need in the details of the plans so that everyone knows exactly when, how, and by whom the plan is to be executed.
6. Periodically review and update the contingency plans to keep them current with existing conditions in the operation.

3.4. Strategic Master Planning

Strategic master planning is an *offensive* tool designed to guard against a predictable future change in warehouse requirements whose timing can be anticipated. Strategic master planning is directed at forecasting future warehousing needs sufficiently in advance of the actual requirement to allow enough lead time to efficiently and effectively meet those needs.

Warehousing strategic master plans are needed to accommodate:

1. Forecasted growth or decline in the throughput
2. Space, labor, and equipment deficiencies
3. Product mix changes
4. Inventory increases or reductions
5. Warehouse control problems

Most of these "problems" do not develop overnight. Future inventory levels and product mixes typically can be predicted, based on historical and future business plans, years in advance. Granted, forecasting with long planning horizons is risky. Forecasts are often inaccurate. Nevertheless, the forecast is the best available information concerning the future we have, and it is folly not to use that information to advantage. With today's costs of warehouse space, labor, and equipment, more and more decision makers are demanding that future warehouse requirements be expressed in quantitative terms rather than in subjective, qualitative assessments of needs. That is what strategic master planning is all about.

Contingency planning and strategic master planning are complementary. Strategic master planning without effective contingency plans will subject the warehouse to unanticipated problems that do not show up in a forecast of future requirements. Likewise, the absence of good strategic master planning will subject the warehouse to a continuous barrage of ''fires'' to be dealt with by contingency plans, many of which could have been avoided through proper insight and strategic planning. In either situation, the absence of one planning approach severely limits the effectiveness of the other.

3.4.1. Qualities of a Strategic Master Plan

A warehousing strategic master plan is a set of documents describing what actions must be accomplished and when they must be accomplished to satisfy the warehousing requirements of an enterprise over a given planning horizon. A closer examination of this definition reveals the important attributes of a good warehouse strategic master plan.

First of all, a good warehouse strategic master plan is a formal set of documents. It should not consist simply of ideas, thoughts, possibilities, desires, and so forth that are casually recorded ''somewhere,'' if at all. A good plan is a formal set of documents that have been created, collected, edited, and so forth specifically as a strategic master plan of action. Common components of this set of documents include an implementation plan, a descriptive narrative, scaled facility drawings, and supporting economic cost and justification data.

Second, a good warehouse strategic master plan is action oriented. Where possible, the plan should set forth very specific actions to be taken to meet requirements rather than simply stating the alternative actions available to meet those requirements. The strategic master plan is established based on a set of premises concerning future production volumes, inventory levels, manpower levels, available technology, and so forth. As long as these premises are clearly stated as a part of the strategic master plan, and understood, problems should not arise with regard to implementing actions that prove to be based on false premises.

The strategic master plan should be time phased to indicate when each recommended action should be implemented to meet changing warehousing requirements. Typically, scaled facility drawings should accompany each recommended action to illustrate what the facility will look like after a given action has been implemented.

Finally, a good warehouse strategic master plan should encompass a specified planning horizon. It should have a definite beginning point and a definite ending point. Typically, the planning horizon is stated in terms of years. A five-year master plan might serve the years 1991 through 1996.

3.4.2. Strategic Master Planning Methodology

The general methodology for developing a warehouse strategic master plan consists of the following seven-step procedure:

1. Document the existing warehouse operation.
2. Determine and document the warehouse storage and throughput requirements over the specified planning horizon.
3. Identify and document deficiencies in the existing warehouse operation.
4. Identify and document alternative warehouse plans.
5. Evaluate the alternative warehouse plans.
6. Select and specify the recommended plan.
7. Update the warehouse master plan.

Step 1 involves obtaining or developing scaled drawings of the existing warehouse facilities and verifying their accuracy. The accuracy of existing drawings should never be assumed. It should always be physically verified on the warehouse floor.

Existing warehouse equipment should be identified and documented. The labor complement of each area of the warehouse should be determined and the general responsibilities of each person documented. Existing standard operating procedures should be scrutinized and compared against what actually takes place on the shop floor. The first step of the master planning process establishes a baseline against which recommendations for improvement can be compared.

Step 2 involves defining what materials will be stored in the warehouse and the volume anticipated during the planning horizon. Items to be stored in the warehouse should be classified into categories according to their material-handling and storage characteristics.

Forecasts or production schedules should then be used to predict the storage volumes and turnover rates of each category of material over the specified planning horizon. Ideally, these volumes would be stated in terms of the unit loads in which the materials would be stored and handled.

Step 3 involves identifying potential areas of improvement in the existing warehouse operation. The potential for improvement may exist because the operation lacks sufficient capacity to handle future requirements or because existing facilities, methods, equipment, and/or labor forces are not the most efficient or effective available.

Step 4 deals with identifying alternative facility, equipment, procedural, and/or personnel plans that will eliminate or minimize the deficiencies identified in the existing warehouse operation. From these alternative plans of action will come the specific time-phased plan of action to be recommended for meeting the warehouse requirements over the given planning horizon.

Step 5 of the master planning process involves performing both an economic and a qualitative assessment of the alternative plans of action. The economic evaluation should consist of a time-value-of-money assessment of the total life-cycle costs of competing alternative plans of action. The qualitative assessment of alternatives requires that the alternatives be subjectively compared on such attributes as personnel safety, flexibility, ease of implementation, maintainability, potential product damage, and so forth.

Step 6 involves selecting the best of the alternative plans of action implicated by the economic and qualitative evaluations and specifying the recommended warehouse strategic master plan. The master plan will document the space, equipment, personnel, and standard operating procedure requirements of the warehouse over the planning horizon. In addition, scaled facility drawings should be included showing the recommended warehouse layout for all revisions recommended by the plan of action.

The first six steps of this procedure will result in a warehouse strategic master plan. The strategic master planning process, however, will not be complete. In fact, it will never be completed, since strategic master planning is a continuous activity. Step 7 is the process, therefore, of updating the master plan. By its very nature, a strategic master plan is inaccurate. Since it is based, to a large extent, on predictions of the future, the warehouse strategic master plan will require updating as better information concerning the future is obtained. Consequently, it should never be used as a precise tool but only as a valuable guideline for planning future warehouse operations.

4. STORAGE SPACE PLANNING

Space planning is the part of the science of warehousing concerned with making a quantitative assessment of warehouse space requirements. As is true of any science, space planning possesses a very specific methodology. The space planning methodology consists of the following general steps:

1. Determine what is to be accomplished.
2. Determine how to accomplish it.
3. Determine space allowances for each element required to accomplish the activity.
4. Calculate the total space requirements.

The first two steps of the space planning process define the activity and techniques, equipment, information, and so on to be used in performing that activity. Step 3 involves determining the space requirements of each element that goes into performing the activity. In warehousing, these elements might include personnel and personnel services, material handling and material storage equipment, maintenance services, and utilities. Finally, step 4 combines the space requirements of the individual elements to obtain total space requirements.

Storage-space planning is particularly critical because the storage activity accounts for the bulk of the space requirements of a warehouse. Inadequate storage-space planning can easily result in a warehouse that is significantly larger or smaller than required. Too little storage space will result in a world of operational problems, including lost stock, inaccessible material, poor housekeeping, damaged material, safety problems, and low productivity. Too much storage space will breed poor use of space so that it appears that all the available space is really needed. The result will be high space costs in the form of land, construction, equipment, and energy.

To avoid these problems, storage-space planning must be approached from a quantitative viewpoint, as opposed to a qualitative assessment of requirements. The following sections present the scientific methodology of storage-space planning, which when followed, will generate a quantitative and defensible assessment of storage-space requirements.

4.1. Define the Materials to Be Stored

The first step in storage-space planning is to define what is to be accomplished; that is, to define the materials to be stored. A useful tool in defining the materials to be stored is the storage analysis chart (SAC) given in Table 1. Columns 1–5 of the SAC define what materials are to be stored,

TABLE 1 Storage Analysis Chart

Company	A.R.C., Inc.	Date	March 18, 1991	Raw Materials	______	In-Process Goods	______
Prepared by	J. Smith	Sheet	1 of 1	Plant Supplies	______	Finished Goods	______

	Unit Loads				Quantity of Unit Loads Stored			Storage Space			
Description (1)	Type (2)	Cap (3)	Size (4)	Weight (5)	Max. (6)	Avg. (7)	Planned (8)	Method (9)	Specs (10)	Area (ft^2) 11	Ceiling Height Required (12)
Steel pipe plug 1.00 in. diameter × 0.50 in.	Wooden crate	3200 pieces	2 ft × 2 ft × 4 ft	825 lbs	14	8	12	Pallet rack	25 ft × 10 ft × 3 ft	66	9 ft
Aluminum bar 2.75 in. × 2.50 in. × 16 ft	Bundles	25 bars	12.5 × 14 in. × 16 ft	1625 lbs	30	17	30	Cantilever racks	Four-Arm dual rack 5 ft × 16 in. ××x 8 ft	160	8 ft
Stainless steel bar 0.875 in. × 12 ft	Bundles	36 bars	6 in. × 6 in. × 12 ft	900 lbs	7	4	7	Cantilever rack	Four-Arm dual rack 4 ft × 12 in. × 10 ft	48	10 ft
Rubber O rings 0.75 in. diameter	Cartons	40,000 O rings	12 in. × 18 in. × 3 ft	125 lbs	2	1	2	Storage shelf	Metal frame 12 ft × 2 ft × 8 ft	24	8 ft
Brass bar 0.75 in. diameter × 12 ft	Bundles	36 bars	6 in × 6 in × 12 ft	720 lbs	15	8	14	Cantilever rack	Four-Arm dual rack 4 ft × 12 ft × 6 ft	48	6 ft

columns 6–8 specify how much is to be stored, and columns 9–12 define how the materials are to be stored. The information requirements for columns 1–5 of the SAC can be obtained by physically surveying the existing storage areas. The survey would proceed by identifying, generically classifying, measuring, and weighing the unit loads presently in the storage areas.

Columns 6 and 7 of the SAC list the maximum and average number of unit loads of each category of material that should be on hand. Column 8 cites the planned inventory level of each type of material for which storage area will be planned. Determining the proper inventory level is directly related to the storage philosophy that will be used for each category of materials. The different storage philosophies and the decision process one should use to determine the proper planned inventory level will be discussed in the next section of this chapter.

The last four columns of the SAC define the physical characteristics of the storage area being planned. These physical characteristics include the method of storage and the space requirements of that method.

4.2. Determine Storage Philosophy

Once the maximum and average inventory levels have been recorded, the inventory level that will be used as a basis for planning required storage space must be determined. The planned inventory level depends on the philosophy followed in assigning material to storage space. There are two major material-storage philosophies: fixed (or assigned) location storage and random (or floating) location storage. In fixed-location storage each individual stock-keeping unit will always be stored in a specific storage location. No other stock-keeping unit may be stored in that location, even though that location may be empty.

With random-location storage, any stock-keeping unit may be assigned to any available storage location. A stock-keeping unit in location A one month might be stored in location B the following month and a different stock-keeping unit stored in location A.

The amount of space planned for a stock-keeping unit is directly related to the method of assigning space. If fixed-location storage is used, a given stock-keeping unit must be assigned sufficient space to store the maximum amount of the stock-keeping unit that will ever be on hand at any one time. For random-location storage, the quantity of items on hand at any time will be the average amount of each stock-keeping unit. In other words, when the inventory level of one item is above average, another item will likely have an inventory level that is below average; the sum of the two will be close to the average.

Oftentimes, the storage philosophy chosen for a specific stock-keeping unit will not be strictly fixed-location storage or random-location storage. Instead, it will be a combination of the two. A grocery store is an excellent example of combination, or hybrid, location storage. Fixed-location storage is used in the front room of a grocery store where the consumers shop. Pickles are assigned a fixed location, and only pickles will be stored in that location. Pickles will not be found in any other location in the front room of the grocery store. In the back room, or storeroom, of the grocery store, however, the excess, or overstock, merchandise is usually stored randomly. Pickles may be found in one location one week and in a different location the next week. Because combination-location storage is based on a mixture of fixed-location storage and random-location storage, its planned inventory level falls between the fixed-location quantity and random-location quantity. At what point between the fixed-location and random-location quantity the planned inventory level falls is dependent on the percentage of inventory to be assigned fixed locations.

To summarize, the planned inventory level recorded in column 8 of the storage analysis chart in Table 1 should be equal to the maximum inventory level (column 6) for fixed-location storage, the average inventory level (column 7) for random-location storage, or a value between the maximum and average quantities for combination-location storage.

Little has been said at this point about the advantages of one storage philosophy over another. Should the storage philosophy be fixed-, random-, or combination-location storage? Unfortunately, an unequivocal answer to this question does not exist. Choosing one storage philosophy over another means making a number of trade-offs, which must be evaluated. Table 2 presents a qualitative comparison of fixed-, random-, and combination-location storage for three extremely important criteria: use of space, accessibility to material, and material handling.

Use of space in a fixed-location system is poor because space for the maximum amount of inventory that will ever be on hand has been allocated although actual on-hand inventory will normally approach the average inventory level. Therefore, a great deal of empty space is common in fixed-location storage. Random-location storage is extremely space efficient because the space requirements are only about 15% above the average amount of inventory expected on hand. Use of space for combination-location storage is better than it is for fixed location storage and worse than it is for random-location storage because the space requirements are based on a planned inventory level somewhere between the fixed-location and random-location quantities.

TABLE 2 Comparison of Storage Philosophies

Criteria \ Philosophy	Fixed Location Storage	Random Location Storage	Combination Location Storage
Use of space	Poor	Excellent	Good
Accessibility to material	Excellent	Good, if there is a good material locator system; poor otherwise	Good
Material handling	Good	Good	Poor

Material in fixed-location storage has excellent accessibility because a given storage location contains only one stock-keeping unit. The location of every item is fixed: it is known. Blocked stock is avoided and every stock-keeping unit is readily accessible. Accessibility to material in random-location storage is good as a long as a good material-locator system exists. The material-locator system keeps track of the present location of every item in storage. Once a specific stock-keeping unit is committed to a storage location, no other stock-keeping unit can be placed in that location until the original stock-keeping unit is completely removed. However, if a material-locator system does not exist, or is poorly designed and maintained, then accessibility to material in a random-location storage system will be extremely poor. Blocked stock, lost material, and obsolete material will inevitably result. Even with a good material-locator system, accessibility to material will never be as good in random-location storage as in fixed-location storage. Accessibility to material in combination storage is good if a good material-locator system exists for the randomly-stored portion of storage, or if the percentage of inventory stored randomly is small.

Fixed-location storage and random-location storage score equally well on the material-handling criterion. In each philosophy, material is received, placed into storage, retrieved from storage, and shipped to a user. The flow of material is straightforward and economical. Material is received, placed in the random-location storage area, retrieved, placed into the fixed-location storage area, retrieved, and shipped to a user. Consequently, combination-location storage involves several extra handling steps not required by either fixed-location storage or random-location storage.

In summary, fixed-location storage trades efficiency in use of space for easy accessibility to material; random-location storage trades accessibility to material for efficiency in use of space; and combination-location storage trades material-handling efficiency for middle-of-the-road efficiency in use of space and accessibility to material. However, a clear-cut decision still cannot be made on the best storage philosophy. Perhaps the only general conclusion that can be drawn is that poor use of space by fixed-location storage is a big factor. Compared to the use of space by random-location storage for the same materials, fixed-location storage will generally require 65–85% more space. With the escalating costs of money, land, and construction, few firms can afford to build a fixed-location storage warehouse, which would be 75% larger than that required for random-location storage. The expense of developing and maintaining an effective material-locator system for random-location storage—when compared with these costs—is easily justified. Consequently, one should always carefully evaluate random-location storage before deciding to use fixed-location storage. Rarely will the gains in accessibility to material made by fixed-location storage be enough to offset its high space costs. Occasionally, however, efficient use of space is not a critical factor, so fixed-location storage is preferred. For example, when the items to be stored are extremely small and/or extremely valuable, accessibility to them and accountability for them may be all-important. Few jewelers care about the use of space when they are storing diamond rings.

4.3. Determine Alternative Storage Method Space Requirements

The space requirements of a storage alternative are directly related to the volume of material to be stored and the use-of-space characteristics of the alternative. The two most important use-of-space characteristics are aisle allowances and honeycombing allowances. Aisle allowance is the percentage of space occupied by aisles within a storage area. Aisles are necessary within a storage area to allow accessibility to the material being stored. The amount of aisle allowance depends on the storage method, which dictates the number of aisles required, and on the material-handling method, which dictates the size of the aisles. Expected aisle allowance must be calculated for each storage alternative under consideration.

Honeycombing allowances are the percentage of storage space lost because of ineffective use of the capacity of a storage area. Honeycombing is illustrated in Figure 1. Honeycombing occurs whenever a storage location is only partially filled with material. The unoccupied area within the storage

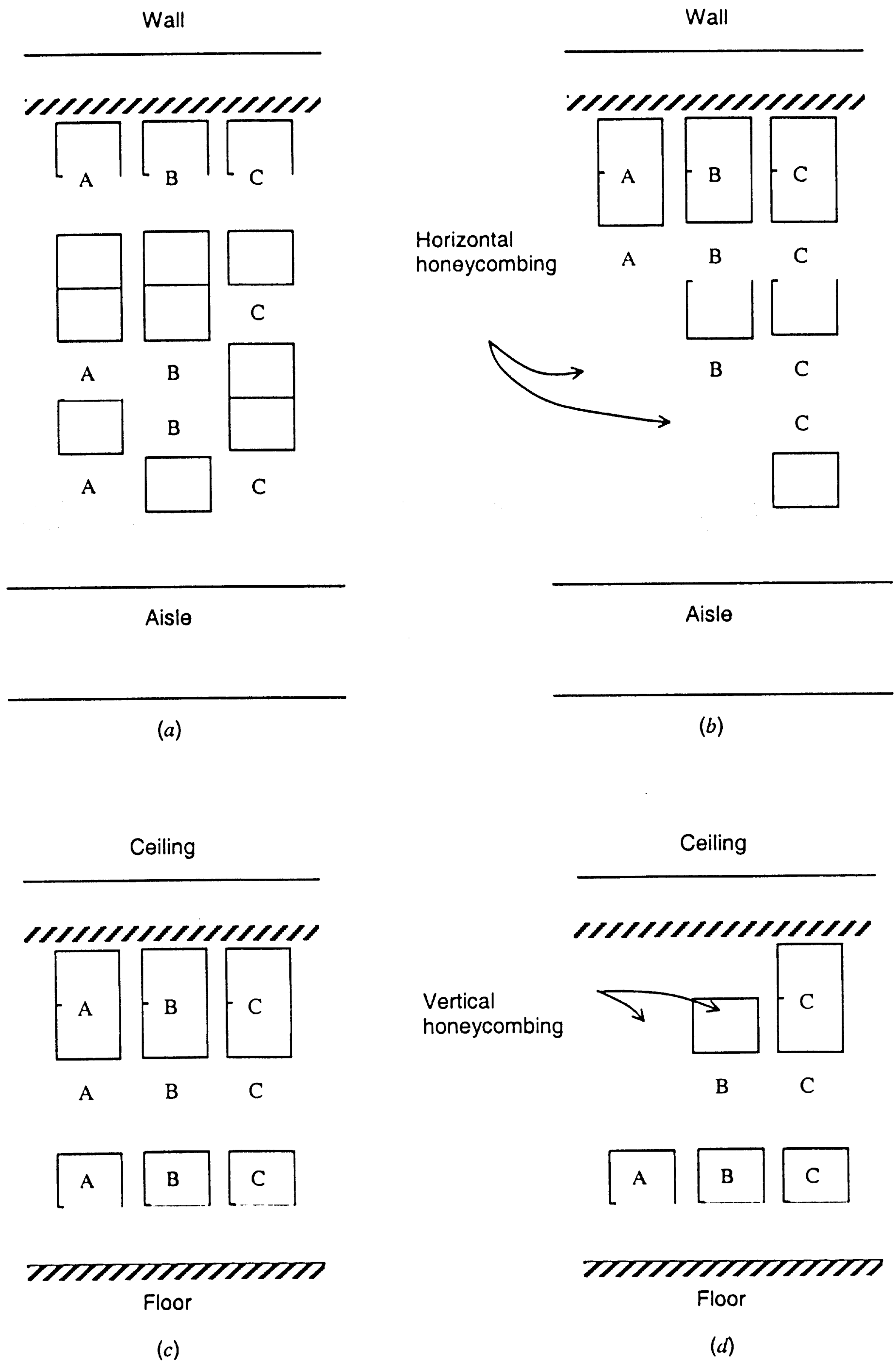


Figure 1 Horizontal and Vertical Honeycombing. (*a*) Plan view of bulk storage area—no honeycombing. (*b*) Plan view of bulk storage area showing horizontal honeycombing. (*c*) Elevation view of bulk storage area—no honeycombing. (*d*) Elevation view of bulk storage area showing vertical honeycombing.

location is honeycombed space. Honeycombing may occur horizontally and vertically. For example, Figure 1(*a*) presents a plan view of a bulk storage area in which material can be placed four units deep. Because the bulk storage area is full, no honeycombing occurs. In Figure 1(*b*), however, two units of product A and one unit of product B have been removed, leaving three empty slots. No other items can be placed in these slots until the remaining units of A and B have been removed (otherwise, blocked stock will result); so these slots are horizontal honeycombing losses. Figure 1(*c*) is an elevation view of a bulk storage area in which material can be stacked three units high. Here again, the storage area is full and no honeycombing occurs. In Figure 1(*d*), however, two units of product A and one unit of product B have been removed, leaving three empty slots. To avoid blocked stock or poor stock rotation, no other units can be placed in these slots until the remaining units of A and B have been removed. Consequently, the empty slots are vertical honeycombing losses. Horizontal and vertical honeycombing losses will occur. Efforts to totally eliminate honeycombing may improve space utilization but will assuredly result in increased material-handling costs related to double handling loads, material damage, and lost productivity. Honeycombing, while it should be minimized, must be considered a natural and allowed-for phenomenon of the storage process. For each storage alternative under consideration, the expected honeycombing allowance must be estimated.

Once the aisle and honeycombing allowances for a storage method alternative have been determined, a space standard can be calculated for that storage method. A space standard is a benchmark

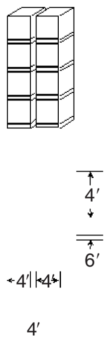
Item A requires special environmental control. A special storage area must be established to house the maximum quantity of item A, which is to be stored on pallets, four pallets high. In a bulk storage analysis chart, how much space should be allocated for the storage of item A?

Case size = 2 ft × 1 ft × 1 ft (height) = 2 ft^3

Palletized = 48 in. × 48 in. × 48 in. pallet × 4 tiers high = 64 ft^3 (32 cases/pallet)

Step 1: The aisle allowance (AA) has been estimated from a proposed layout to be 10%. The honeycombing allowance (HA) has been estimated to be 25%.

Step 2: The pallet height is 6 in. and the clearance between stacks is 4 in. The total space required for one four-pallet-high stack of item A is therefore:



Stack width × stack depth × stack height = (4 ft + 0.33 ft) × 4 ft × [(4 ft + 0.5 ft) × 4] = 312 ft^3 for 128 cases of item A

Step 3: The inclusion of allowances for aisles and honeycombing results in the following space standard:

$$\frac{312 \text{ ft}^3}{(1 - \text{AA})(1 - \text{HA})(128 \text{ cases})} = \frac{312 \text{ ft}^3}{(1 - 0.10)(1 - 0.25)(128 \text{ cases})} = 3.61 \text{ ft}^3\text{/case}$$

Step 4: A total storage space required for the maximum anticipated volume of item A, using the proposed storage method, is:

Total storage space required = 300,000 cases × 3.61 ft^3/case
= 1,083,000 ft^3
or 60,167 ft^2 having a clear stacking height of 18 ft

Figure 2 Example Space Standard Calculation for Storage Area.

that defines the amount of space required per unit of product stored. Given the space standard and the total inventory of a class of items to be stored, the total space required for that class of items may then be calculated. Figure 2 presents an example illustrating the calculation and use of space standards.

5. WAREHOUSE LAYOUT PLANNING

5.1. Objectives of a Warehouse Layout

Before layout planning can begin, the specific objectives of a warehouse layout must be determined. In general, the objectives of a warehouse layout are:

1. To use space efficiently
2. To allow the most efficient material handling
3. To provide the most economical storage in relation to costs of equipment, use of space, damage to material, and handling labor
4. To provide maximum flexibility in order to meet changing storage and handling requirements
5. To make the warehouse a model of good housekeeping

The astute observer will notice that the first three objectives are essentially identical to the overall objectives of a warehouse. Recall that the objectives of a warehouse are:

1. To maximize effective use of space
2. To maximize effective use of equipment
3. To maximize effective use of labor
4. To maximize accessibility of all items
5. To maximize protection of all items

It is true that the objectives of a warehouse layout are redundant. This shows the importance of layout planning to warehouse planning. Without a good warehouse layout, it is impossible to have a good warehouse. The objective of layout planning is to arrange and coordinate the space, equipment, and labor resources of the warehouse. Poor layout planning can undermine superior space, equipment, and personnel planning. Put another way, accomplishing the objectives of warehousing depends on having a good layout. If the warehouse layout is bad, the warehouse as a whole will be bad. Conversely, if the warehouse as a whole is bad, chances are the warehouse layout is bad.

The fourth objective of a warehouse layout recognizes the fact that warehousing exists not within a static, unchanging environment but within a dynamic, ever-changing environment. If the mission of a warehouse changes, the warehouse layout should very likely change, too, to adapt to the new mission. However, a good warehouse layout possesses the flexibility to absorb minor variances in expected storage volumes and product mixes with few or no alterations required. This flexibility allows the warehouse to function even if the forecasts on which it was planned prove to be wrong, as they inevitably do.

The last objective of warehousing follows the principle that there is efficiency in order. Good housekeeping is essential to good warehousing; a good warehouse cannot exist without good housekeeping. Yet good housekeeping by itself will not ensure a good warehouse. If the space, equipment, personnel, and layout are not properly planned, all the housekeepers in the world could not get a warehouse to function. But poor housekeeping will surely undermine good space, equipment, personnel, and layout planning.

5.2. Layout Planning Methodology

Warehouse layout planning methodology consists of two steps:

1. Generate a series of warehouse layout alternatives
2. Evaluate each alternative against specific criteria to identify the best warehouse layout

These two steps are discussed in the following sections.

5.3. Generate Alternative Layouts

Generating alternative warehouse layouts is as much art as science. The quality of the layout alternatives will largely depend on the skill and ingenuity of the layout planner. This fact is crucial to the most common approach to generating layout alternatives: template juggling. The word ‘‘juggle’’ means ‘‘to skillfully manipulate a group of objects to obtain a desired effect.’’ Consequently, template juggling is the skillful manipulation of a group of templates, models, or other representations of warehouse space, equipment, and personnel in order to obtain a warehouse layout that meets objectives. In other words, template juggling is a trial-and-error approach to finding the proper arrangement and coordination of the physical resources of the warehouse.

The quality of the alternatives created from template juggling depends on the creativity of the layout planner. Unfortunately, layout planners often either lack creativity or do not attempt to express their creativity. Many layout planners approach the problem with a preconceived idea about what the solution should be. They tend to base the layout planning process on that preconceived solution. As a result, creativity is stifled. Oftentimes, the layout chosen for a new warehouse looks exactly like the layout used for the old warehouse. The generation of layout alternatives thrives on the creativity of the layout planner, yet many layout planners withhold this basic and essential ingredient.

The generation of warehouse layout alternatives should be accomplished by the following procedure:

1. *Define the location of fixed obstacles.* Some objects in a warehouse can be located only in certain places, and they can have only certain configurations. These objects should be identified and placed in the layout alternative first, before objects with more flexibility are located. Some fixed obstacles are building support columns, stairwells, elevator shafts, lavatories, sprinkler system controls, heating and air conditioning equipment, and, in some cases, offices. Failure to consider the location of these types of items first will prove disastrous. The warehousing corollary to Murphy's law states: "If a column can be in the wrong position, it will be." Don't be the layout planner who designs a warehouse and buys the storage and material-handling equipment only to find that when the equipment is installed, the location of the building columns makes an aisle too narrow for the handling equipment.
2. *Define the location of the receiving and shipping function.* Oftentimes, the configuration of the warehouse site will dictate the location of the receiving and shipping functions. When this is not true, however, the receiving and shipping location decision becomes an important one. Receiving and shipping are high-activity areas and should be located so as to maximize productivity, improve material flow, and properly utilize the warehouse site. The location of access roads and railroad tracks, if rail service is required, are important considerations in locating receiving and shipping. The question of whether receiving and shipping should be located together or in different areas of the warehouse must be addressed. Common receiving/shipping docks can often result in economies of scale related to sharing space, equipment, and personnel. Separate receiving and shipping areas may, on the other hand, be best to ensure better material control and reduce congestion. Energy considerations are important. Where a choice exists, receiving and shipping docks should not be located on the side of the building that faces north. Avoiding this location reduces the amount of heat loss in the winter from northerly winds entering the warehouse through the open dock doors. The preferred location of the receiving and shipping docks is the south side of the warehouse, with east and west as second and third choices. The particular weather patterns around each warehouse site should be examined, however, to identify the prevailing wind direction at that particular site. Then the docks should be located away from the prevailing wind.
3. *Locate the storage areas and equipment, including required aisles.* The types of storage areas and equipment to be used will dictate to some extent the configuration of the storage layout and the aisle requirements. Be sure to make allowances for the fixed obstacles in the facility. Main warehouse aisles should connect the various parts of the warehouse. The cross-aisle at the end of the storage area may need to be wider than the aisles within the storage area, depending on the type of material-handling equipment used. For example, a side-loading fork truck that can operate with a 7-foot-wide storage aisle may require 12-foot-wide cross-aisles at the ends of the storage aisles to allow maneuvering into and out of the storage aisle.
4. *Assign the material to be stored to the storage locations.* This step in the generation of layout alternatives ensures that storage allowances have been made for all the items to be stored. In addition, it allows the performance of a mental simulation of the activities expected within the warehouse.
5. *Repeat the process to generate other alternatives.* Once a warehouse layout alternative has been established, following the four steps just outlined, the process must be repeated many times to generate additional layout alternatives. Different layout configurations, building shapes, and equipment alternatives should be used. The creativity of the layout planner should be taxed to ensure that each succeeding layout alternative is not essentially identical to the first layout alternative generated.

5.4. Evaluate the Alternative Layouts

A number of warehouse layout philosophies exist to serve as guidelines for the development of an effective warehouse layout. Each warehouse layout alternative should be evaluated against the specific criteria established for each of these warehouse layout philosophies.

1. *Popularity philosophy:* In a typical warehouse, it is not unusual to find that 85% of the product throughout is attributable to 15% of the items, another 10% of the product throughput is attributable to 30% of the items, and the remaining 5% of the product throughput is attributable to 55% of the items. Consequently, the warehouse contains a very small number of highly active items (often called A items), a slightly larger number of moderately active items (often called B items), and a very large number of infrequently active items (often called C items). The warehouse layout philosophy on popularity suggests that the warehouse should be planned around the small number of highly active items that constitute the great majority of the activity in the warehouse. The popularity philosophy maintains that the materials having the greatest throughput should be located in an area that allows the most efficient material handling. Consequently, high-turnover items should be located as close as possible to the point of use. The popularity philosophy also suggests that the popularity of the items helps determine the storage method used. Items with the greatest throughput should be stored by methods that maximize the use of space. For example, if bulk storage is used, high-turnover items should be stored in as deep a space block as possible. Because the items are moving into and out of storage at a relatively high rate, the danger of excessive honeycombing losses is reduced and excellent use of space will result from the high-density storage. Low-throughput items in deep bulk storage blocks will cause severe honeycombing losses because no other items can be stored in that location until the low-throughput item is removed.
2. *Similarity philosophy:* Items that are commonly received and/or shipped together should be stored together. For example, consider a retail auto parts distributor. Chances are that a customer who requires a spark plug wrench will not buy, at the same time, an exhaust system tail pipe. Chances are good, however, that a customer who buys the spark plug wrench might also require a condenser, points, and spark plugs. Because these items are typically sold (shipped) together, they should be stored in the same area. The exhaust system tail pipe should be stored in the same area in which the mufflers, brackets, and gaskets are stored. Sometimes, certain items are commonly received together, possibly from the same vendor; they should be stored together. Similar types of items should be stored together. They will usually require similar storage and handling methods, so their consolidation in the same area results in more efficient use of space and more efficient material handling. An exception to the similarity philosophy arises whenever items are so similar that storing them close together might result in order-picking and shipping errors. Examples of items that are too similar are two-way, three-way, and four-way electrical switches, which look identical but function quite differently. Storing these items close together will inevitably result in order-picking and shipping errors.
3. *Size philosophy:* The size philosophy suggests that heavy, bulky, hard-to-handle goods should be stored close to their point of use. The cost of handling these items is usually much greater than that of handling other items. This is an incentive to minimize the distance over which they are handled. In addition, if the ceiling height in the warehouse varies from one area to another, the heavy items should be stored in the areas with a low ceiling and the lightweight, easy-to-handle items should be stored in the areas with a high ceiling. Available cubic space in the warehouse should be used in the most effective way while meeting restrictions on floor loading capacities. Lightweight material can be stored at greater heights within typical floor loading capacities than heavy materials can. The size philosophy also asserts that the size of the storage location should fit the size of the material to be stored. Do not store a unit load of 10 ft^3 in a storage location capable of accommodating a unit load of 30 ft^3. A variety of storage location sizes must be provided so that different items can be stored differently. In addition to looking at the physical size of an individual item, one must consider the total quantity of the item to be stored. Different storage methods and layouts will be used for storing 2 pallet loads of an item than will be used for storing 200 pallet loads of the same material.
3. *Product-characteristics philosophy:* Some materials have certain attributes or traits that restrict or dictate the storage methods and layout used. Perishable material is quite different from nonperishable material, from a warehousing point of view. The warehouse layout must encourage good stock rotation so that limitations on shelf life are met. Oddly shaped and crushable items, subject to stacking limitation, will dictate special storage methods and layout configurations to use available cubic space effectively. Hazardous material such as explosives, corrosives, and highly flammable chemicals must be stored in accordance with government regulations. Items of high value or items commonly subject to pilferage may require increased security measures such as isolated storage with restricted access. The warehouse layout must be adapted to provide the needed protection. The compatibility of items stored close together must also be examined. Contact between certain individually harmless materials can result in extremely hazardous reactions and/or significant product damage. Specific steps must be taken to separate incompatible materials. Oftentimes, the easiest way to accomplish this objective is through the warehouse layout.

5. *Space-utilization philosophy:* This philosophy can be separated into four areas: conservation of space, limitations on use of space, accessibility of material, and orderliness.
   - **(a)** The conservation-of-space principle asserts that the maximum amount of material should be concentrated within a storage area, the total cubic space available should be effectively used, and the potential honeycombing within the storage area should be minimized. Unfortunately, these objectives often conflict. Increased concentration of material will usually cause increased honeycombing allowances. Therefore, determining the proper level of space conservation is a matter of making trade-offs among the objectives that maximize use of space.
   - **(b)** Limitations on use of space must be identified early in the layout planning process. Space requirements for building support columns, trusses, sprinkler system components, heating system components, fire extinguishers and hoses, and emergency exits will affect the suitability of certain storage and handling methods and layout configurations. Floor loading capacities will restrict storage heights and densities.
   - **(c)** The warehouse layout should meet specified objectives for material accessibility. Main travel aisles should be straight and should lead to doors in order to improve maneuverability and reduce travel times. Aisles should be wide enough to permit efficient operations, but they should not waste space. Aisle widths should be tailored to the type of handling equipment, using the aisle and the amount of traffic expected.
   - **(d)** The orderliness principle emphasizes the fact that good warehouse housekeeping begins with housekeeping in mind. Aisles should be well marked with aisle tape or paint; otherwise, materials will begin to infringe on the aisle space, and accessibility to material will be reduced. Void spaces within a storage area must be avoided, and they must be corrected when they do occur. If a storage area is designed to accommodate five pallets, and, in the process of placing material into that area, one pallet infringes on the space allocated for the adjacent pallet, a void space will result. Because of this, only four pallets can actually be stored in the area designed for five pallets. The lost pallet space will not be regained until the entire storage area is emptied.

The alternative warehouse layouts should be evaluated by comparing each against specific expectations relative to the layout philosophies as discussed here. The layout planner must determine which layout philosophies are most important under the specific circumstances and attempt to maximize the extent to which the recommended layout adheres to those philosophies. Remember, however, that warehousing exists within a dynamic environment; therefore, the layout chosen as best today may not be so as conditions change. The extent and timing of changing requirements in the future should be forecast and a warehouse master plan established to compensate effectively for the changing mission of the warehouse.

6. WAREHOUSE EQUIPMENT PLANNING

Like space planning, effective equipment planning must follow a very specific methodology. The general steps to this methodology are:

1. Specify what functions the equipment must perform.
2. Identify equipment alternatives.
3. Evaluate the equipment alternatives.
4. Select the equipment.

This methodology is appropriate for equipment planning for all warehouse activities: receiving, shipping, storage, order picking, and data processing.

The first step in the equipment planning methodology is to define the function the equipment must perform: what must the chosen equipment be able to do in order to accomplish the desired objective? This question is crucial, and it must be thoroughly answered before one begins to identify alternatives. Failure to adequately specify the objective the equipment must accomplish, and the minimum capabilities the proper equipment should have to achieve that objective, will often result in selection of equipment that fails to solve the real problem. It is amazing how often poor specification of requirements provides a brilliant solution to the wrong problem.

Unfortunately, no standard guidelines exist that guarantee a thorough specification of the capabilities desired of the equipment. What is desired of the equipment will vary, not only from warehouse to warehouse but also from activity to activity performed in a given warehouse. Although each circumstance will require different answers to different questions, the *types* of questions that will allow adequate specification of the capabilities the equipment must have are virtually the same for all activities within a warehouse. Table 3 lists the types of questions one might have to answer before specifying begins. The specifications of the capabilities desired of equipment should then be detailed; they should be in writing; then they should be reviewed by each member of warehouse management who will be affected by the equipment in order to identify any overlooked specifications.

TABLE 3 Typical Information Required to Specify Capabilities Required of Equipment

Objective of Equipment	Typical Questions That Must Be Answered
Unload incoming truck shipments	1. What types of trucks will be serviced? 2. What types of unit loads will be handled? 3. How heavy are the unit loads that will be handled? 4. What combination of unit loads might be found on a given shipment? 5. Where will the unit loads be deposited after unloading? 6. What constraints in maneuvering space must be met? 7. Is lifting capability required? To what heights? 8. What productivity rates must be achieved? 9. What other activities will this equipment be required to perform?
Place materials into storage racks	1. What type of storage rack will be used? 2. What type of unit load will be handled? 3. How heavy are the unit loads that will be handled? 4. How high must the unit loads be lifted? 5. From where will the unit loads be obtained? 6. What constraints in storage-aisle width must be met? 7. What constraints in maneuvering space outside the storage area must be met? 8. What other activity occurs simultaneously in the operating area of this equipment? 9. What other activities will this equipment be required to perform?
Retrieve materials from storage rack	1. What types of loads will be retrieved? Full unit loads? Full cases? Individual pieces? 2. How much do the loads that will be retrieved weigh? 3. What type of storage rack will be used? 4. How high off the floor is material stored? 5. What constraints in storage aisle width must be met? 6. What constraints in maneuvering space outside the storage area must be met? 7. What order-picking philosophy will be used: zone picking, full-order picking, simultaneous picking of multiple orders? 8. Where will the materials be deposited after retrieval? 9. What productivity rates must be achieved? 10. What other activities occur simultaneously within the operating area of this equipment? 11. What other activities will this equipment be required to perform?
Load materials into carriers for shipment	1. What types of loads will be handled? Unit loads? Loose cartons? What combination of loads? 2. How heavy are loads that will be handled? 3. From where will loads to be handled be obtained? 4. Is lifting capacity required? How much? 5. What types of carriers will be loaded? 6. What maneuvering space constraints must be met? 7. What productivity rates must be achieved? 8. What other activities must this equipment perform?

The next step in equipment planning is to identify specific equipment alternatives that meet the needed specifications. This step is critical because if the ideal equipment for the job is never identified, then obviously the ideal equipment will not be selected.

At this point in the equipment planning process, the intent should not be to identify the specific make or model of each alternative but rather to identify generic categories of alternatives. First, one must compare the various generic equipment alternatives in order to identify the best alternative; then, in step 4 of the equipment planning process, the specific makes and models in that generic category are compared.

Unfortunately, choosing the best equipment alternatives is easier said than done because of the enormous variety of warehouse equipment on the market today. The number of combinations of equipment that can be made to achieve a certain goal is virtually limitless. A great deal of ingenuity and foresight is often required to predict the impact of integrating several types of equipment into a warehouse system. Consequently, the identification of warehouse equipment alternatives is an art as well as a science. The art does not necessarily have to be inborn; it can be acquired by keeping abreast of the capabilities of existing warehouse equipment and new innovations in the state of the art. Excellent sources of continuing education on warehouse equipment are the many trade publications on warehousing and material handling; trade shows, where equipment manufacturers show and discuss their wares; and seminars and conferences on warehousing and material handling.

A proper evaluation of warehouse equipment alternatives must be a *quantitative* comparison of the alternatives. This is not to say, however, that the choice should be based solely on dollars and cents or that the many *qualitative* attributes of the alternatives—flexibility, reliability, or maintainability, for example—have no bearing on the merits of one alternative or another. On the contrary, superior qualitative attributes of an alternative will often overshadow its apparent economic inferiority to the point where this alternative is chosen as best. In fact, where such a decision is made, the ''economically inferior'' alternative is judged not to be really economically inferior because its qualitative attributes do indeed have economic value. The problem, then, is an inability to express this qualitative value in quantifiable, economic units (dollars and cents). One solution to this problem is to discontinue the attempt to quantify economically the qualitative attributes of an alternative and instead quantify the qualitative attributes in judgmental units and convert the economic units—dollars and cents—into these judgmental units to form a common base for comparison of alternatives.

The first step in the economic evaluation of equipment alternatives is to identify and estimate the relevant costs of each alternative over its useful life. Relevant costs are usually divided into two categories: investment costs and annual operating costs. Investment costs are incurred to obtain the equipment; they occur on a one-time or periodic basis. The most common investment cost is the purchase price of the equipment. Typically, investment costs are depreciable, and they are often subject to capital investment tax credits.

Annual operating costs are the recurring expenses that keep the equipment in operation. Typical annual operating costs are the wages of operating personnel, the costs of equipment maintenance, and the taxes and insurance costs incurred by owning the equipment. Annual operating costs are generally not depreciable.

Once the relevant life-cycle costs of the alternatives have been identified and estimated, a detailed time-value-of-money analysis must be performed for each alternative. Economic analysis techniques are presented in Chapters 52 and 54 of this Handbook.

Consideration of the qualitative attributes of the equipment alternatives may very well result in selection of equipment that might not have been chosen if the economic analysis had been the sole basis of comparison. However, a casual discussion of the intangible, qualitative attributes of the equipment alternatives that causes a reversal of a decision originally based on the tangible dollar costs of the alternatives will often not withstand the scrutiny of those who must review the decision. Consequently, the discussion of the qualitative aspects of equipment alternatives must be explicit and well documented.

Some qualitative factors that are often looked at are:

- Ability of the equipment to fit into and serve warehouse operations
- Versatility and ability to adapt to day-to-day changes in products and fluctuations in productivity requirements
- Flexibility (ease of changing or rearranging the installed methods)
- Limitations imposed by the equipment on the flexibility and ease of expansion of the layout, building, or both
- Use of space
- Safety and housekeeping
- Working conditions and employee satisfaction

Ease of supervision and control
Availability of trained operators
Frequency and seriousness of potential breakdowns
Ease of maintenance and rapidity of repair
Volume of spare parts that must be stocked
Availability of repair parts
Quality of product and risk of damage to materials
Ability to pace, or keep pace with, productivity requirements
Personnel problems: training capability, disposition of unnecessary workers, job description changes, and union contracts or work practices
Availability of needed equipment
Tie-in scheduling, inventory control, and paperwork
Effect of natural conditions: land, weather, etc.
Potential delays from required synchronization and peak loads
Supporting services required
Time required to get into operation, i.e., to complete installation, training, and debugging
Availability of capital or investment money
Promotional or public-relations value

The final step of the equipment planning process is to select the specific equipment. The selection process is as follows:

1. Sell management on the proposed equipment and obtain approval for any capital appropriations required.
2. Compose detailed specifications of the equipment required.
3. Identify vendors who can potentially provide the equipment.
4. Prepare and distribute a vendor bid package.
5. Receive and evaluate the vendors' bids.
6. Select and order the equipment.

Evaluating vendors and their specific equipment requires the same decision process that should be used when selecting the desired generic equipment. The decision should be based on a combination of economic and qualitative factors. The obvious economic factor that must be considered is the invoice price, which will include purchase price, sales tax, freight costs, installation costs, and so on. The qualitative factors to be considered will include many of the same factors as the evaluation of generic-equipment alternatives, such as the volume of spare parts that must be kept on hand, the ease of maintenance, the rapidity of repair, and the availability of repair parts and service. In addition, other factors specifically related to vendor selection are the availability of the equipment, installation and debugging services provided, warranties, and the reputation of the manufacturer and its local representative. Consequently, equipment and vendor selection should never be based solely on a low invoice bid. The judgmental units used to select generic categories should be used here.

7. WAREHOUSE OPERATIONS AUDIT

Critical to the ongoing success of storage and warehousing operations is the continuous analysis and evaluation of the day-to-day operations to identify opportunities for improvement. A formal, periodic audit of the existing operations, conducted in a systematic manner, can be an effective tool for achieving continuous improvements. While a number of specific methodologies can be utilized to conduct such an audit, the following discussion will define one approach that has been successfully used.

7.1. Operations Audit Performance Categories

The operations audit is a process that evaluates 10 categories of performance in the warehouse. Utilizing information on the performance of the warehouse in these categories, a quantitative overall performance measure is determined. The 10 categories assessed by the operations audit are:

1. Customer service
2. Control systems
3. Inventory accuracy

4. Space utilization
5. Labor productivity
6. Layout
7. Equipment methods
8. Equipment utilization
9. Building facilities
10. Housekeeping and safety

The first category, customer service, is a primary concern to the warehouse management and upper management. Rating of customer service is based on how well the warehouse performs against its corporate service goals. These goals may include order-to-delivery cycle, order-to-ship cycle, and out-of-stock occurrences.

Control systems is the second category to be evaluated. This is by definition not just computer controls. Evaluation of controls looks at what paperwork is used, how data integrity is used, what duplication of efforts and paperwork exists, how special requests are serviced, and how effective is the use of computer controls, if available. The assessed need for increased computer control is based on the ability of existing manual or computer-controlled operations to adequately control the warehouse. Some indicators that enhanced computer control is needed are the inability to find material, excessive time required to find material, increased obsolescence, and inefficient labor utilization. In most cases a top-rated warehouse has a real-time, online, order entry system that develops truck loads, batches items for picking, preroutes and preposts picking, and manages labor with real-time instructions via data terminals in the warehouse.

Inventory accuracy is critical because many other categories can be affected by poor inventory control. The rating assigned is based on performance against corporate goals. The accuracy of inventory count for all items in total should be considered, as well as the percentage of different items (SKUs, stock-keeping units) found to be accurate in counting. Lack of accuracy on small, inexpensive items can have as big an impact on customer service as on the larger, more expensive items. Item count, dollars on hand, and total part count are all 99% or better, and cycle counting is performed in a top-rated warehouse. Initially, though, the rating assigned should be against the corporate goal, with the goal being improved as consistency is achieved.

Space utilization is calculated for the entire warehouse, based on the storage method being used. The quantity of positions occupied vs. the total available positions is used to calculate the utilization for each type of storage in the warehouse. The utilization of each area, the square footage of the area, and the total square footage of the warehouse are then used to calculate the overall utilization. This overall utilization is compared to the maximum efficient utilization, usually 80–90%, to determine the operating utilization. A review of the projected growth can then be utilized to determine the life expectancy of the warehouse. This life expectancy, the time until operationally full, is used to determine the rating. Typically, a new warehouse takes between 12 and 24 months to design, construct, and occupy. If the life expectancy is less than this time, a low rating is assigned. Also, if the life expectancy is beyond five to six years and growing, a low rating is assigned. Also, if the life expectancy exists, the warehouse space should be reviewed for use by other functions, or for sale.

Labor productivity, category 5, means different things to many warehouse managers. The rating is based on a review of the operating procedures for the warehouse. Each of the major functions in the warehouse—receive, store, pick, and ship—are evaluated. The procedures are reviewed to determine how effectively they support high labor productivity. The existence and use of labor standards is also considered. Effective procedures and proper use of standards is needed for a top rating.

Category 6, layout, is integral to the successful performance of other categories. The objectives of a proper warehouse layout are:

1. To use space effectively
2. To allow the most efficient material handling
3. To provide the most economical storage in relation to costs of equipment, use of space, damage to material, and handling labor

Rating the layout of the warehouse is based on how well these objectives are met. Effective use of space for storage, operational, and support functions is considered here. The transport and storage of material is analyzed to determine how well the layout supports reduced handling costs and increased labor productivity.

Equipment methods refer to the appropriateness of the types of equipment and the use of this equipment in the warehouse. At least two major types of equipment exist in every warehouse: storage equipment and handling equipment. Rating is based not on how much each is utilized, but how well. For example, storage equipment should contain the proper items based on physical characteristics (e.g., size, weight, fragility) and activity level. Handling equipment is also evaluated based on these same characteristics, as well as how the equipment interfaces with storage and delivery points.

Equipment utilization is calculated for each group of equipment in the warehouse. This may include forklift trucks, storage/retrieval systems, conveyors, carousels, and automatic guided vehicles. The utilization, together with the variation in demand, is considered to assign a rating. Too high a utilization can be as detrimental as too low. The operational utilization must be considered with the actual run time for a vehicle. A forklift should travel with a load the majority of the time. High use of vehicles traveling empty is not acceptable. In a top-rated warehouse, the utilization is at or just below the operational maximum with the growth to meet the life expectancy considered.

Building facilities are often overlooked areas of the warehouse. Building facilities include:

Dock capacity
Lighting
Personnel services (offices, restrooms, break areas, etc.)
Fire protection
Outside space (truck aprons, service areas, etc.)

The utilization of docks depends on two factors: the turnaround time to load or unload and the arrival pattern of trucks at the docks. Typically, the dock utilization should be 70–80%. Also, the use of proper dock equipment is evaluated. Dock locks or chocks, levelers, and light should be available. Lighting should not only be sufficient to support operations but also be located properly to avoid equipment interferences. Personnel services should be properly located and of sufficient size and quantity to support the staff. Fire protection is rated based on the type of facility, the equipment methods used, and the type of material stored. Outside space is most often overlooked in building facilities. Proper allowances for truck access, personnel access, and other services can affect safety and efficiency.

The last category is housekeeping and safety. There is a strong relationship between housekeeping and safety. Poor safety conditions do not necessarily mean housekeeping is poor, but poor housekeeping always impacts negatively on safety. Housekeeping is reviewed in several specific areas. Material should be put away, not lying on the floor and in aisles. Empty pallets, cartons, or tools should be stored neatly. The warehouse should be clean; the rack should be aligned properly on working aisles. The issue of safety in the warehouse is a direct function of professionalism. The equipment operators should be trained, certified, and periodically recertified. The equipment should be in proper working order. Lighting and other environmental conditions should be proper for the work. Personnel access to high-traffic areas for equipment should be limited. All material must be stored properly. Bulk materials should be stacked properly, not exceeding allowable load heights. Pallets in racks should have the proper amount of overhang and be loaded within the capacity limits. The rating is based on these rules being followed throughout the warehouse.

7.2. Operations Audit Methodology

Each performance category is rated on a scale of 1 to 5, with 5 being the highest. The rating is based on both quantitative and qualitative assessments. The auditor should record specific factors or indi-

TABLE 4 Calculation of Performance Index

Category	Rating	Target Rating	Weight	Category Score	Target Score
Customer service	1 2 3 4 5	5	40	120	200
Control systems	1 2 3 4 5	4	30	120	120
Inventory accuracy	1 2 3 4 5	5	30	150	150
Space utilization	1 2 3 4 5	4	20	60	80
Labor productivity	1 2 3 4 5	5	20	80	100
Layout	1 2 3 4 5	5	20	100	100
Equipment methods	1 2 3 4 5	5	10	30	50
Equipment utilization	1 2 3 4 5	5	10	50	50
Building facilities	1 2 3 4 5	5	10	50	50
Housekeeping/safety	1 2 3 4 5	5	10	40	50
Total				800	950
Performance index					84%

TABLE 5 Warehouse Class

Warehouse Class	Performance Index	Rating ≤3
(A+) Excellent	95–100%	0
(A) Very Good	90–94%	2
(B) Good	85–89%	3
(C) Average	80–84%	3
(C−) Below average	70–79%	4
(D) Poor	<70%	>4

cators used to obtain the assigned rating. After rating of each category, determination of overall performance is straightforward. Before the results of the audit are calculated, two additional actions must be performed. The first is to assign weights to the performance categories. Each category varies in importance to a particular warehouse operation. To account for this, a weight is assigned to each category, reflecting its relative importance. The total of all weights is 200, which together with the maximum rating of each category (5) yields a maximum possible score of 1000 points. Second, for a particular warehouse the realistic maximum rating for a category may be less than 5. Due to the warehouse size or activity level, for instance, a computer control system may not be practical. Therefore, a target rating is assigned to each category. In future audits of the same warehouse, this target rating may change to reflect consistent high levels of performance or changes in activity and size.

The category rating and target ratings are multiplied by the category weight to obtain a category score and target score. The total of the category scores is then divided by the total target scores to obtain a performance index (PI). Table 4 shows the results of a typical audit and calculation of the PI. In this particular example, a performance index of 84% is achieved. The performance index is one part of the analysis to determine the warehouse class. The other part of the analysis needed to determine the class is based on the consistency of ratings. The number of categories with a rating of 3 or less is obtained. In the example, this is equal to 3. Table 5 shows how the warehouse class is determined for the example in Table 4.

The first step is to identify a class based on the performance index. In each class, there is a limit to the number of ratings that are less than or equal to 3. In the example, the performance index is 84%, which is a class C, which has a limit of three ratings less than or equal to 3. This warehouse has three ratings less than or equal to three, so the class does not change. Exceeding the number of ratings less than or equal to three causes a drop in class, but the inverse is not true. Class cannot improve over the performance index level achieved.

The results of the audit show warehouse management how well the warehouse is doing and provide a tool to communicate this performance. The breakdown of ratings for each category can be used as a road map to plan improvements. The operations audit should be performed on an annual or semiannual basis to track the results of improvement efforts. Following each audit, new goals for improvement in each category must be set, and plans made to implement required operations changes.

ADDITIONAL READING

Ackerman, K. B., *Practical Handbook of Warehousing,* 4th Ed., Traffic Service Corporation, Washington, DC, 1999.

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